136

Pat

45867
5.B.

Vol. I

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DeFOREST RADIO COMPANY, PETITIONER,

vs.

GENERAL ELECTRIC COMPANY

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT
COURT OF APPEALS FOR THE THIRD CIRCUIT

PETITION FOR CERTIORARI FILED JANUARY 8, 1931

CERTIORARI GRANTED FEBRUARY 25, 1931

(35,552)

INDEX.

PLEADINGS AND TESTIMONY.

	Vol.	Page
Docket Entries in No. 589	I	1
Docket Entries in No. 598	I	3
Bill of Complaint in No. 589	I	5
Answer as Amended in No. 589	I	10
Defendant's Bill of Particulars	I	14
Defendant's Supplemental Bill of Particulars	I	20
Bill of Complaint in No. 598	I	22
Answer as Amended in No. 598	I	29
Stipulation	I	36
Stipulation	I	133
Plaintiff's Prima Facie Proofs	I	35
Defendant's Proofs	I	145
Defendant's Depositions	II	959
Plaintiff's Rebuttal Proofs	II	1073
Defendant's Sur-Rebuttal Proofs	III	1789
Plaintiff's Sur-Rebuttal Proofs	III	1910
Appendix to Plaintiff's Record	III	1940
Opinion of the Court	III	1943
Decree in No. 589	III	1981
Plaintiff's Petition for Appeal in No. 589	III	1982
Order Allowing Appeal	III	1983
Plaintiff's Assignments of Error in No. 589	III	1984
Citation on Plaintiff's Appeal in No. 589	III	1985
Stipulation as to Transcript in No. 589	III	1987
Order Approving Stipulation	III	1988
Decree in No. 598	III	1989
Plaintiff's Petition for Appeal in No. 598	III	1991
Order Allowing Appeal	III	1992
Plaintiff's Assignments of Error in No. 598	III	1993
Citation on Plaintiff's Appeal in No. 598	III	1995
Defendant's Petition for Appeal in No. 598	III	1996
Order Allowing Appeal	III	1997
Defendant's Assignments of Error in No. 598	III	1998
Citation on Defendant's Appeal in No. 598	III	1999
Stipulation as to Transcript in No. 598	III	2000
Order Approving Stipulation	III	2001
Clerk's Certificate	III	2002

INDEX—Continued.

PLAINTIFF'S PRIMA FACIE PROOFS.

	Vol.	Page
Hogan, John V. L.—		
Direct Examination	I	39
Cross-Examination	I	94
Re-Direct Examination	I	126
Re-Cross-Examination	I	135
Re-Direct Examination	I	144

DEFENDANT'S PROOFS.

	Vol.	Page
Arnold, Harold D.—		
Direct Examination	I	553
Cross-Examination	I	628
Re-Direct Examination	II	746
Re-Cross-Examination	II	765
Re-Direct Examination (Resumed)	II	783
Re-Cross-Examination (Resumed)	II	785
Beal, Ralph R.—		
Direct Examination	II	1044
Beck, Helene—		
Direct Examination	II	960
Cross-Examination	II	976
Re-Direct Examination	II	991
Blackwell, Otto B.—		
Direct Examination	II	804
Chaffee, E. Leon—		
Direct Examination	I	145
Cross-Examination	I	200
Re-Direct Examination	I	373
Re-Cross-Examination	I	388
Clark, Leland B.—		
Direct Examination	II	1016
Cross-Examination	II	1024
Colpitts, Edwin H.—		
Direct Examination	I	481
Cross-Examination	I	527
Re-Direct Examination	I	549
Colpitts, Edwin H. (Recalled)—		
Direct Examination	II	802
Hewlett, Palmer—		
Direct Examination	II	1005
Cross-Examination	II	1012
Re-Direct Examination	II	1015

INDEX—Continued.

	Vol.	Page
Hyde, Ralph—		
Direct Examination	II	993
Cross-Examination	II	998
Re-Direct Examination	II	1003
Re-Cross-Examination	II	1004
Jewett, Frank B.—		
Direct Examination	I	393
Cross-Examination	I	431
Re-Direct Examination	I	436
Re-Cross-Examination	I	437
Kelly, Marvin J.—		
Direct-Examination	II	811
Cross-Examination	II	857
Re-Direct Examination	II	910
Lamont, G. E.—		
Direct Examination	II	1025
Direct Examination (Resumed)	II	1065
Cross-Examination	II	1067
Re-Direct Examination	II	1067
Millikan, Robert A.—		
Direct Examination	I	440
Cross-Examination	I	459
Re-Direct Examination	I	479
Rodman, Harold Lee—		
Direct Examination	II	1057
Sarnoff, David (Stipulated Testimony)	III	1446
Tuel, Austin Y.—		
Direct Examination	II	1060
Waterman, Frank N. (Stipulated Testimony)	III	1486
Watkins, James O.—		
Direct Examination	II	1053
Cross-Examination	II	1055
Re-Direct Examination	II	1055

PLAINTIFF'S REBUTTAL PROOFS.

	Vol.	Page
Alexanderson, Ernst F. W.—		
Direct Examination	III	1448
Cross-Examination	III	1461
Coolidge, William D.—		
Direct Examination	III	1496
Cross-Examination	III	1532

INDEX—Continued

	Vol.	Page
Hogan, John V. L.—		
Direct Examination	III	1563
Cross-Examination	III	1639
Direct Examination (Resumed)	III	1659
Direct Examination (Resumed)	III	1721
Cross-Examination (Resumed)	III	1767
Langmuir, Irving—		
Direct Examination	II	1073
Cross-Examination	II	1299
Re-Direct Examination	III	1436
Re-Cross-Examination	III	1439
White, William C.—		
Direct Examination	III	1467
Cross-Examination	III	1490

DEFENDANT'S SUR-REBUTTAL PROOFS.

	Vol.	Page
Arnold, Harold D. (Recalled)—		
Direct Examination	III	1867
Cross-Examination	III	1878
Becker, Joseph A.—		
Direct Examination	III	1789
Cross-Examination	III	1824
Re-Direct Examination	III	1847
Re-Cross-Examination	III	1847
Folk, George E.—		
Direct Examination	III	1852
Cross-Examination	III	1862
Re-Direct Examination	III	1867
Hunter, Frederick L.—		
Direct Examination	III	1893
Cross-Examination	III	1905
Re-Direct Examination	III	1907
Re-Cross-Examination	III	1907
Langmuir, Irving—		
Direct Examination	III	1848

PLAINTIFF'S SUR-REBUTTAL PROOFS.

	Vol.	Page
Bayard, Fairfax—		
Direct Examination	III	1910
Cross-Examination	III	1911
Langmuir, Irving—		
Direct Examination	III	1912

PLAINTIFF'S EXHIBITS.

GENERAL INDEX.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
1.	Langmuir U. S. Patent No. 1,558,436, Oct. 20, 1925	I	35	IV	1
2.	Langmuir U. S. Patent No. 1,244,216, Oct. 23, 1917	I	36	IV	11
3.	Langmuir U. S. Patent No. 1,244,217, Oct. 23, 1917	I	36	IV	16
4.	Langmuir U. S. Patent No. 1,529,597, Mar. 10, 1925	I	36	IV	20
5.	DeForest Type H Rectifier Tube	I	51	—	—
6.	DeForest Type H Audion Tube	I	51	—	—
7.	DeForest DV 5 Vacuum Tube	I	51	—	—
8.	DeForest DV5 Vacuum Tube	I	51	—	—
8-A.	Data sheet accompanying DeForest DV 5 Vacuum tube	I	93	IV	27
9.	Defendant's Circular	I	51	IV	28
10.	Defendant's Leaflet	I	51	IV	29
11.	Hogan Fig. 1, Diagram of Two Electrode Tube	I	52	IV	31
12.	Hogan Fig. 2, Diagram of Three electrode tube	I	52	IV	32
13.	Hogan Table I showing Power of Numbers	I	69	IV	33
14.	Hogan Chart A of Table I, Simple Powers of Numbers, Arithmetic Paper	I	69	IV	34
15.	Hogan Chart B of Table I, Simple Powers of Numbers, Logarithmic Paper	I	70	IV	35
16.	Plaintiff's UV 199 Tube	I	92	—	—
16-A.	Data sheet enclosed with UV 199 tube	I	92	IV	36
17.	Plaintiff's UX 201A Tube	I	93	—	—
17-A.	Data sheet enclosed with UX 201A Tube	I	93	IV	37
18.	Hogan Drawing illustrating Plff.'s UX 201A tube	I	94	IV	38
19.	Hogan Drawing illustrating Defendant's DV 5 tube	I	94	IV	39
	[Nos. 20 to 161, incl. Langmuir Exhibits in Interference Record and not reprinted. *See Separate Index.*]	II	927	—	—
162.	Opinion of Court of Appeals, District of Columbia, in Langmuir v. Arnold, dated June 1, 1925	II	935	IV	41
163.	Langmuir explanatory diagram	II	1126	IV	45
164.	Langmuir 2/3 power plot diagram	II	1195	IV	46
165.	Langmuir 3/2 power plot diagram	II	1195	IV	47

Ex.		Admitted		Printed	
No.		Vol.	Page	Vol.	Page
166.	Langmuir plot of volts on plate and grid against current audion No. 2	II	1198	IV	48
167.	Langmuir explanatory diagram	II	1260	IV	49
168.	Langmuir explanatory diagram A	II	1267	IV	50
168-A.	Langmuir explanatory diagram A^1	II	1267	IV	51
168-B.	Langmuir explanatory diagram B	II	1267	IV	52
168-C.	Langmuir explanatory diagram B^1	II	1267	IV	53
168-D.	Langmuir explanatory diagram D	II	1267	IV	54
168-E.	Langmuir explanatory diagram E	II	1267	IV	55
168-F.	Langmuir explanatory diagram F	II	1267	IV	56
169.	Letter from Alexanderson to Patent Department, General Electric Co., February 5, 1913	III	1452	IV	57
170.	File wrapper and contents Arnold U. S. patent No. 1,297,309, March 18, 1919	II	788	IV	59
171.	White notebook No. 462 (certain pages only)	III	1468	IV	91
172.	White test records (Card & 7 sheets)	III	1479	IV	108
173.	White report on relaying of high frequency currents by means of improved audions	III	1483	IV	115
174.	Coolidge notebook No. 327	III	1506	IV	121
175.	Coolidge notebook No. 446, extract from	III	1518	IV	128
176.	Hogan diagram of vapor pressures of sodium	III	1612	IV	129
177.	DeForest Bulletin B-14 of 1914	III	1632	IV	130
178.	DeForest Bulletin B-15 of 1915	III	1632	IV	134
179.	DeForest Bulletin C-16 of 1916	III	1633	IV	149
180.	DeForest Catalogue L	III	1633	IV	153
181.	DeForest Catalogue B of 1919	III	1633	IV	156
182.	DeForest type T audion Tube	III	1633	—	—
183.	Circular of Sterling Reactivator	III	1638	IV	161
184.	Hewlett sketch of circuit	III	1639	IV	165
185.	Letter and data sheets furnished by witness Kelly	III	1738	IV	167
186.	Hogan Logarithmic plot of Audion 64-91	III	1744	IV	175
187.	Hogan Logarithmic plot of Kelly data for tube 102-D	III	1745	IV	176
188.	Hogan Logarithmic plot of characteristics of small receiving tube corrected for contact differential	III	1748	IV	177
189.	Hogan plot (Anode Current) 2/3—Anode Voltage Characteristics of Type G Power Tube	III	1749	IV	178

PLAINTIFF'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
189-A.	Hogan plot of Anode current—anode voltage Characteristics of Type G Power Tube	III	1749	IV	179
190.	Hogan logarithmic plot of plate current-plate voltage of UX-201A Tube (H-20)	III	1750	IV	180
191.	Logarithmic plot of Kelly's data on Tube 105	III	1752	IV	181
192.	Hogan copy of Deft.'s Exhibit 54-A, with additional lines thereon	III	1755	IV.	182
193.	Hogan Logarithmic plot of Type 7510 with nitrogen	III.	1758	IV	183
194.	Physical Review, Vol. 26, No. 4, October, 1925, pp. 436-435, "Probability of Ionization of Gas Molecules by Electron Impacts," by Compton and Van Voorhis	III	1761	IV	185
195.	Paper No. 4, Arnold v. Langmuir Interference 40,380	III	1762	IV	203
196.	Paper No. 6, Arnold v. Langmuir Interference 40,380	III	1762	IV	204
197.	Paper No. 9, Arnold v. Langmuir Interference 40,380	III	1762.	IV	205
198.	Paper No. 10, Arnold v. Langmuir Interference 40,380	III	1762	IV	206
199.	Paper No. 32, Arnold v. Langmuir Interference 40,380	III	1762	IV	207
200.	Paper No. 85, Arnold v. Langmuir Interference 40,380	III	1763	IV	208
201.	Option Agreement, Dec. 16, 1912, between Hewett and A. T. & T. Co.	III	1763	IV	210
201-A.	Agreement A, between Hewett and A. T. & T. Co.	III	1763	IV	214
202.	Hewett U. S. Patent No. 781,001, Jany. 31, 1905	III	1763	IV	235
203.	Hewett U. S. Patent No. 781,002, Jany. 31, 1905	III	1763	IV	238
204.	Hewett U. S. Patent No. 749,791, Jany. 19, 1904	III	1763	IV	241
205.	Hewett U. S. Patent No. 749,792, Jany. 19, 1904	III	1763	IV	244
206.	Hewett U. S. Patent No. 749,793, Jany. 19, 1904	III	1763	IV	247
207.	Hewett U. S. Patent No. 758,650, May 3, 1904	III	1763	IV	250
208.	Hewett U. S. Patent No. 954,434, Apr. 12, 1910	III	1763	IV	252
209.	Hewett U. S. Patent No. 991,304, May 2, 1911	III	1763	IV	255
210.	Table of Mechanical Repeater Installations, 1904-1918, in Gherardi deposition	III	1765	IV	261
210-A.	Table of Repeater Installations, 1904-1918, Gherardi deposition	III	1766	IV	262
211.	Philosophical Magazine (1912), Vol. 23, pp. 192-200, "Ionization Produced by Carbon at High Temperatures," by Pring & Parker	III	1766	IV	263
212.	Fleming U. S. Patent No. 954,619, April 12, 1910	III	1766	IV	269

PLAINTIFF'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
213.	DeForest U. S. Patent No. 879,532, Feby. 18, 1908	III	1766	IV	273
214.	Modification of license agreement dated July 1, 1920 between General Electric Co. and A. T. & T. Co.	III	1786	IV	277
215.	Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1820	IV	313
216.	Nicolson notebook (Not printed in full)	II	801	—	—
216-A.	Certain pages of Nicolson notebook	II	801	IV	322
217.	DeForest U. S. Patent No. 1,201,273, Oct. 17, 1916	III	1887	IV	328
218.	Certain pages of book of O. W. Richardson entitled "The Emission of Electricity from Hot Bodies"	III	1891	IV	332
219-A.	Langmuir replot of data taken from Defendant's Exhibit No. 295	III	1930	IV	358
219-B.	Langmuir Parabolic Plots of currents taken from Defendant's Exhibit No. 299	III	1930	IV	359
219-C.	Langmuir Parabolic plot of currents taken from Defendant's Exhibit No. 297	III	1930	IV	360
220.	Langmuir Logarithmic current voltage curve for different pressures of nitrogen	III	1931	IV	361

PLAINTIFF'S EXHIBITS.

CLASSIFIED INDEX.

Diagrams and Drawings.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
184.	Hewlett sketch of circuit	III	1639	IV	165
11.	Hogan Fig. 1, Diagram of Two electrode Tube	I	52	IV	31
12.	Hogan Fig. 2, Diagram of Three electrode Tube	I	52	IV	32
13.	Hogan Table I showing Power of Numbers	I	69	IV	33
14.	Hogan Chart A of Table I, Simple Powers of Numbers, Arithmetic Paper	I	69	IV	34
15.	Hogan Chart B of Table I, Simple Powers of Numbers, Logarithmic Paper	I	70	IV	35
18.	Hogan Drawing illustrating Plff.'s UX 201A tube	I	94	IV	38
19.	Hogan Drawing illustrating Defendant's DV 5 tube	I	94	IV	39
176.	Hogan diagram of vapor pressures of sodium	III	1612	IV	129
186.	Hogan Logarithmic plot of Audion 64-91	III	1744	IV	175
187.	Hogan Logarithmic plot of Kelly data for tube 102-D	III	1745	IV	176
188.	Hogan Logarithmic plot of characteristics of small receiving tube corrected for contact differential	III	1748	IV	177
189.	Hogan plot (Anode Current) 2/3—Anode Voltage Characteristics of Type G Power Tube	III	1749	IV	178
189-A.	Hogan plot of Anode current—anode voltage Characteristics of Type G Power Tube	III	1749	IV	179
190.	Hogan logarithmic plot of plate current—plate voltage of UX-201A Tube (H-20)	III	1750	IV	180
192.	Hogan copy of Deft.'s Exhibit 54-A, with additional lines thereon	III	1755	IV	182
193.	Hogan Logarithmic plot of Type 7510 with nitrogen	III	1758	IV	183
191.	Logarithmic plot of Kelly's data on Tube 105	III	1752	IV	181
163.	Langmuir explanatory diagram	II	1126	IV	45
164.	Langmuir 2/3 power plot diagram	II	1195	IV	46
165.	Langmuir 3/2 power plot diagram	II	1195	IV	47
166.	Langmuir plot of volts on plate and grid against current audion No. 2	II	1198	IV	48
167.	Langmuir explanatory diagram	II	1260	IV	49

PLAINTIFF'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
168.	Langmuir explanatory diagram A	II	1267	IV	50
168-A.	Langmuir explanatory diagram A¹	II	1267	IV	51
168-B.	Langmuir explanatory diagram B	II	1267	IV	52
168-C.	Langmuir explanatory diagram B¹	II	1267	IV	53
168-D.	Langmuir explanatory diagram D	II	1267	IV	54
168-E.	Langmuir explanatory Diagram E	II	1267	IV	55
168-F.	Langmuir explanatory diagram F	II	1267	IV	56
219-A.	Langmuir replot of data taken from Defendant's Exhibit No. 295	III	1930	IV	358
219-B.	Langmuir Parabolic Plots of currents taken from Defendant's Exhibit No. 299	III	1930	IV	359
219-C.	Langmuir Parabolic plot of currents taken from Defendant's Exhibit No. 297	III	1930	IV	360
220.	Langmuir Logarithmic current voltage curve for different pressures of nitrogen	III	1931	IV	361

Documentary, Miscellaneous.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
201-A.	Agreement A, between Hewett and A. T. & T. Co.	III	1763	IV	214
183.	Circular of Sterling Reactivator	III	1638	IV	161
8-A.	Data sheet accompanying DeForest DV 5 Vacuum tube	I	93	IV	27
16-A.	Data sheet enclosed with UV 199 tube	I	92	IV	36
17-A.	Data sheet enclosed with UX 201A Tube	I	93	IV	37
9.	Defendant's Circular	I	51	IV	28
10.	Defendant's Leaflet	I	51	IV	29
177.	DeForest Bulletin B-14 of 1914	III	1632	IV	130
178.	DeForest Bulletin B-15 of 1915	III	1632	IV	134
179.	DeForest Bulletin C-16 of 1916	III	1633	IV	149
180.	DeForest Catalogue L	III	1633	IV	153
181.	DeForest Catalogue B of 1919	III	1633	IV	156
169.	Letter from Alexanderson to Patent Department, General Electric Co., February 5, 1913	III	1452	IV	57
185.	Letter and data sheets furnished by Witness Kelly	III	1738	IV	167
214.	Modification of license agreement dated July 1, 1920 between General Electric Co. and A. T. & T. Co.	III	1786	IV	277
162.	Opinion of Court of Appeals, District of Columbia, in Langmuir v. Arnold, dated June 1, 1925	II	935	IV	41

PLAINTIFF'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
201.	Option Agreement, Dec. 16, 1912, between Hewett and A. T. & T. Co.	III	1763	IV	210
195.	Paper No. 4, Arnold v. Langmuir Interference 40,380	III	1762	IV	203
196.	Paper No. 6, Arnold v. Langmuir Interference 40,380	III	1762	IV	204
197.	Paper No. 9, Arnold v. Langmuir Interference 40,380	III	1762	IV	205
198.	Paper No. 10, Arnold v. Langmuir Interference 40,380	III	1762	IV	206
199.	Paper No. 32, Arnold v. Langmuir Interference 40,380	III	1762	IV	207
200.	Paper No. 85, Arnold v. Langmuir Interference 40,380	III	1763	IV	208
210.	Table of Mechanical Repeater Installations, 1904-1918, in Gherardi deposition	III	1765	IV	261
210-A.	Table of Repeater Installations, 1904-1918, Gherardi deposition	III	1766	IV	262
172.	White test records (Card & 7 sheets)	III	1479	IV	108
173.	White report on relaying of high frequency currents by means of improved audions	III	1483	IV	115

File Wrapper and Contents.

170.	File wrapper and contents Arnold U. S. Patent No. 1,297,309, March 18, 1919	II	788	IV	59

Notebooks.

174.	Coolidge Notebook No. 327	III	1506	IV	121
175.	Coolidge Notebook No. 446, Extract from	III	1518	IV	128
216.	Nicolson notebook (Not printed in full)	II	801	Not printed	
216-A.	Certain pages of Nicolson notebook	II	801	IV	322
171.	White Notebook No. 462 (Certain pages only)	III	1468	IV	91

Patents, United States.

213.	DeForest, No. 879,532, Feby. 18, 1908	III	1766	IV	273
217.	DeForest, No. 1,201,273, Oct. 17, 1916	III	1887	IV	328
212.	Fleming, No. 954,619, April 12, 1910	III	1766	IV	269
202.	Hewett, No. 781,001, Jany. 31, 1905	III	1763	IV	235
203.	Hewett, No. 781,002, Jany. 31, 1905	III	1763	IV	238
204.	Hewett, No. 749,791, Jany. 19, 1904	III	1763	IV	241
205.	Hewett, No. 749,792, Jany. 19, 1904	III	1763	IV	244

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
206.	Hewett, No. 749,793, Jany. 19, 1904	III	1763	IV	247
207.	Hewett, No. 758,650, May 3, 1904	III	1763	IV	250
208.	Hewett, No. 954,434, Apr. 12, 1910	III	1763	IV	252
209.	Hewett, No. 991,304, May 2, 1911	III	1763	IV	255
1.	Langmuir, No. 1,558,436, Oct. 20, 1925	I	35	IV	1
2.	Langmuir, No. 1,244,216, Oct. 23, 1917	I	36	IV	11
3.	Langmuir, No. 1,244,217, Oct. 23, 1917	I	36	IV	16
4.	Langmuir, No. 1,529,597, Mar. 10, 1925	I	36	IV	20
215.	Langmuir, No. 1,558,437, Oct. 20, 1925	III	1820	IV	313

Publications.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
211.	Philosophical Magazine (1912), Vol. 23, pp. 192-200, "Ionization Produced by Carbon at High Temperatures," by Pring & Parker	III	1766	IV	263
194.	Physical Review, Vol. 26, No. 4, October, 1925, pp. 436-435, "Probability of Ionization of Gas Molecules by Electron Impacts," by Compton and Van Voorhis	III	1761	IV	185
218.	Certain pages of book of O. W. Richardson, entitled "The Emission of Electricity from Hot Bodies"	III	1891	IV	332

Physical Exhibits.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
5.	Deforest Type H Rectifier Tube	I	51	—	—
6.	DeForest Type H Audion Tube	I	51	—	—
7.	DeForest DV 5 Vacuum Tube	I	51	—	—
8.	DeForest DV 5 Vacuum Tube	I	51	—	—
182.	DeForest type T audion Tube	III	1633	—	—
16.	Plaintiff's UV 199 Tube	I	92	—	—
17.	Plaintiff's UX 201A Tube	I	93	—	—

INDEX TO PLAINTIFF'S EXHIBITS
in
INTERFERENCE RECORD.*

Inter. Ex. No.	Trial Ex. No.		Inter Record Page
1.	20.	Diagram, Fig 1	1018
2.	21.	Physical Review Paper of December, 1913	Not printed
3.	22.	Diagram, Fig. 2	1042
4.	23.	Diagram, Fig. 3	1047
5.	24.	Diagram, Fig. 4	1052
6.	25.	American Electro-Chemical Society Paper of 1016	Not printed
7.	26.	American Chemical Society Paper of November, 1916	Not printed
8.	27.	Diagram, Fig. 5	1090
9.	28.	Diagram, Fig. 6	1094
10.	29.	Diagra[illegible] Fig. 7	1095
11.	30.	Diagram, Fig. 8	1097
12.	31.	Diagram, Fig. 9	1103
13.	32.	Logarithmic Plot of Volt-Ampere Characteristics of Regulator Kenotron with High Vacuum	1117
14.	33.	Volt-Ampere Characteristics of Regulator Kenotron with High Vacuum	1118
15.	34.	Logarithmic Plot of Volt-Ampere Characteristics of Regulator Kenotron with Filament Current at 1.25 Amperes and with High Vacuum	1120
16.	35.	Volt-Ampere Characteristics of Regulator Kenotron with Filament Current at 1.25 Amperes and with High Vacuum	1121
17.	36.	Logarithmic Plot of Volt-Ampere Characteristics of Regulator Kenotron with Mercury Vapor Present	1123
18.	37.	Volt-Ampere Characteristics of Regulator Kenotron with Mercury Vapor Present	1124
19.	38.	Diagram of Circuit Connections	1127
20.	39.	Regulator Kenotron with Appendix and Charcoal Tube (Photograph printed)	1109
21.	40.	Nickel Anode Tube (Photograph printed)	1130
21-A.	41.	Curve Sheets of Nickel Anode Tube	1141

---

*Referred to in Interference record as "Langmuir Exhibits."

INDEX TO PLAINTIFF'S EXHIBITS IN INTERFERENCE RECORD —Continued.

Inter. Ex. No.	Trial Ex. No.		Inter. Record Page
22.	42.	Standard Coolidge X-ray Tube (Photograph printed)	1151
23.	43	Volt-Ampere Characteristics of Standard Coolidge X-ray Tube	1157
24.	44	Logarithmic Plot of Volt-Ampere Characteristics of Standard Coolidge X-ray Tube	1158
25.	45.	Standard Coolidge X-ray Tube with Cathode Shield Removed (Photograph printed)	1151
26.	46.	Volt-Ampere Characteristics of Standard Coolidge X-ray Tube with Cathode Shield Removed	1159
27.	47.	Logarithmic Plot of Volt-Ampere Characteristics of Standard Coolidge X-ray Tube with Cathode Shield Removed	1160
28.	48.	Radiator Type Coolidge X-ray Tube (Photograph printed)..	1151
29.	49.	Volt-Ampere Characteristics of Coolidge X-ray Tube, Radiator Type	1163
30.	50.	Logarithmic Plot of Volt-Ampere Characteristics of Coolidge X-ray Tube, Radiator Type	1164
31.	51.	Type P Pliotron (Photograph printed)	1152
32.	52.	Volt-Ampere Characteristics of Type P Pliotron	1167
33.	53.	Logarithmic Plot of Volt-Ampere Characteristics of Type P Pliotron	1168
34.	54.	Volt-Ampere Characteristics of Type P Pliotron, taken with Rotating Commutator	1169
35.	55.	Logarithmic Plot of Volt-Ampere Characteristics of Type P Pliotron, taken with Rotating Commutator	1170
36.	56.	Rotating Commutator	—
37.	57.	Diagram of Circuit Connections	1172
38.	58.	Type U Pliotron (Photograph printed)	1152
39.	59.	Volt-Ampere Characteristics of Type U Pliotron	1175
40.	60.	Logarithmic Plot of Volt-Ampere Characteristics of Type U Pliotron	1176
41.	61.	Type T Pliotron (Photograph printed)	1153
42.	62.	Volt-Ampere Characteristics of Type T Pliotron	1179
43.	63.	Logarithmic Plot of Volt-Ampere Characteristics of Type T Pliotron	1180
44.	64.	Type G Pliotron VT-11 (Photograph printed)	1153
45.	65.	Type G Pliotron VT-13 (Photograph printed)	1153

INDEX TO PLAINTIFF'S EXHIBITS IN INTERFERENCE RECORD

—Continued.

Inter. Ex. No.	Trial Ex. No.		Inter. Record Page
46.	66.	Volt-Ampere Characteristics of Type G Pliotron VT-11	1183
47.	67.	Logarithmic Plot of Volt-Ampere Characteristics of Typ G Pliotron VT-11	1184
48.	68.	Volt-Ampere Characteristics of Type G Pliotron VT-13, with Grid connected to Negative End of Filament	1185
49.	69.	Logarithmic Plot of Volt-Ampere Characteristics of Type G Pliotron VT-13, with Grid connected to Negative End of Filament	1186
50.	70.	Volt-Ampere Characteristics of Type G Pliotron VT-13, Grid connected to Anode	1187
51.	71.	Logarithmic Plot of Volt-Ampere Characteristics of Type G Pliotron VT-13, Grid connected to Anode	1188
52.	72.	Kenotron Regulator Tube, Type TB-1 (Photograph printed)	1154
53.	73.	Volt-Ampere Characteristics of Kenotron Regulator Tube, Type TB-1	1191
54.	74.	Logarithmic Plot of Volt-Ampere Chart	1192
55.	75.	Kenotron, with Filamentary Anode (Photograph printed) ..	1154
56.	76.	Volt-Ampere Characteristics of Kenotron with Filamentary Anode at Different Filament Temperatures	1193
57.	77.	Temperature Current Characteristics of Kenotron with Filamentary Anode	1194
58.	78.	Logarithmic Plot of Volt-Ampere Characteristics of Kenotron with Filamentary Anode	1195
59.	79.	Diagram, Fig. 10	1203
60.	80.	Diagram, Fig. 11	1204
61.	81.	Diagram, Fig. 12	1208
62.	82.	Diagram, Fig. 13	1209
63.	83.	Diagram, Fig. 14	1211
64.	84.	Diagram, Fig. 15	1212
65.	85.	Thomson Lecture Reported in "Engineering"	Not printed
66.	86.	Logarithmic Plot of Richardson Data	1268
67.	87.	Volt-Ampere Characteristics of Fleming Vacuum Valve	1319
68.	88.	Logarithmic Plot of Volt-Ampere Characteristics of Fleming Vacuum Valve	1320
69.	89.	Pliotron No. 79 (Photograph printed)	1486

INDEX TO PLAINTIFF'S EXHIBITS IN INTERFERENCE RECORD —Continued.

Inter. Ex. No.	Trial Ex. No.		Inter. Record Page
70.	90.	Plot of Van der Bijl's Data on page 47 of Arnold's Record	1531
71.	91.	Logarithmic Plot of Van der Bijl's Data on page 47 of Arnold's Record	1532
72.	92.	Plot of Van der Bijl's data on pages 49, 50 of Arnold's Record	1536
73.	93.	Logarithmic Plot of Van der Bijl's Data of pages 49, 50 of Arnold's Record	1537
74.	94.	Plot of Van der Bijl's Data on page 51 of Arnold's Record	1539
75.	95.	Plot of Van der Bijl's Data on page 67 of Arnold's Record	1544
76.	96.	Logarithmic Plot of Van der Bijl's Data on page 67 of Arnold's Record	1545
77.	97.	Plot of Van der Bijl's Data on page 211 of Arnold's Record	1547
78.	98.	Logarithmic Plot of Van der Bijl's Data on page 211 of Arnold's Record	1548
79.	99.	Sweetser Record Sheets S-1146 to S-1214, Experiment No. 291	Not printed
80.	100.	Sweetser Record Sheets S-1345 to S-1432-13, Experiment No. 317	Not printed
81.	101.	Langmuir Notebook No. 413, pages 1-145	Not printed
82.	102.	Volt-Ampere Characteristics of Pliotron No. 79	1592
83.	103.	Logarithmic Plot of Volt-Ampere Characteristics of Pliotron No. 79	1593
84.	104.	Proceedings of the Institute of Radio Engineers, September, 1915	Not printed
85.	105.	Tungsten Wire Audion No. 2 (Photograph printed)	1619
86.	106.	General Electric Review Article on Coolidge X-ray Tubes	Not printed
87.	107.	Lt. Gutton's Article in Revue Generale de l'Electricite	Not printed
88.	108.	Calculations Involving Maxwell's Distribution Law	Not printed
89.	109.	DeForest Audion Record Sheets	Not printed
90.	110.	Logarithmic Plot of DeForest Audion Data	1981
A.	111.	Logarithmic Plot of Pierce's Data	2029
B.	112.	Logarithmic Plot of Pierce's Data	2032
C.	113.	Plot of Pierce's Data	2035
D.	114.	Plot of Pierce's Data	2060
E.	115.	Plot of Pierce's Data	2063
F.	116.	Plot of Pierce's Data on Audion 20.4	2073

INDEX TO PLAINTIFF'S EXHIBITS IN INTERFERENCE RECORD
—Continued.

Inter. Ex. No.	Trial Ex. No.		Inter. Record Page
G.	117.	Plot of Pierce's Data on Tubes A-3 and B-3	2078
H.	118.	Plot of Characteristics of Audion A-9.111	2085
I.	119.	Plot of Sweetser's Data of August, 1912	2091
J.	120.	Volume Gillette Photographs	Not printed
K.	121.	Gillette Negative	——
L.	122.	Photograph of Langmuir's Laboratory	2096
M.	123.	Lamp Vacuum Committee Reports	Not printed
N.	124.	Robinson Notebook	Not printed
O.	125.	Mackay Notebook	Not printed
P.	126.	Dushman Notebook No. 436	Not printed
Q.	127.	Dushman Notebook No. 464	Not printed
R.	128.	Plot of Data of Lamp No. 2 of November 19, 1912	2101
S.	129.	Gartner Letter of February 6, 1913	2111
T.	130.	Diagram	2112
U.	131.	Langmuir Notebook No. 458	Not printed
V.	132.	Langmuir Notebook No. 504	Not printed
*	133.	U. S. Patent No. 1,103,688, W. L. Richards	2333
	134.	U. S. Patent No. 1,114,845, H. DeF. Arnold	2345
	135.	U. S. Patent No. 1,128,279, H. DeF. Arnold	2348
	136.	U. S. Patent No. 1,128,280, H. DeF. Arnold	2375
	137.	U. S. Patent No. 1,128,292, E. H. Colpitts	2336
	138.	U. S. Patent No. 1,129,942, H. DeF. Arnold	2356
	139.	U. S. Patent No. 1,129,943, H. DeF. Arnold	2362
	140.	U. S. Patent No. 1,129,959, E. H. Colpitts	2340
	141.	U. S. Patent No. 1,130,008, A. McL. Nicholson	2369
	142.	U. S. Patent No. 1,130,009, A. McL. Nicholson	2373
	143.	U. S. Patent No. 1,130,042, H. J. Van Der Bijl, et al.	2366
	144.	U. S. Patent No. 1,130,043, H. J. Van Der Bijl, et al.	2378
	145.	U. S. Patent No. 1,137,275, A. McL. Nicholson	2371
	146.	U. S. Patent No. 1,137,315, R. A. Heising	2388
	147.	U. S. Patent No. 1,137,384, E. H. Colpitts	2352
	148.	U. S. Patent No. 1,168,270, H. DeF. Arnold	2391

---

*Patents Exhibits Nos. 133 to 161, incl., not given any Exhibit number in Interference record.

INDEX TO PLAINTIFF'S EXHIBITS IN INTERFERENCE RECORD —Continued.

Inter. Ex. No.	Trial Ex. No.		Inter. Record Page
*	149.	U. S. Patent No. 1,169,182, A. McL. Nicholson	2397
	150.	U. S. Patent No. 1,169,422, A. McL. Nicholson	2382
	151.	U. S. Patent No. 1,183,875, R. V. L. Hartley	2414
	152.	U. S. Patent No. 1,193,206, H. J. Van Der Bijl	2400
	153.	U. S. Patent No. 1,194,820, E. H. Colpitts	2410
	154.	U. S. Patent No. 1,196,474, A. McL. Nicholson	2385
	155.	U. S. Patent No. 1,196,805, J. C. R. Palmer	2394
	156.	U. S. Patent No. 1,198,699, E. H. Colpitts	2406
	157.	U. S. Patent No. 1,198,700, E. H. Colpitts	2417
	158.	U. S. Patent No. 1,199,180, R. A. Heising	2421
	159.	U. S. Patent No. 1,200,796, H. DeF. Arnold	2403
	160.	U. S. Patent No. 1,237,210, Langmuir	2433
	161.	U. S. Patent No. 1,251,388, Langmuir	2437

---

*Patents Exhibits Nos. 133 to 161, incl., not given any Exhibit number in Interference record.

DEFENDANT'S EXHIBITS.

GENERAL INDEX.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
1.	Hogan Graph plotted between filament and plate currents (Pltff.'s Ex. 52, Hewlett v. A. T. & T. Co., S. D. of N. Y.)	I	145	V	1
2.	Nature, July 15, 1875, p. 217, "Charcoal Vacua," by James DeWar	I	196	V	3
3.	Physikalische Zeitschrift, Vol. 29, pp. 46-50, 1909, "Tests of the Methods Used for Producing High Vacua," by Scheel & Heuse	I	196	V	8
4.	Annalin der Physik, Vol. 12 (1881) pp. 425-445, "A New Construction of the Mercury Pump of Toepler and Describing Some Experiments Made Therewith," by Bessel-Hagen	I	196	V	16
5.	Edison U. S. Patent No. 411,019, Sept. 17, 1889	I	196	V	37
6.	Malignani U. S. Patent No. 537,693, April 16, 1895	I	196	V	40
7.	Dwyer U. S. Patent No. 596,654, Jan. 4, 1898	I	197	V	42
8.	American Electrician, Vol. VIII, No. 1, May, 1896, "Crookes Tubes and Experiments With Roentgen Rays," by Thomas Duncan	I	197	V	47
9.	Proceedings of the Royal Society, A, Vol. 64, pp. 231-238, "Liquid Hydrogen for the Production of High Vacua," by James DeWar	I	197	V	53
10.	Annalin der Physik, Vol. II (1900), pp. 359-374, "Production of Cathode Rays by Ultra-Violet Light," by P. Lenard	I	197	V	62
10-A.	Annalin der Physik, Vol. VIII, (1902), pp. 149-198, "Photoelectric Action," by P. Lenard	I	197	V	79
11.	Electrical World and Engineer, Vol. III, May 21, 1904, pp. 963-965, "A Resume of Incandescent Electric Lamps Exhausting," by S. E. Doane	I	197	V	122
12.	Recklinghausen U. S. Patent No. 946,068, Jan. 11, 1910	I	197	V	135
13.	Merritt U. S. Patent No. 909,811, Jan. 12, 1909	I	197	V	138

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
14.	Proceedings of the Royal Society, Vol. 74 (1905), pp. 476-487, "Conversion of Electric Oscillations into Continuous Currents by Means of a Vacuum Valve," by J. A. Fleming	I	197	V	142
15.	Fleming U. S. Patent No. 803,684, Nov. 7, 1905	I	197	V	157
16.	Scientific American Supplement, No. 1568, Jan. 20, 196, pp. 25129-25131, "On the Electric Conductivity of a Vacuum," by J. A. Fleming	I	197	V	165
17.	Soddy U. S. Patent No. 859,021, July 2, 1907	I	198	V	181
18.	Nature, Nov. 21, 1907, pp. 53-54, "The Wehnelt Kathode in a High Vacuum," by Frederick Soddy	I	198	V	190
18-A.	Proceedings of the Royal Society (1907), Vol. 78-A, pp. 429-458, "Calcium as an Absorbent of Gases for the Production of High Vacua and Spectroscopic Research," by Frederick Soddy	I	198	V	192
19.	Physikalische Zeitschrift, Vol. 9 (1908), p. 193, Reply to Soddy by Lilienfeld	I	198	V	222
20.	Proceedings of the American Academy of Arts and Sciences, Vol. XIV, No. 1, August, 1909, pp. 1-17, "Friction in Gases at Low Pressures," by J. L. Hogg	I	198	V	225
21.	Annalin der Physik, Vol. 31, (1910), pp. 169-304, "A Contribution to the Knowledge of the Inertia of Moving Electrons," by E. Hupka	I	198	V	241
22.	Physikalische Zeitschrift, Vol. 10, (1909), pp. 168-176, "Concerning Slow Cathode Rays," by O. V. Baeyer	I	198	V	281
23.	Thatcher U. S. Patent No. 1,028,636, June 4, 1912	I	198	V	305
24.	Friedrich U. S. Patent No. 1,083,677, Jan. 6, 1914	I	198	V	309
25.	Annalin der Physik, Vol. 32 (1910), pp. 673-738, "Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	315
25-A.	Leipsiger Berichte, Vol. 63, (1911), pp. 534-539, "The Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	388
26.	Verhandlunger der Deutschen Physikalischen Gesellschaft, Vol. 13, (1911), pp. 601-606, "On a Method of Producing Very Soft Roentgen Rays in the Highest Vacuum," by H. Dember	I	198	V	397

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
27.	Annalin der Physik, Vol. 36 (1911), pp. 995-1026, "Reflection and Secondary Radiation of Photoelectrically Liberated Cathode Rays," by A. Gehrts...	I	199	V	403.
28.	Marshall U. S. Patent No. 205,002, Nov. 14, 1916....	I	199	V	433
29.	Physical Review, Vol. 32, (1911), pp. 492-511, "Discharge from Hot CAO," by C. D. Child.....	I	199	V	437
30.	Atti Della Raele Accademia Dei Lincei, Vol. XXI, (1912), pp. 235-239, "On Electromagnetic Wave Indicators Based on the principle of Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	457
30-A.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 274-277, "On a New Type of Indicator of Electromagnetic Waves Based Upon Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	465
31.	Fortschritte uf dem Gebiete der Rontgen Strahlen, Vol. 18 (1912), pp. 256-263, "An X-Ray Tube of an Optional and Instantaneously Attainable Degree of Hardness Independent of Vacuum," by J. E. Lilienfeld and W. J. Rosenthal	I	199	V	472
32.	Physikalische Zeitschrift, Vol. XIII (1912), pp. 594-595, "About the Distribution of Light During the Stratified Discharge in Vapors of Alkali Metals," by Kunz and Kemp	I	199	V	488
33.	American Institute of Electrical Engineers, Proceedings of, June 25, 1912, pp. 1207-1217, "Vacua," by W. R. Whitney	I	199	V	491
34.	Clark U. S. Patent No. 1,121,803, Dec. 22, 1914....	I	199	V	502
35.	Annalin der Physik, Vol. 41 (1913), pp. 1-26, "Concerning the Pressure of Cathode Rays," by Ernst V. Angerer	I	199	V	507
36.	Clough U. S. Patent No. 246,054, Nov. 13, 1917....	I	200	V	539
37.	Mackay U. S. Patent No. 1,208,597, Dec. 12, 1916..	I	200	V	542
38.	Coolidge U. S. Patent No. 1,082,933, Dec. 30, 1913..	I	382	V	545.
39.	Langmuir New Zealand Patent No. 35,611, April 8, 1924	I	384	V	556

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
40.	General Electric Co. Australian Patent No. 14,677, Oct. 22, 1914	I	384	V	580
41.	British Thomson-Houston Co., Ltd., British Patent No. 15,788 of 1914	I	387	V	592
42.	White U. S. Patent No. 1,159,307, Nov. 2, 1915	I	387	V	604
43.	Arnold U. S. Patent No. 1,118,172, Nov. 24, 1914	I	494	V	610
44.	Hewitt U. S. Patent No. 1,025,464, May 7, 1912	I	583	V	614
45.	Hewitt U. S. Patent No. 682,699, Sept. 17, 1901	I	583	V	619
46.	Hewitt U. S. Patent No. 682,692, Sept. 17, 1901	I	583	V	622
47.	Kelly's approximate duplicate tube of Arnold priority record Exhibit No. 30	II	816	—	—
48.	Kelly diagram for Arnold Priority Exhibit No. 30	II	826	V	629
49.	Kelly diagram for Western Electric Standard 102-D Vacuum Tube	II	828	V	630
50.	Kelly diagram for tube 201-A	II	828	V	631
51.	Kelly approximate duplicate tube of Arnold Priority Exhibit No. 32	II	833	—	—
52.	Kelly diagram for Arnold Priority Exhibit No. 32 and approximate duplicate tube	II	834	V	633
53.	Kelly diagram for Arnold Priority Exhibit No. 32 and Arnold Audion 9.111	II	836	V	634
54.	Kelly diagram for data of Audion 9.111 in Arnold priority Exhibit No. 34	II	837	VI	635
54-A.	Kelly diagram showing correction of lowermost line of Exhibit No. 54	II	852	VI	636
55.	Circulars of General Electric tubes including tube UV-200	II	840	VI	637
56.	Kelly Helium filled tube	II	845	—	—
57.	Kelly diagram for Helium filled tube	II	845	VI	651
58.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	652
58-A.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	653
58-B.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	654
59.	Kelly diagram of two-way telephone repeater	II	849	VI	655

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
60.	Diagram of Page 591 of Warner Article, Proceedings of Radio Engineers, showing curves for tubes UV-199, 201 and 201-A	II	854	VI	656
61.	Kelly diagram for Arnold priority Exhibit No. 32 and approximate duplicate tube, plotted for exponent 3/2 or its inverse	II	856	VI	657
62.	File wrapper and contents, Langmuir U. S. Patent No. 1,558,436	II	912	VI	659
63.	File wrapper and contents Langmuir U. S. Patent No. 1,244,216	II	912	VI	786
64.	File wrapper and contents Langmuir U. S. Patent No. 1,244,217	II	912	VI	824
65.	File wrapper and contents Langmuir U. S. Patent No. 1,522,597	II	912	VI	852
66.	Physical Review, December, 1913, "A Powerful Roentgen Ray Tube With a Pure Electron Discharge," by W. D. Coolidge	II	913	VI	919
67.	File wrapper and contents Coolidge U. S. Patent No. 1,203,495	II	913	VI	941
68.	Drawing of pump used by Lamont	II	915	VI	1031
69.	Drawing of pump used by Lamont	II	916	VI	1033
70.	Photograph of Lamont preliminary pump	II	916	VI	1034
71.	Photograph of Lamont mercury pump	II	916	VI	1035
72.	Hewlett pump sketch	II	916	VI	1036
73.	Clark pump sketch	II	916	VI	1037
74.	Lamont account book (cash)	II	917	VI	1038
75.	Lamont account book (order)	II	917	VI	1048
76.	Shop card, amplifiers (3-stage)	II	918	VI	1054
77.	Shop card, amplifier tubes	II	918	VI	1055
78.	Letter, McCandless & Co. to Federal Telegraph Co., May 4, 1912	II	918	VI	1056
78-A.	Letter, McCandless & Co. to Federal Telegraph Co., June 9, 1912	II	918	VI	1057
78-B.	Letter, McCandless & Co. to Federal Telegraph Co., Dec. 23, 1912	II	918	VI	1058
78-C.	Letter, McCandless & Co. to Federal Telegraph Co., Jan. 8, 1913	II	918	VI	1059

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
79.	Letter, Federal Telegraph Co. to McCandless & Co., April 27, 1912	II	919	VI	1060
79-A.	Letter, Federal Telegraph Co. to McCandless & Co., July 26, 1912	II	919	VI	1061
79-B.	Letter, Federal Telegraph Co. to McCandless & Co., August 14, 1912	II	919	VI	1062
79-C.	Letter, Federal Telegraph Co. to G. E. Lamont, Oct. 16, 1912	II	919	VI	1063
80.	Watkin's photograph	II	919	VI	1064
81.	Drawing 88, Federal Telegraph Co.	II	919	VI	1065
82.	Drawing 229, Federal Telegraph Co.	II	919	VI	1067
83.	DeForest Audion structure, California depositions (Exhibit withdrawn)	II	920	—	—
84.	Jahnke Tube, California depositions (Exhibit withdrawn)	II	920	—	—
85.	Letter, Commissioner of Patents to Irving Langmuir, Sept. 8, 1916	II	923	VI	1069
86.	Telegram, Albert G. Davis to Edw. Williams, Sept. 15, 1916	II	923	VI	1070
87.	Supplemental petition of Irving Langmuir that claims be added, Interference No. 40,380	II	924	VI	1071
88.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1075
89.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1076
90.	Memorandum, Albert G. Davis on motion to dissolve and to add counts, Interference No. 40,380, Feb. 2, 1921	II	925	VI	1079
91.	Stipulation between attorneys for Langmuir and Arnold, Interference No. 40,380	II	925	VI	1081
92.	Communication from Law Examiner, Stipulation to amend, Interference No. 40,380, March 18, 1921	II	925	VI	1083
93.	Langmuir U. S. Patent No. 1,280,769, Oct. 8, 1918	II	925	VI	1085
94.	Hull U. S. Patent No. 291,527, Jan. 14, 1919	II	925	VI	1090
95.	Payne U. S. Patent No. 313,112, Aug. 12, 1919	II	925	VI	1095
96.	Hull U. S. Patent No. 1,313,187, Aug. 12, 1919	II	925	VI	1099
97.	Hull U. S. Patent No. 313,188, Aug. 12, 1919	II	925	VI	1104

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
98.	Hull U. S. Patent No. 1,385,873, July 26, 1921	II	925	VI	1108
99.	Hull, U. S. Patent No. 387,984, Aug. 16, 1921	II	925	VI	1117
	[Nos. 100 to 278, incl., Arnold Exhibits in Interference Record and not reprinted. *See Separate Index.*]	II	927	—	—
279.	(No Exhibit.)				
280.	Dushman U. S. Patent No. 172,961, Feb. 22, 1916	II	948	VI	1126
281.	Hawkins U. S. Patent No. 1,172,990, Feb. 22, 1916	II	948	VI	1130
282.	Meikle U. S. Patent No. 1,182,290, May 9, 1916	II	948	VI	1133
283.	Meikle U. S. Patent No. 266,517, May 14, 1918	II	948	VI	1137
284.	Langmuir U. S. Pateut No. 1,273,628, July 23, 1918	II	949	VI	1141
285.	Langmuir re-issued Patent No. 15,278, Jan. 31, 1922	II	949	VI	1144
286.	Berg U. S. Patent No. 1,352,242, Sept. 7, 1920	II	949	VI	1150
287.	White U. S. Patent No. 1,365,576, Jan. 11, 1921	II	949	VI	1153
288.	Pratt U. S. Patent No. 1,374,679, April 12, 1921	II	949	VI	1157
289.	Alexanderson U. S. Patent No. 1,477,413, Dec. 11, 1923	II	949	VI	1160
290.	White U. S. Patent No. 1,506,468, Aug. 26, 1924	II	949	VI	1163
291.	Hull U. S. Patent No. 1,523,776, Jan. 20, 1925	II	949	VI	1168
292.	Alexanderson U. S. Patent No. 1,535,082, April 21, 1925	II	949	VI	1178
293.	Alexanderson U. S. Patent No. 1,549,737, Aug. 18, 1925	II	950	VI	1181
294.	Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	II	950	VI	1194
295.	Becker diagram for low current values of Sweetser, August, 1912; notes	III	1799	VI	1202
296.	Becker approximate duplicate Sweetser tube, August 1912	III	1804	—	—
297.	Becker diagram for current pressure relation in tube, Defendant's Exhibit No. 296	III	1804	VI	1204
298.	Becker current temperature diagrams for hydrogen Sweetser notes for Nov. and Dec., 1912	III	1809	VI	1205
299.	Becker diagram for current pressure data of Defendant's Exhibit No. 298 reduced to common voltage	III	1813	VI	1206

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
300.	Petition, specification, oath and drawings, Langmuir U. S. Patent No. 558,437, Oct. 20, 1925	III	1851	VI	1207
301.	Amendment B to application, Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1851	VI	1228
302.	Alexanderson U. S. Patent No. 1,102,628, July 7, 1914	III	1821	VI	1233
303.	White U. S. Patent No. 1,195,632, Aug. 22, 1916	III	1821	VI	1241
304.	Langmuir U. S. Patent No. 1,273,627, July 23, 1918	III	1821	VI	1246
305.	White U. S. Patent No. 1,298,613, March 25, 1919	III	1821	VI	1251
306.	Langmuir U. S. Patent No. 1,301,279, April 22, 1919	III	1821	VI	1257
307.	Alexanderson U. S. Patent No. 313,042, Aug. 12, 1919	III	1821	VI	1263
308.	Langmuir re-issued U. S. Patent No. 15,495, Nov. 21, 1922	III	1822	VI	1267
309.	Goldsmith U. S. Patent No. 1,323,759, Dec. 2, 1919	III	1822	VI	1271
310.	Goldsmith and Weinberger U. S. Patent No. 1,334,087, March 16, 1920	III	1822	VI	1276
311.	Alexanderson U. S. Patent No. 1,340,101, May 11, 1920	III	1822	VI	1280
312.	Alexanderson U. S. Patent No. 1,373,931, April 5, 1921	III	1822	VI	1285
313.	Payne U. S. Patent No. 1,400,235, Dec. 13, 1921	III	1822	VI	1289
314.	Bradbury U. S. Patent No. 1,430,883, Oct. 3, 1922	III	1822	VI	1293
315.	Beverage U. S. Patent No. 1,434,984, Nov. 7, 1922	III	1822	VI	1297
316.	Beverage U. S. Patent No. 1,434,985, Nov. 7, 1922	III	1823	VI	1303
317.	Bradbury U. S. Patent No. 1,443,209, Jan. 23, 1923	III	1823	VI	1314
318.	Becker U. S. Patent No. 1,455,099, May 15, 1923	III	1823	VI	1317
319.	Alexanderson U. S. Patent No. 1,466,263, Aug. 28, 1923	III	1823	VI	1321
320.	Traver U. S. Patent No. 1,470,582, Oct. 9, 1923	III	1823	VI	1325
321.	Alexanderson U. S. Patent No. 1,491,372, April 22, 1924	III	1823	VI	1331
322.	White U. S. Patent No. 1,544,202, June 30, 1925	III	1823	VI	1337
323.	Hull U. S. Patent No. 1,547,153, July 21, 1925	III	1823	VI	1341
324.	Letter, Charles Neave to H. B. Thayer, Oct. 10, 1913, with Memorandum "Cooper-Hewitt Matters" annexed	III	1853	VI	1349

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
325.	Letter, C. E. Scribner to D. C. Tanner, Feb. 10, 1915 with Memorandum from H. D. Arnold to E. H. Colpitts annexed	III	1859	VI	1358
326.	Physical Review, Vol. II, No. 5, Oct. 18, 1913, Abstract of Langmuir paper "The Effect of Space Charge and Residual Gases on the Thermionic Current in High Vacuum"	III	1886	VI	1361
327.	Logarithmic plot of Volt-Ampere characteristics of Type U pliotron (Plaintiff's Exhibit No. 60 with additions)	III	1886	VI	1363
328.	Data sheets furnished to plaintiff by defendant's witness Kelly	III	1887	VI	1364
329.	Tube used by Arnold in demonstration in Court of Blue Glow	III	1893	—	—
330.	DeForest tube as placed on pump	III	1901	—	—
331.	DeForest tube sealed off from pump	III	1901	—	—
332.	DeForest tube prior to volatilization of magnesium	III	1902	—	—
333.	DeForest tube in completed commercial form	III	1903	—	—

DEFENDANT'S EXHIBITS.

CLASSIFIED INDEX.

Diagrams, Drawings and Photographs.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
295.	Becker diagram for low current values of Sweetser August, 1912, notes	III	1799	VI	1202
297.	Becker diagram for current pressure relation in tube, Defendant's Exhibit No. 296	III	1804	VI	1204
298.	Becker current temperature diagrams for hydrogen Sweetser notes for Nov. and Dec., 1912	III	1809	VI	1205
299.	Becker diagram for current pressure data of Defendant's Exhibit No. 298 reduced to common voltage	III	1813	VI	1206
73.	Clark pump sketch	II	916	VI	1037
81.	Federal Telegraph Co., Drawing 88	II	919	VI	1065
82.	Federal Telegraph Co., Drawing 229	II	919	VI	1067
72.	Hewlett pump sketch	II	916	VI	1036
1.	Hogan graph plotted between filament and plate currents (Pltff.'s Ex. 52, Hewlett v. A. T. & T. Co., S. D. of N. Y.)	I	145	V	1
48.	Kelly diagram for Arnold Priority Exhibit No. 30	II	826	V	629
49.	Kelly diagram for Western Electric Standard 102-D Vacuum Tube	II	828	V	630
50.	Kelly diagram for tube 201-A	II	828	V	631
52.	Kelly diagram for Arnold Priority Exhibit No. 32 and approximate duplicate tube	II	834	V	633
53.	Kelly diagram for Arnold Priority Exhibit No. 32 and Arnold Audion 9.111,	II	836	V	634
54.	Kelly diagram for data of Audion 9.111 in Arnold priority Exhibit No. 34	II	837	VI	635
54-A.	Kelly diagram showing correction of lowermost line of Exhibit No. 54	II	852	VI	636
57.	Kelly diagram for Helium filled tube	II	845	VI	651
58.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	652
58-A.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	653

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
58-B.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	654
59.	Kelly diagram of two-way telephone repeater	II	849	VI	655
61.	Kelly diagram for Arnold priority Exhibit No. 32 and approximate duplicate tube, plotted for exponent 3/2 or its inverse	II	856	VI	657
68.	Lamont, Drawing of pump used by	II	915	VI	1031
69.	Lamont, Drawing of pump used by	II	916	VI	1033
70.	Lamont preliminary pump, Photograph of	II	916	VI	1034
71.	Lamont mercury pump, Photograph of	II	916	VI	1035
327.	Logarithmic plot of Volt-Ampere characteristics of Type U pliotron (Plaintiff's Exhibit No. 60 with additions)	III	1886	VI	1363
60.	Warner Article, Diagram on Page 591 of, Proceedings of Radio Engineers, showing curves for tubes UV-199, 201 and 201-A	II	854	VI	656
80.	Watkin's photograph	II	919	VI	1064

Documentary, Miscellaneous.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
301.	Amendment B to application, Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1851	VI	1228
55.	Circulars of General Electric tubes including tube UV-200	II	840	VI	637
92.	Communication from Law Examiner, Stipulation to amend, Interference No. 40,380, March 18, 1921	II	925	VI	1083
328.	Data sheets furnished to plaintiff by defendant's witness Kelly	III	1887	VI	1364
74.	Lamont account book (cash)	II	917	VI	1038
75.	Lamont account book (order)	II	917	VI	1048
78.	Letter, McCandless & Co. to Federal Telegraph Co., May 4, 1912	II	918	VI	1056
78-A.	Letter, McCandless & Co. to Federal Telegraph Co., June 9, 1912	II	918	VI	1057
78-B.	Letter, McCandless & Co. to Federal Telegraph Co., Dec. 23, 1912	II	918	VI	1058
78-C.	Letter, McCandless & Co. to Federal Telegraph Co., Jan. 8, 1913	II	918	VI	1059

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
79.	Letter, Federal Telegraph Co. to McCandless & Co., April 27, 1912	II	919	VI	1060
79-A.	Letter, Federal Telegraph Co. to McCandless & Co., July 26, 1912	II	919	VI	1061
79-B.	Letter, Federal Telegraph Co. to McCandless & Co., August 14, 1912	II	919	VI	1062
79-C.	Letter, Federal Telegraph Co., to G. E. Lamont, Oct. 16, 1912	II	919	VI	1063
85.	Letter, Commissioner of Patents to Irving Langmuir, Sept. 8, 1916	II	923	VI	1069
88.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1075
89.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1076
324.	Letter, Charles Neave to H. B. Thayer, Oct. 10, 1913, with Memorandum "Cooper-Hewitt Matters" annexed	III	1853	VI	1349
325.	Letter, C. E. Scribner to D. C. Tanner, Feb. 10, 1915 with Memorandum from H. D. Arnold to E. H. Colpitts annexed	III	1859	VI	1358
90	Memorandum, Albert G. Davis on motion to dissolve and to add counts, Interference No. 40,380, Feb. 2, 1921	II	925	VI	1079
76.	Shop card, amplifiers (3-stage)	II	918	VI	1054
77.	Shop card, amplifier tubes	II	918	VI	1055
91.	Stipulation between attorneys for Langmuir and Arnold, Interference No. 40,380	II	925	VI	1081
87.	Supplemental petition of Irving Langmuir that claims be added, Interference No. 40,380	II	924	VI	1071
86.	Telegram, Albert G. Davis to Edw. Williams, Sept. 15, 1916	II	923	VI	1070

File Wrappers and Contents.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
67.	File wrapper and contents Coolidge U. S. Patent No. 1,203,495	II	913	VI	941
62.	File wraper and contents, Langmuir U. S. Patent No. 1,558,436	II	912	VI	659

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
63.	File wrapper and contents Langmuir U. S. Patent No. 1,244,216	II	912	VI	786
64.	File wrapper and contents Langmuir U. S. Patent No. 1,244,217	II	912	VI	824
65.	File wrapper and contents Langmuir U. S. Patent No. 1,522,597	II	912	VI	852
300.	Petition, specification, oath and drawing, Langmuir U. S. Patent No. 558,437, Oct. 20, 1925	III	1851	VI	1207

Patent, Australian.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
40.	General Electric Co., No. 14,677, Oct. 22, 1914	I	384	V	580

Patent, British.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
41.	Thomson-Houston Co., Ltd., British, No. 15,788 of 1914	I	387	V	592

Patent, New Zealand.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
39.	Langmuir, No. 35,611, April 8, 1924	I	384	V	556

Patents, United States.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
289.	Alexanderson, No. 1,477,413, Dec. 11, 1923	II	949	VI	1160
292.	Alexanderson, No. 1,535,082, April 21, 1925	II	949	VI	1178
293.	Alexanderson, No. 1,549,737, Aug. 18, 1925	II	950	VI	1184
302.	Alexanderson, No. 1,102,628, July 7, 1914	III	1821	VI	1233
307.	Alexanderson, No. 313,042, Aug. 12, 1919	III	1821	VI	1263
311.	Alexanderson, No. 1,340,101, May 11, 1920	III	1822	VI	1280
312.	Alexanderson, No. 1,373,931, April 5, 1921	III	1822	VI	1285
319.	Alexanderson, No. 1,466,263, Aug. 28, 1923	III	1823	VI	1321
321.	Alexanderson, No. 1,491,372, April 22, 1924	III	1823	VI	1331
43.	Arnold, No. 1,118,172, Nov. 24, 1914	I	494	V	610
318.	Becker, No. 1,455,099, May 15, 1923	III	1823	VI	1317
286.	Berg, No. 352,242, Sept. 7, 1920	II	949	VI	1150
315.	Beverage, No. 1,434,984, Nov. 7, 1922	III	1822	VI	1297
316.	Beverage, No. 1,434,985, Nov. 7, 1922	III	1823	VI	1303
314.	Bradbury, No. 1,430,883, Oct. 3, 1922	III	1822	VI	1293
317.	Bradbury, No. 1,443,209, Jan. 23, 1923	III	1823	VI	1314

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

34.	Clark, No. 1,121,803, Dec. 22, 1914	I	199	V	502
36.	Clough, No. 246,054, Nov. 13, 1917	I	200	V	539
38.	Coolidge, No. 1,082,933, Dec. 30, 1913	I	382	V	545
280.	Dushman, No. 172,961, Feb. 22, 1916	II	948	VI	1126
7.	Dwyer, No. 596,654, Jan. 4, 1898	I	197	V	42
5.	Edison, No. 411,019, Sept. 17, 1889	I	196	V	37
15.	Fleming, No. 803,684, Nov. 7, 1905	I	197	V	157
24.	Friedrich, No. 1,083,677, Jan. 6, 1914	I	198	V	309
309.	Goldsmith, No. 1,323,759, Dec. 2, 1919	III	1822	VI	1271
310.	Goldsmith and Weinberger, No. 1,334,087, March 16, 1920	III	1822	VI	1276
281.	Hawkins, No. 1,172,990, Feb. 22, 1916	II	948	VI	1130
44.	Hewitt, No. 1,025,464, May 7, 1912	I	583	V	614
45.	Hewitt, No. 682,699, Sept. 17, 1901	I	583	V	619
46.	Hewitt, No. 682,692, Sept. 17, 1901	I	583	V	622
94.	Hull, No. 291,527, Jan. 14, 1919	II	925	VI	1090
96.	Hull, No. 1,313,187, Aug. 12, 1919	II	925	VI	1099
97.	Hull, No. 313,188, Aug. 12, 1919	II	925	VI	1104
98.	Hull, No. 1,385,873, July 26, 1921	II	925	VI	1108
99.	Hull, No. 387,984, Aug. 16, 1921	II	925	VI	1117
291.	Hull, No. 1,523,776, Jan. 20, 1925	II	949	VI	1168
323.	Hull, No. 1,547,153, July 21, 1925	III	1823	VI	1341
93.	Langmuir, No. 1,280,769, Oct. 8, 1918	II	925	VI	1085
284.	Langmuir, No. 1,273,628, July 23, 1918	II	949	VI	1141
285.	Langmuir, Re-issue, No. 15,278, Jan. 31, 1922	II	949	VI	1144
294.	Langmuir, No. 1,558,437, Oct. 20, 1925	II	950	VI	1194
304.	Langmuir, No. 1,273,627, July 23, 1918	III	1821	VI	1246
306.	Langmuir, No. 1,301,279, April 22, 1919	III	1821	VI	1257
308.	Langmuir, Re-issue, No. 15,495, Nov. 21, 1922	III	1822	VI	1267
37.	Mackay, No. 1,208,597, Dec. 12, 1916	I	200	V	542
6.	Malignani, No. 537,693, April 16, 1895	I	196	V	40
28.	Marshall, No. 205,002, Nov. 14, 1916	I	199	V	433
282.	Meikle, No. 1,182,290, May 9, 1916	II	948	VI	1133
283.	Meikle, No. 266,517, May 14, 1918	II	948	VI	1137
13.	Merritt, No. 909,811, Jan. 12, 1909	I	197	V	138
95.	Payne, No. 313,112, Aug. 12, 1919	II	925	VI	1095
313.	Payne, No. 1,400,235. Dec. 13, 1921	III	1822	VI	1289
288.	Pratt, No. 1,374,679, April 12, 1921	II	949	VI	1157

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
12.	Recklinghausen, No. 946,068, Jan. 11, 1910	I	197	V	135
17.	Soddy, No. 859,021, July 2, 1907	I	198	V	181
23.	Thatcher, No. 1,028,636, June 4, 1912	I	198	V	305
320.	Traver, No. 1,470,582, Oct. 9, 1923	III	1823	VI	1325
42.	White, No. 1,159,307, Nov. 2, 1915	I	387	V	604
287.	White, No. 1,365,576, Jan. 11, 1921	II	949	VI	1153
290.	White, No. 1,506,468, Aug. 26, 1924	II	949	VI	1163
303.	White, No. 1,195,632, Aug. 22, 1916	III	1821	VI	1241
305.	White, No. 1,298,613, March 25, 1919	III	1821	VI	1251
322.	White, No. 1,544,202, June 30, 1925	III	1823	VI	1337

Publications.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
20.	American Academy of Arts and Sciences, Proceedings of the, Vol. XIV, No. 1, August, 1909, pp. 1-17, "Friction in Gases at Low Pressures," by J. L. Hogg	I	198	V	225
8.	American Electrician, Vol. VIII, No. 1, May, 1896, "Crookes Tubes and Experiments with Roentgen Rays," by Thomas Duncan	I	197	V	47
33.	American Institute of Electrical Engineers, Proceedings of, June 25, 1912, pp. 1207-1217, "Vacua," by by W. R. Whitney	[illegible]	199	V	491
4.	Annalin der Physik, Vol. 12 (1881), pp. 425-445, "A New Construction of the Mercury Pump of Toepler and Describing Some Experiments Made Therewith," by Bessel-Hagen	I	196	V	16
10.	Annalin der Physik, Vol. II, (1900), pp. 359-374, "Production of Cathode Rays by Ultra-Violet Light," by P. Lenard	I	197	V	62
10-A.	Annalin der Physik, Vol. VIII, (1902), pp. 149-198, "Photoelectric Action," by P. Lenard	I	197	V	79
21.	Annalin der Physik, Vol. 31, (1910), pp. 169-304, "A Contribution to the Knowledge of the Inertia of Moving Electrons," by E. Hupka..............	I	198	V	241
25.	Annalin der Physik, Vol. 32 (1910), pp. 673-738, "Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	315

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
27.	Annalin der Physik, Vol. 36 (1911), pp. 995-1026, "Reflection and Secondary Radiation of Photoelectrically Liberated Cathode Rays," by A. Gehrts	I	199	V	403
35.	Annalin der Physik, Vol. 41, (1913), pp. 1-26, "Concerning the Pressure of Cathode Rays," by Ernst V. Angerer	I	199	V	507
30.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 235-239, "On Electromagnetic Wave Indicators Based on the Principle of Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	457
30-A.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 274-277, "On a New Type of Indicator of Electromagnetic Waves Based Upon Electronic Emissions From Incandescent Wires," by Quirino Majorana	I	199	V	465
11.	Electrical World and Engineer, Vol. III, May 21, 1904, pp. 963-965, "A Resume of Incandescent Electric Lamps Exhausting," by S. E. Doane	I	197	V	122
31.	Fortschritte uf dem Gebiete der Rontgen Strahlen, Vol. 18 (1912), pp. 256-263, "An X-Ray Tube of An Optional and Instantaneously Attainable Degree of Hardness Independent of Vacuum," by J. E. Lilienfeld and W. J. Rosenthal	I	199	V	472
25-A.	Leipsiger Berichte, Vol. 63, (1911), pp. 534-539, "The Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	388
2.	Nature, July 15, 1875, p. 217, "Charcoal Vacua," by James DeWar	I	196	V	3
18.	Nature, Nov. 21, 1907, pp. 53-54, "The Wehnelt Kathode in a High Vacuum," by Frederick Soddy	I	198	V	190
29.	Physical Review, Vol. 32, (1911), pp. 492-511, "Discharge from Hot CAO," by C. D. Child	I	199	V	437
66.	Physical Review, December, 1913, "A Powerful Roentgen Ray Tube With a Pure Electron Discharge," by W. D. Coolidge	II	913	VI	919

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
326.	Physical Review, Vol. II, No. 5, Oct. 18, 1913, Abstract of Langmuir paper "The Effect of Space Charge and Residual Gases on the Thermionic Current in High Vacuum"	III	1886	VI	1361
3.	Physikalische Zeitschrift, Vol. 29, pp. 46-50, 1909, "Tests of the Methods Used for Producing High Vacua," by Scheel & Heuse	I	196	V	8
19.	Physikalische Zeitschrift, Vol. 9 (1908), p. 193, Reply to Soddy by Lilienfeld	I	198	V	222
22.	Physikalische Zeitschrift, Vol. 10 (1909), pp. 168-176, "Concerning Slow Cathode Rays," by O. v. Baeyer	I	198	V	281
32.	Physikalische Zeitschrift, Vol. XIII (1912), pp. 594-595, "About the Distribution of Light During the Stratified Discharge in Vapors of Alkali Metals," by Kunz and Kemp	I	199	V	488
9.	Royal Society, Proceedings of the, A, Vol. 64, pp. 231-238, "Liquid Hydrogen for the Production of High Vacua," by James DeWar	I	197	V	53
14.	Royal Society, Proceedings of the, Vol. 74 (1905), pp. 476-487, "Conversion of Electric Oscillations Into Continuous Currents by Means of a Vacuum Valve," by J. A. Fleming	I	197	V	142
18-A.	Royal Society, Proceedings of the, (1907), Vol. 78-A, pp. 429-458, "Calcium as an Absorbent of Gases for the Production of High Vacua and Spectroscopic Research," by Frederick Soddy	I	198	V	192
16.	Scientific American Supplement, No. 1568, Jan. 20, 1906, pp. 25129-25131, "On the Electric Conductivity of a Vacuum," by J. A. Fleming	I	197	V	165
26.	Verhandlunger der Deutschen Physikalischen Gesellschaft, Vol. 13, (1911), pp. 601-606, "On a Method of Producing Very Soft Roentgen Rays in the Highest Vacuum," by H. Dember	I	198	V	397

Physical Exhibits.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
329.	Arnold, tube used by, in demonstration in Court of Blue Glow	III	1893	—	—

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
296.	Becker approximate duplicate Sweetser tube, August, 1912	III	1804	—	—
83.	DeForest Audion structure, (California depositions) [Exhibit withdrawn]	II	920	—	—
330.	DeForest tube as placed on pump	III	1901	—	—
331.	DeForest tube sealed off from pump	III	1901	—	—
332.	DeForest tube prior to volatilization of magnesium	III	1902	—	—
333.	DeForest tube in completed commercial form	III	1903	—	—
84.	Jahnke Tube, (California depositions) [Exhibit withdrawn]	II	920	—	—
47.	Kelly's approximate duplicate tube of Arnold priority record Exhibit No. 30	II	816	—	—
51.	Kelly's approximate duplicate tube of Arnold Priority Exhibit No. 32	II	833	—	—
56.	Kelly Helium filled tube	II	845	—	—

INDEX TO DEFENDANT'S EXHIBITS
in
INTERFERENCE RECORD.†

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page
1.	100.	Van der Bijl Diagram No. 1	423
2.	101.	Van der Bijl Diagram No. 2	424
3.	102.	Van der Bijl Diagram No. 3	425
4.	103.	Van der Bijl Diagram No. 4	426
5.	104.	Van der Bijl Diagram No. 5	427
6.	105.	Van der Bijl Diagram No. 6	428
7.	106.	Van der Bijl Diagram No. 7	429
8.	107.	Van der Bijl Diagram No. 8	430
9.	108.	Van der Bijl Diagram No. 9	431
10.	109.	Van der Bijl Diagram No. 10	432
*	110.	Vacuum Tube No. 17,482	—
11.	111.	Van der Bijl Diagram No. 11	433
12.	112.	Van der Bijl Diagram No. 12	434
1.	113.	Millikan Sketch No. 1	435
2.	114.	Millikan Sketch No. 1	436
1-A.	115.	Arnold Exhibit No. 1-A	437
1-B.	116.	Arnold Exhibit No. 1-B	438
2-A.	117.	Arnold Exhibit No. 2-A	439
2-B.	118.	Arnold Exhibit No. 2-B	440
3-A.	119.	Arnold Exhibit No. 3-A	441
3-B.	120.	Arnold Exhibit No. 3-B	442
3-C.	121.	Arnold Exhibit No. 3-C	443
3-D.	122.	Arnold Exhibit No. 3-D	444
4-A.	123.	Arnold Exhibit No. 4-A	445
4-B.	124.	Arnold Exhibit No. 4-B	446
*	125.	Buckley Article	447
1.	126.	Calibration Curve No. 1	450
2.	127.	Calibration Curve No. 2	451

---

*Not given Exhibit No. in Interference record.

†Referred to in Interference record as Arnold Exhibits.

INDEX TO DEFENDANT'S EXHIBITS IN INTERFERENCE RECORD

—Continued.

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page
13.	128.	Van der Bijl Diagram No. 13	452
14.	129.	Van der Bijl Diagram No. 14	453
*	130.	Van der Bijl Diagram No. 8 simplified	454
15.	131.	Van der Bijl Diagram No. 15	455
16.	132.	Van der Bijl Diagram No. 16	456
17.	133.	Van der Bijl Diagram No. 17	457
18.	134.	Van der Bijl Diagram No. 18	458
*	135.	Photograph of Tube R. D. Q. 165	459
1.	136.	Richardson Exhibit No. 1	267
2.	137.	Richardson Exhibit No. 2	268
*	138.	Vacuum Tube No. 17,482 (same as Exhibit No. 110)	–
39.	139.	DeForest Audion 7-A	–
40.	140.	Van der Bijl Test Circuits for Amplifier	517
41.	141.	Van der Bijl Circuits for Detector	520
42.	142.	Van der Bijl Comparison Test Circuits for Detector	521
43.	143.	Vacuum Tube Conference Report of February 8, 1918	963
44.	144.	Signal Corps Specification for Receiver Tubes, Dated February 12, 1918	968
45.	145.	Test Specification for Transmitter Tubes, Dated November 1, 1918	973
46.	146.	Diagram for Regulator Kenotron Experiment Carried to 300 Volts	535
47.	147.	Diagram for Regulator Kenotron Experiment at Graded Pressures, with Tungsten Filament	538
48.	148.	Diagram for Regulator Kenotron Experiment at Graded Pressures, with Wehnelt Cathode	544
49.	149.	Diagram Illustrating Effect of Filament Voltage Drop	556
50.	150.	Logarithmic Diagram Illustrating Effect of Filament Voltage Drop	557
51.	151.	Comparative Diagram Langmuir Exhibits 33 and 35	561
52.	152.	Logarithmic Diagram at Different Pressures with Wehnelt Cathode	564

---

*Not given Exhibit No. in Interference record.

INDEX TO DEFENDANT'S EXHIBITS IN INTERFERENCE RECORD
—Continued.

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page
53.	153.	Diagrams on Successive Days with Wehnelt Cathode, Using Liquid Air	565
54.	154.	Logarithmic Diagram Corresponding to Exhibit 53, Rebuttal Fig. 13	567
55.	155.	Characteristics for Unbaked Tube with Filamentary Tungsten Anode	574
56.	156.	Logarithmic Plot Corresponding to Exhibit 55, Rebuttal Fig. 15	576
57.	157.	Characteristics for Unbaked Tube with Coiled Filamentary Tungsten Anode	578
58.	158.	Logarithmic Plot Corresponding to Exhibit 57, Rebuttal Fig. 17	580
59.	159.	Characteristics Corresponding to Exhibit 57, Fig. 17, but with Higher Temperatures	581
60.	160.	Characteristics for Unbaked Tube with Equal Filamentary Tungsten Electrodes	582
61.	161.	Characteristics for Unbaked Tube with Equal Parallel Carbon Electrodes	584
62.	162.	Logarithmic Plot Corresponding to Exhibit 61, Fig. 21	585
63.	163.	Characteristics Corresponding to Exhibit 61, Fig. 21, but Pushed to Higher Currents	587
64.	164.	Logarithmic Plot Corresponding to Exhibits 63, Fig. 23	588
65.	165.	Characteristics for Unbaked Tube with Equal Carbon Hairpin Electrodes	589
66.	166.	Logarithmic Plot Corresponding to Exhibit 65, Fig 25	591
67.	167.	Characteristics for Unbaked Tube with Equal Carbon Electrodes	592
68.	168.	Characteristics for Unbaked Tube with Equal Carbon Hairpin Electrodes	593
69.	169.	Logarithmic Diagram Illustrating 2/3 Slope for Considerable Gas Present (based on Exhibit 47, Fig. 7)	601
70.	170.	Comparative Direct Diagrams of Langmuir's Exhibits 32 to 35	617
71.	171.	Plate Current-Grid Volt Characteristic for Standard Telephone Repeater Tube	624

INDEX TO DEFENDANT'S EXHIBITS IN INTERFERENCE RECORD —Continued.

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page
72.	172.	Current-Voltage and Resistance-Voltage Characteristics for Standard Telephone Repeater Tube	625
73.	173.	Logarithmic Plot corresponding to Exhibit 72, Fig. 37	626
74.	174.	Diagram showing two 3/2 slopes for a single tube	[illegible]35
75.	175.	Diagram showing three 3/2 slopes for a single tube	637
76.	176.	Logarithmic diagram corresponding to Exhibit 67, Fig. 27	638
77.	177.	Comparative diagram for DeForest tube 7-A and General Electric tubes VT-11 and VT-13	650
78.	178.	Volt-ampere diagram for small Western Electric tube	651
79.	179.	Logarithmic diagram corresponding to Exhibit 78, Fig. 44	653
80.	180.	Diagram for small Western Electric tube, corrected for contact potential difference	654
81.	181.	Logarithmic diagram corresponding to Exhibit 80, Fig. 46	655
82.	182.	Diagram showing volt-ampere and volt-ohm characteristics for VT-1 tube	656
83.	183.	Diagram showing logarithmic volt-ampere characteristics for VT-1 tube	657
84.	184.	Diagram showing plate current-grid volt characteristics for VT-1 tube	658
85.	185.	Diagram for type W radio transmitting tube	659
86.	186.	Logarithmic diagram for type W radio transmitting tube	660
87.	187.	Diagram showing characteristics for type G power tube	661
88.	188.	Diagram showing logarithmic characteristics for type G power tube	662
89.	189.	Diagram showing characteristics for type I power tube	664
90.	190.	Diagram showing logarithmic characteristic for type I power tube	665
91.	191.	Diagram obtained by pushing a VT-1 tube to excessive voltages	671
92.	192.	Logarithmic diagram corresponding to Exhibit 91, Fig. 57	672
93.	193.	Diagram for a VT-1 tube to excessive voltage and then for decreasing voltages	674
94.	194.	Logarithmic diagram corresponding to Exhibit 93, Fig. 59	675
95.	195.	Arnold Exhibit No. 95, Tube for Figs. 8, 12, 13 and 14	—
96.	196.	Arnold Exhibit No. 96, Tube for Figs. 15 and 16	—

INDEX TO DEFENDANT'S EXHIBITS IN INTERFERENCE RECORD —Continued.

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page
97.	197.	Arnold Exhibit No. 97, Tube for Figs. 17, 18 and 19	—
98.	198.	Arnold Exhibit No. 98, Tube for Fig. 20	—
99.	199.	Arnold Exhibit No. 99, Tube for Figs. 21, 22 and 40	—
100.	200.	Arnold Exhibit No. 100, Tube for Figs. 23, 24 and 39	—
101.	201.	Arnold Exhibit No. 101, Tube for Figs. 25 and 26	—
102.	202.	Arnold Exhibit No. 102, Tube for Figs. 27 and 41	—
103.	203.	Arnold Exhibit No. 103, Tube for Fig. 28	—
104.	204.	Arnold Exhibit No. 104, Tube for Figs. 36, 37 and 38	—
105.	205.	Arnold Exhibit No. 105, Tube for Figs 44, 45, 46 and 47	—
106.	206.	Arnold Exhibit No. 106, Tube for Figs 48, 49 and 50	—
107.	207.	Arnold Exhibit No. 107, Tube for Figs. 51 and 52	—
108.	208.	Arnold Exhibit No. 108, Tube for Figs. 53 and 54	—
109.	209.	Arnold Exhibit No. 109, Tube for Figs. 55 and 56	—
110.	210.	Arnold Exhibit No. 110, Tube for Figs. 57 and 58	—
111.	211.	Arnold Exhibit No. 111, Tube for Figs. 59 and 60	—
112.	212.	Direct volt-ampere plot for unbaked tubular bulb	708
113.	213.	Logarithmic volt-ampere plot for unbaked tubular bulb	710
114	214-222, inclusive.	Diagram for batch of unbaked tubes pumped and tested December 12 and 13, 1919	746 to 754
115.	223.	Volt-ampere diagram for tube of Van der Bijl rebuttal XQs. 192 and 201	762
116.	224.	Diagram for tube No. 35	763
117.	225.	Diagram for tube No. 36	764
118.	226.	Diagram for tube No. 38	765
119.	227.	Diagram for tube No. 45	766
120.	228 229 230	Diagrams for tube No. 50	767 768 769
121.	231 232 233	Diagrams for tube No. 67	770 771 772
122.	234.	Diagram for tube No. 67	797
*	235.	Langmuir Exhibits 16 and 18 plotted together	835
*	236.	Logarithmic Diagram for Von Baeyer data (Phys. Zeit. 10, 5, 169-1909)	871

*Not given No. in Interference record.

INDEX TO DEFENDANT'S EXHIBITS IN INTERFERENCE RECORD —Continued.

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page
125.	237.	Certified copy of Armstrong testimony in Marconi v. DeForest case	Withdrawn
*Pr. 1.	238.	Photostat copy of Richards Book 4, pp. 137, 138 and 165. Dates and Diagrams for meeting with DeForest; address of McCandless; and notes on the artificial transcontinental line test	** Not printed
Pr. 2.	239.	Audion 1-A. A Physical Exhibit	"
Pr. 3.	240.	Photograph of Audion 7-A	"
Pr. 4.	241.	Audion No. 11. A Physical Exhibit	"
Pr. 5.	242.	Photograph of Audion No. 11	"
Pr. 6.	243.	Arnold diagram of audion circuits for November 1, 1912	"
Pr. 7.	244.	Photostat copy of Pierce Book 20, pp. 16 to 41, inclusive. Tests of DeForest Audion 7-A	"
Pr. 8.	245.	Blueprints of sketches accompanying Exhibit 7	"
Pr. 9.	246.	Comparative diagram for Audion 7-A and type G pliotron (VT-13)	"
Pr. 10.	247.	Photostat and blueprint copy of Pierce-Arnold memorandum of December 18, 1912, on "Efficiency of the Audion"	"
Pr. 11.	248.	Copy of order for molecular pump	"
Pr. 12.	249.	Photostat copy of Letter to Crandell of March 17, 1913, fixing date of Arnold's trip to Princeton	"
Pr. 13.	250.	Photostat copy of Kendall Book 25, p. 25, noting arrival of new molecular pump	"
Pr. 14.	251.	Photostat copy of Trimble Book 18, pp. 89 to 95. Record of pumping twenty audions in January, 1913	"
Pr. 15.	252.	Photostat copy of Arnold-Nicolson 3/2 law memorandum	"
Pr. 16.	253.	Photostat copy of Arnold-Kendall 3/2 law computations	"

---

*Exhibit numbers preceded by "Pr." are exhibits referred to in Interference record as "Exhibits accompanying the statements in behalf of Arnold on the Question of Priority."

**Arnold Priority Exhibits Nos. 1 to 41, inclusive (Defendant's Exhibits Nos. 238 to 278, inclusive, in this case) not printed, but are bound in chronological order in brown cloth back book.

INDEX TO DEFENDANT'S EXHIBITS IN INTERFERENCE RECORD
—Continued.

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page **
Pr. 17.	254.	Photostat copy of Arnold letter to Millikan of May 5, 1913, giving 3/2 law computations	Not printed
Pr. 18.	255.	Photostat copy of Pierce Book 20, pp. 101 to 115, relating to use of new molecular pump with Audions 20, A and B	"
Pr. 19.	256.	Blueprints of sketches accompanying Exhibit 18	"
Pr. 20.	257.	Photostat copy of selected cards from Trimble's card index. Cards 1 to 10, 23, 64 and 100	"
Pr. 21.	258.	Photostat copy of Kendall Book 25, pp. 39, 40 and 50, relating to the audion installation at Philadelphia	"
Pr. 22.	259.	Photostat copy of Kendall Report of September 10, 1913, on two-way audion repeater with artificial lines	"
Pr. 23.	260.	Photostat and blueprint copy of Kendall memorandum of October 1, 1913, on the use of the audion for repeating	"
Pr. 24.	261.	Blueprint of Kendall cord circuit audion repeater drawing of October 2, 1913	"
Pr. 25.	262.	Photostat copy of Kendall Book 42, p. 5, on the commencement of commercial service at Philadelphia	"
Pr. 26.	263.	Photostat and blueprint copy of Kendall Report of October 22, 1913, on commercial operation of audion at Philadelphia	"
Pr. 27.	264.	Photostat copy of Kendall Book 42, p. , for December 20, 1913. Record of commercial service for audions at Philadelphia	"
Pr. 28.	265.	Audion 6.11 a Physical Exhibit	"
Pr. 29.	266.	Photograph of Audion 6.11	"
Pr. 30.	267.	Audion 64, a Physical Exhibit	"
Pr. 31.	268.	Photograph of Audion 64	"
Pr. 32.	269.	Audion 100, a Physical Exhibit	"
Pr. 33.	270.	Photograph of Audion 100	"
Pr. 34.	271.	Photostat copy of Pierce Book 20, pp. 182 and 183, and ES-93571. Data on Audion 9.111	"
Pr. 35.	272.	Photostat copy of Colpitts Memorandum of March 27, 1913, on audion improvements	"

**Arnold Priority Exhibits Nos. 1 to 41, inclusive (Defendant's Exhibits Nos. 238 to 278, inclusive, in this case) not printed, but are bound in chronological order in brown cloth back book.

INDEX TO DEFENDANT'S EXHIBITS IN INTERFERENCE RECORD
—Continued.

Inter. Record Ex. No.	Trial Ex. No.		Inter. Record Page **
Pr. 36.	273.	Photostat copy of Nicolson's daily memorandum sheet for February 4, 1913, fixing date for Exhibit 15	Not printed
Pr. 37.	274.	Photostat copy of Richards Book 4, pp. 155 and 156, on connecting audion grid and plate with a high resistance leak	"
Pr. 38.	275.	Photostat copy of Pierce Book 20, p. 146, showing resistance-capacity combination in audion plate circuit	"
Pr. 39.	276.	Life Test Record in April, 1914	"
Pr. 40.	277.	Data from Langmuir's Lamp No. 2 of November, 1912 ...	"
Pr. 41.	278.	Plot to exhibit the inaccuracy of a straight line relation be- I 2/3 and E as an indicator of high vacuum	"

**Arnold Priority Exhibits Nos. 1 to 41, inclusive (Defendant's Exhibits Nos. 238 to 278, inclusive, in this case) not printed, but are bound in chronological order in brown cloth back book.

UNITED STATES OF AMERICA, }
DISTRICT OF DELAWARE, } *ss.:*

BE IT REMEMBERED, that at a District Court of the United States for the District of Delaware, begun and held at the United States Court House and Post Office Building, in the City of Wilmington, in the said District of Delaware, at the time and place required by law, among other, the following proceedings were had, to wit:

GENERAL ELECTRIC COMPANY,
Plaintiff,
v.
THE DE FOREST RADIO COMPANY,
Defendant.

No. 589 IN EQUITY.

DOCKET ENTRIES

Jan. 26, 1926. Bill of complaint filed; same day subpœna issued, returnable February 15, 1926.

Jan. 26, 1926. Marshal returns on subpœna, "Served," &c; same day writ filed.

Jan. 28, 1926. Report to Commissioner of Patents mailed and copy filed.

May 27, 1926. Answer filed.

May 27, 1926. Stipulation filed; same day order extending time to file answer; same day order filed.

May 27, 1926. Order granting leave to file stipulation; same day order and stipulation filed.

Oct. 11, 1926. Defendant's bill of particulars filed.

Oct. 11, 1926. Defendant's supplemental bill of particulars filed.

Oct. 28, 1926. Order granting defendant leave to amend answer; same day amendment filed.

Oct. 11, 12, 18, 19, 20, 21, 22, 25, 26, 27, 28, 29, 1926. Trial before the Court.

Nov. 1, 2, 3, 4, 5, 9, 10, 11, 1926. Trial before the Court.

Oct. 28, 1926. Depositions of Mrs. A. W. F. Beck, Ralph Hyde, Palmer Hewlett, Leland B. Clark, G. E. Lamont, Ralph R. Beal, Austin Y. Tuel, James O. Watkins and Harold Lee Rodman, on behalf of defendant, filed.

Nov. 11, 1926. Record of proceeding at trial filed.

Apr. 12, 13, 14, 1927. Hearing on pleadings and proofs.

Jan. 3, 1928. Opinion of court filed.

Jan. 16, 1928. Final decree dismissing bill of complaint, with costs to be taxed; same day decree filed.

Jan. 23, 1928. Plaintiff's petition for appeal with assignments of error filed; same day order allowing appeal, bond in the sum of $500; same day order filed.

Jan. 27, 1928. Order approving bond on appeal in the sum of $500.00 with United States Fidelity and Guarantee Company as surety; same day bond filed.

Jan. 27, 1928. Citation issued.

Jan. 30, 1928. Citation, with acceptance of service by solicitor for defendant-appellee, endorsed thereon, filed.

Feb. 7, 1928. Report to Commissioner of Patents mailed and copy filed.

Mar. 8, 1928. Stipulation as to transcript of record filed; same day order approving stipulation; same day order filed.

GENERAL ELECTRIC COMPANY,
Plaintiff,
v.
DE FOREST RADIO COMPANY,
Defendant.

No. 598 IN EQUITY.

DOCKET ENTRIES

Apr. 28, 1926.	Bill of complaint filed; same day subpœna issued, returnable May 18, 1926.
Apr. 30, 1926.	Marshall returns on subpœna, "Served," &c.; same day writ filed.
Apr. 30, 1926.	Report to Commissioner of Patents mailed and copy filed.
May 1, 1926.	Answer filed.
Oct. 11, 1926.	Plaintiff's motion for bill of particulars filed.
Oct. 11, 1926.	Defendant's bill of particulars filed. (Filed in No. 589).
Oct. 11, 1926.	Defendant's supplemental bill of particulars filed. (Filed in No. 589).
Oct. 28, 1926.	Order granting leave to amend answer; same day amendment filed.
Oct. 28, 1926.	Depositions of Mrs. A. W. F. Beck, Ralph Hyde, Palmer Hewlett, Leland B. Clark, G. E. Lamont, Ralph R. Beal, Austin Y. Tuel, James O. Watkins and Harold Lee Rodman filed on behalf of defendant. (Filed in No. 589).

Oct. 11, 12, 18, 19, 20, 21, 22, 25, 26, 27, 28, 29, 1926. Trial before the Court.

Nov. 1, 2, 3, 4, 5, 9, 10, 11, 1926. Trial before the Court.

Nov. 11, 1926. Record of proceedings at trial filed.

Apr. 12, 13, 14, 1927. Hearing on pleadings and proofs.

Jan. 3, 1928. Opinion of court filed. (Filed in No. 589).

Jan. 16, 1928.	Interlocutory decree that bill of complaint be dismissed as to Patents Nos. 1,244,216 and 1,529,597; that patent No. 1,244,217 is valid and infringed; that injunction issue; and that costs be reserved for entry of final decree, &c; same day decree filed.
Jan. 16, 1928.	Injunction issued.
Jan. 23, 1928.	Plaintiff's petition for appeal, with assignments of error, filed; same day order allowing appeal, bond in the sum of $500; same day order filed.
Jan. 27, 1928.	Order approving bond on appeal in the sum of $500. with United States Fidelity and Guarantee Company as surety; same day bond filed.
Jan. 27, 1928.	Citation issued.
Jan. 30, 1928.	Citation, with acceptance of service by solicitor for defendant-appellee endorsed thereon, filed.
Feb. 7, 1928.	Marshal returns on Injunction, "Served", &c.; same day writ filed.
Feb. 7, 1928.	Report to Commissioner of Patents mailed and copy filed.
Feb. 17, 1928.	Petition of defendant for appeal, with assignments of error filed; same day order allowing appeal, bond in the sum of $500; same day order filed.
Mar. 7, 1928.	Order approving bond of defendant on appeal in the sum of $500; with Indemnity Insurance Company of North America as surety; same day bond filed.
Mar. 7, 1928.	Citation issued.
Mar. 8, 1928.	Stipulation as to transcript of record filed; same day order approving stipulation; same day order filed.
Mar. 8, 1928.	Citation, with acceptance of service by solicitor for plaintiff-appellee endorsed thereon, filed.

BILL OF COMPLAINT.

(Filed January 26, 1926.)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company, v. *The DeForest Radio Company.*	No. 589. IN EQUITY. Langmuir Patent, No. 1,558,436.

To the Honorable the Judges of the District Court of the United States for the District of Delaware.

The plaintiff for its bill of complaint says that it is informed and believes and therefore avers as stated in Paragraphs I to VII, inclusive, as follows:

I. The plaintiff is a corporation organized and existing under the laws of the State of New York having a regular and established place of business in Schenectady, New York, and a citizen of the United States, and the defendant, The DeForest Radio Company is a Corporation duly organized and existing under the laws of the State of Delaware, and a citizen of the State of Delaware, and said defendant has a regular and established place of business in the State of Delaware, within the District of Delaware, within which District, as well as elsewhere in the United States of America, the acts of infringement hereinafter complained of took place.

II. Irving Langmuir, being, within the meaning of the Statutes of the United States, the first, original and sole inventor of certain Electrical Discharge Apparatus and Process of Preparing and Using the Same, and being entitled to a patent therefor under the provisions of said statutes, duly applied to the Commissioner of Patents of the United States of America for letters patent for said improvements, which were not known or used by others in this country before his invention or discovery thereof and not patented or described in any printed publication in this or any foreign country before his invention or discovery thereof or more than two years prior to his said application for patent, and not in public use or on sale in this country for more than two years prior to said application and not abandoned to the public, and said invention has not been patented in any country foreign to the United States of America on an application filed by said Langmuir or his legal representatives or assigns more than twelve months prior to said application for United States patent. The plaintiff, having acquired by instrument in writing, all the rights to said invention, and all the requirements of the statutes then in force having been complied with, there were, under date of October 20, 1925, duly granted to the plaintiff Letters Patent No. 1,558,436 for said improvements, whereby there were secured to the plaintiff, its legal representatives and assigns for the term of seventeen years from the said date of October 20, 1925, the exclusive right to make, use and sell said improvements, as will appear by said patent or a certified copy thereof in court to be produced, and of which profert is hereby made.

III. The improvements forming the subject of said letters patent are of great value, importance and benefit to the public and to the plaintiff and its licensees; and the plaintiff has expended large sums of money in making said improvements available and profitable to the public, and the plaintiff and its licensees have manufactured and sold and used said improvements extensively, and are prepared to supply the whole demand which has been created therefor; and the plaintiff has marked or caused to be marked the radio tubes made and sold by the plaintiff or under its authority by imprinting on the inclosures thereof the word "Patented" together with the day and year said letters patent were granted.

IV. Since the grant of the letters patent mentioned the plaintiff has been at all times, and is now, possessed of all the right, title and interest in said improvements and letters patent therefor, and entitled to all the benefits thereof.

V. Within six years last past prior to the filing of this Bill of Complaint, the defendant, The DeForest Radio Company, has within the District of Delaware, and elsewhere in the United States of America made, used and sold or caused to be made, used or sold radio tubes embodying or containing the improvements described and claimed in said Letters Patent 1,558,436, and has practiced or caused to be practiced the process of said patent, unlawfully and without license of the plaintiff and in infringement of said letters patent and plaintiff's rights thereunder, and defendant threatens to continue said infringement, and defendant has gained great profits from said infringement, wherefore plaintiff prays that the defendant may be required to make full discovery of its gains from said infringement.

VI. But for the wrongful acts of defendant the plaintiff and its licensees and customers would now be able to make, use and sell the patented improvements of the said letters patent with greater profit and advantage. By such wrongful acts of defendant the plaintiff is suffering irreparable damage, unless this infringement by defendant is restrained by order of this Honorable Court, and the plaintiff has no adequate remedy at law.

VII. Plaintiff has notified the defendant of its ownership of said letters patent and of defendant's infringement thereof, and has requested the defendant to desist from further infringement thereof, but defendant, after such notice has continued such infringement.

Wherefore, the plaintiff prays:

1. For such preliminary and perpetual injunction against infringement, direct or contributory, of said letters patent by defendant, its agents, attorneys, workmen and employees and officers and directors, and all persons in privity with any of them, as to this Court may seem just;

2. For an accounting for damages and profits due to said infringement, and that defendant be compelled to pay over to the plaintiff the said damages as well as the profits;

3. For costs; and

4. For such other relief as to equity may seem just.

The plaintiff further prays for a writ of *subpœna ad respondendum* directed to the defendant, The De Forest Radio Company, commanding it to appear and make answer (but not under oath, an answer under oath being hereby waived) to this Bill of Complaint and to perform and abide by such orders and decrees as to this Court may seem required by the principles of equity and good conscience.

GENERAL ELECTRIC COMPANY,
By (Sgd.) F. S. Terry,
Vice-President.

Attest:
(Sgd.) ....
(Seal) *Asst. Secretary.*

(Sgd.) Wm. G. Mahaffy,
Solicitor for the Plaintiff,
Equitable Building,
Wilmington, Delaware.

(Sgd.) Howson and Howson,
Of Counsel for Plaintiff,
55 Liberty Street,
New York City.

State of New York, }
County of New York, } *ss.:*

F. S. Terry, being duly sworn, deposes and says, that he is Vice-President of General Electric Company, the corporation named as plaintiff in the foregoing Bill of Complaint subscribed by him; that he has read said bill and knows the contents thereof; that the same are true except as to the matters alleged on information and belief, and as to those matters he believes the complaint to be true; that he verily believes said Irving

Langmuir to be the first, original and sole inventor of the improvements set forth in Patent No. 1,558,436.

(Sgd.) F. S. TERRY,
Vice-President.

Subscribed and sworn to before me this twenty-fifth day of January, 1926.

(Seal) (Sgd.) GERTRUDE C. LANDLER,
Notary Public.

N. Y. Co. No. 84; N. Y. Co. Register's No. 8002.
Commission expires March 30, 1926.

AMENDED ANSWER.

(Filed May 27, 1926.*)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company,
Plaintiff,
v.
DeForest Radio Company,
Defendant.

EQUITY No. 589.
On Langmuir Pat. No. 1,558,436.

The DEFOREST RADIO COMPANY, for its answer to the bill of complaint herein, or as much thereof as it is advised is material or necessary to be answered, says:

1. This defendant denies each and every allegation contained in paragraph II of the said bill of complaint, except that it has seen what purports to be a copy of Letters Patent No. 1,558,436, issued to plaintiff, as assignee of Irving Langmuir.

---

*Amendment to answer filed October 28, 1926.

2. This defendant denies each and every allegation contained in paragraph III of the bill of complaint.

3. This defendant denies the allegations of paragraph IV of the said bill of complaint.

4. This defendant denies the allegations of paragraph V of the said bill of complaint.

5. This defendant denies the allegations of paragraph VI of the bill of complaint.

6. Further in answer to said bill of complaint, this defendant upon information and belief avers that the Langmuir patent is wholly invalid and void and of no effect, for each of the following reasons:

(a) Irving Langmuir was not the first inventor of any substantial or material part of the thing patented, but that the same was first invented by others, to wit:

Lee DeForest, of New York, N. Y., at New York, N. Y., and Palo Alto, California;
Harold D. Arnold, of and at New York, N. Y.

and/or others, the names, addresses and places of invention this defendant is not at present advised but begs leave to add hereto when information thereof is obtained.

(b) Because the thing or things alleged to be patented by the Langmuir patent was known and/or used by others before the alleged invention or discovery thereof by Langmuir; and/or more than two years prior to the application for patent therefor, by Langmuir, to wit:

Lee DeForest, of New York, N. Y., at New York, N. Y., and Palo Alto, California;
Harold D. Arnold, of and at New York, N. Y.

and/or others, the names, addresses and circumstances of such knowledge and/or use this defendant is not at present advised, but begs leave to add hereto when such information is obtained.

(c) Because the thing or things alleged to be patented by the Langmuir patent were shown in patents and in printed publications in this country and countries foreign to the United States, before the alleged invention or discovery thereof by Langmuir; and/or more than two years prior to the filing of the application for the said Langmuir patent, the complete data as to the names and numbers of said patents, dates of issuance thereof, and the names and dates of said publications, this defendant is not at present advised, but begs leave to add hereto when this information has been obtained.

(d) Because the Langmuir patent is directed to subject matter not lawfully patentable, which subject matter does not constitute invention in view of the state of the art prior thereto, full information as to said prior art, this defendant is not at present possessed, but begs leave to add hereto by proper amendment when the same is obtained.

(e)* Because the thing or things alleged to be patented had been previously patented to the same party in interest, namely, the General Electric Company, plaintiff herein, in Patent No. 1,203,495, applied for May 9, 1913, and issued October 31, 1916, in the name of W. D. Coolidge, assignor, as illustrated, solely as examples, in claims 1, 13, 16 and 32 of said Coolidge patent, wherefore, plaintiff made election as to inventorship of the subject matter in suit; is estopped from asserting that Coolidge is not the prior inventor thereof; and Patent No. 1,558,436 is, therefore, void.

---

*Paragraph (e) added by amendment October 28, 1926.

WHEREFORE, this defendant denies that the plaintiff is entitled to the relief prayed for or any relief and therefore prays to be hence dismissed with its proper costs in this cause sustained and with such other and further affirmative relief as to the Court may seem just.

DEFOREST RADIO COMPANY,
By (Sgd.) DARBY & DARBY,
Attorneys for Defendant.

(Sgd.) E. E. BERL,
Solicitor for Defendant.

(Sgd.) SAMUEL E. DARBY, JR.,
(Sgd.) THOMAS G. HAIGHT,
Of Counsel.

Dated, New York, N. Y., May 10, 1926.

DEFENDANT'S BILL OF PARTICULARS.

(Filed October 11, 1926.)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company, Plaintiff, v. *The DeForest Radio Company,* Defendant.	IN EQUITY. Nos. 589 and 598.

NOW COMES DEFENDANT and for its particulars states as follows:

1. The patents and publications which will be offered in evidence at the trial of the cause,

(*a*) to illustrate the prior art;

(*b*) to support a contention of anticipation; and

(*c*) for any other purposes,

are as follows:

Patent No.	*Inventor.*
307,031	T. A. Edison
909,811	M. M. Merritt
1,032,914	O. O. Kruh
1,038,910	R. Von Lieben and E. Reisz
879,532	L. DeForest
1,169,082	R. Von Lieben, E. Reisz and S. Strauss
1,028,636	C. T. Thacher
1,249,978	G. M. J. MacKay
258,966	E. Weston
411,019	T. A. Edison
1,122,011	Dr. Lillienfeld
1,218,423	Dr. Lillienfeld

OTHER PATENTS.

Patent No.	*Inventor.*
1,001,105	Welsbach
968,407	F. J. Planchon
829,568	J. M. Canello
1,205,002	J. T. Marshall
537,693	A. Malignoni
909,811	M. M. Merritt
596,654	E. F. Dwyer
845,671	P. H. Thomas
859,021	F. Soddy
946,068	M. Von Recklinghausen
1,203,495	Coolidge
1,083,677	C. A. Friedrich
1,159,307	W. C. White
1,250,815	F. M. Dorsey
552,036	L. K. Bohm
1,018,502	Just & Hanaman
1,008,806	K. Farkas
872,936	J. A. Heaney
927,935	W. Von Bolton
1,422,019	J. A. Yunck
1,142,625	E. Reisz
1,246,054	J. H. Clough
1,121,802	E. L. Clark
1,376,604	T. W. Case

An article by ALBERT TURPIN and a book entitled "LES APPLICATIONS PRACTIQUES DES ONDEX'E ELECTRIQUES," pages 30 to 31, published in 1902 (Plaintiff's Exhibit 62 in MARCONI v. DEFOREST on FLEMING PATENT);

"LA TELEGRAPHÈRE LANS FILAET LES ONDES ELECTRIQUES," by J. BOULANGER and G. FERRIE, Seventh Edition, 1907, pages 260 to 265 (Plaintiff's Exhibit 123, No. 6A, MARCONI v. DEFOREST on FLEMING PATENT).

ADDITIONAL REFERENCES.

LILLIENFELD, ROSENTHAL:
Fort. aus. den Gebiet der Roentgen Strahlen, Bd. 18, 256.

ROLLINS, BOSTON, 1903:
Notes on X Lights.

ELSTER & GEITEL:
Wied. Ann., V. 38, 1889, p. 40.

GOLDSTEIN:
Wied. Ann., V. 24, 1885, 83.

PROF. GUTHRIE:
Phil. Mag., XIV, p. 308, 1873.

COOLIDGE:
Phys. Rev., 2, p. 409, 1913.

SODDY:
Phys. Zeit., v. 9, 8 (1908).

LANGMUIR:
Phys. Rev., 2, 450, 1913;
Phys. Zeit., 15, 516, 1914.

MCBAIN:
Trans., Faraday, Soc. 14, 1 (1919).

LANGMUIR:
Jour. Am. Chem. Soc., 37, 1139 (1915);
Jour. Am. Chem. Soc., 38, 2221 (1916).

WHITNEY:
Trans. Am. I. E. E., 31, 921 (1912).

ILAGENOU:
Phys. Rev., 13, 415 (1919).

SKINNER:
Ann. d. Phys., 50, 769 (1916);
Phil. Mag., 12, 481 (1906);
Phys. Rev., 21, 1169 (1905).

LANGMUIR:
G. E. Rev., May, 1915;
June, 1920.
July, 1920.

HAGENOW:
Phys. Rev., 13, 415, 1919.

CAMPBELL:
Phil. Mag., 41, 685 (1921);
Phil. Mag., 40, 585 (1920).

LANGMUIR:
Trans. A. I. E. E., 32, 1921 (1913).

DEUSHMAN:
Phys. Rev., 5, 223 (1915);
Engineering, Jan. 14 (1921).

PROC. ROY. SOC.:
85 A. 219 (1911);
Zeit. d. Deutsch. Phys. Ges., 13, 271 (1911);
Phys. Rev., 4, 401 (1914);
Jour. Am. Chem. Soc., 35, 931 (1913).

SODDY & MACKENZIE:
Proc. Roy. Soc., 80, A, 92 (1908).

ADDITIONAL REFERENCES.

1. "LA TELEGRAPHIE SANS FIL ET LES ONDES ELECTRIQUES," Paris, 1909, BOULANGET and FERRIE.
2. PROC. ROY. SOC., Feb., 1890, Crookes.
3. ANN. D. PHYS. U. CHEM., Bd. XVI, ELSTER & GEITEL. Also WIED. ANN., 38 p. 27. Also WIED. ANN., XLI, p. 166.
4. FLEMING:
    a. Proc. Roy. Inst., London, 1890-1892, pp. 34 to 49;

b. The Conduction and Measurement of Electric Waves, 1906;
c. Ionized gas detectors, 1910 ed.;
d. Technics, April, 1905;
e. Proc. Royal Soc., 74, p. 476-487, 1890.

5. DEFOREST:
a. Proc. A. I. E. E., Oct., 1906.

6. DEWAR:
Nature, July 15, 1875;
Charcoal, Vacua;
Proc. Roy. Soc., June, 1904;
Proc. Roy. Soc., Dec., 1898.

7. BUTCHER:
The Wireless Age, Jan., 1914.

8. LANGMUIR:
a. Proc. I. R. E., Sept., 1915.

9. MARK WATT:
Edinburgh Philosophical Journal, 1828.

10. WEHNELT:
a. Ann. d. Phys., 14, 425 (1904).

11. MERRITT & STEWART:
Phys. Rev., Apr. (1904), 239.

12. PREECE:
The Electrician, Apr. 4 (1885).

In addition to the foregoing, the patents and publications forming part of the record of ARNOLD v. LANGMUIR, Interference No. 40,380, of which plaintiff has copies,

2. The instance or instances of prior knowledge and use defendant will attempt to prove at the trial of this cause under paragraph 6 of its answer are:

H. D. Arnold and Western Electric Company, of and at New York City and elsewhere as appears in the record of the Arnold v. Langmuir Interference above identified. Messrs. Hyde, Hewlett, Clark, LaMont, Beal, Tuel, Rodman, Watkins and DeForest, as appears in the testimony taken in San Francisco, California, in General Electric Company v. DeForest Radio, Telephone and Telegraph Company and McPhilben Radio Electric Corporation, in Equity, United States District Court, Eastern District of New York, 1723-1724, a copy of which counsel for plaintiff has in his possession and the taking of which testimony was attended by counsel for plaintiff.

3. The instance or instances of prior knowledge, invention and use defendant will attempt to prove at the trial of this cause under paragraph 8 of the answer are those set forth in paragraphs 1 and 2 of this bill of particulars.

4. The instance or instances of prior publications of the alleged invention which defendant will attempt to prove under paragraph 7 of its answer are those set forth in paragraphs 1 and 2 hereof.

THE DeFOREST RADIO COMPANY,
By (Sgd.) Darby & Darby,
Attorneys.

(Sgd.) E. E. Berl,
(Sgd.) Darby & Darby,
Solicitors for Defendant.

....

(Sgd.) S. E. Darby, Jr.,
Of Counsel.

Service of a copy of the within bill of particulars acknowledged this 2d day of October, 1926.

S. O. EDMONDS,
Per I. McIntosh.
Attorney for Plaintiff.

SUPPLEMENTAL BILL OF PARTICULARS.

(Filed October 11, 1926.)

In the United States District Court,
for the District of Delaware.

General Electric Company,
Plaintiff,
v.
DeForest Radio Company,
Defendant.

In Equity.
Nos. 589 and 598.

Now Comes the Defendant, and supplementing paragraph 2 of its Bill of Particulars herein states that, with respect to the prior knowledge and use of Messrs. Hyde, Hewlett, Clark, Lamonte, Beal, Tuel, Rodman, Watkins and DeForest, that the said prior knowledge and used relied upon will be that testified to by the above named persons; that the vacuum tubes so used were the tubes so described in the depositions given by the above named persons; that it is not alleged that any of said tubes were sold or offered for sale by Dr. DeForest, other than to the Federal Telegraph Company; that so far as is now known, none of said tubes is now in existence, and that there are no records, documentary or otherwise, concerning the same, other than such as was put in evidence, as exhibits or referred to in the depositions of the above named witnesses.

DeFOREST RADIO COMPANY.
By (Sgd.) Darby & Darby,
Its Attorneys.

Dated, New York, N. Y., October 5, 1926.

BILL OF COMPLAINT.

(Filed April 28, 1926.)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company, Plaintiff, v. *DeForest Radio Company,* Defendant.	No. 598. IN EQUITY.

To the Honorable Judges of the United States District Court for the District of Delaware.

GENERAL ELECTRIC COMPANY, a corporation organized and existing under the laws of the State of New York and having its principal office in the Borough of Manhattan, City of New York and State of New York, brings this, its bill of complaint, against the DeForest Radio Company, a corporation organized and existing under the laws of the State of Delaware and having a regular and established place of business within said State. And thereupon the plaintiff states that it is advised and therefore upon information and belief avers:

First.—That this is a suit in equity arising under the patent laws of the United States.

Second.—That on and prior to the fifteenth day of July, 1914, Irving Langmuir, of Schenectady, New York, was the original, first and sole inventor of certain new and useful improvements in Electron Discharge Apparatus and Method of Preparation, not known or used by others in this country before his invention or discovery thereof, and not patented or described in any printed publication in this or any foreign country before his invention or discovery thereof, or more than two years prior to his application for letters patent of the United States hereinafter mentioned, and not in public use or on sale in this country for more than two years prior to his said application, and not abandoned by him prior to his said application, and not patented or caused to be patented by him or his legal representatives or assigns in any foreign country upon an application filed more than twelve months prior to the filing of his said application in this country. And that being such original, first and sole inventor, said Langmuir did on the said fifteenth day of July, 1914, make application in due form of law to the Commissioner of Patents of the United States for letters patent for such invention and duly swore to the specification thereof and requested the Commissioner of Patents to issue to him any letters patent which might be granted on his said invention, and then and there in all respects complied with the necessary conditions and requirements of the statutes of the United States in such case made and provided, and duly assigned said invention and application and the letters patent to be issued pursuant to said application by proper assignment in writing duly executed and delivered to the plaintiff, General Electric Company. That thereupon such proceedings were had with respect to the said invention and application that on the twenty-third day of October, 1917, Letters Patent No. 1,244,216 were duly issued to said plaintiff for said invention and on said application in conformity with the requirements of the statutes in such case made and provided. And the plaintiff brings here into court a duly authenticated copy of said letters patent and prays that the same may be taken as part of this bill.

Third.—That on and prior to the twenty-eighth day of October, 1915, Irving Langmuir, of Schenectady, New York, was the original, first and sole inventor of certain new and useful improvements in Electron Discharge Apparatus and Method of Operating the Same, not known or used by others in this country before his invention or discovery thereof, and not patented or described in any printed publication in this or any foreign country before his invention or discovery thereof, or more than two years prior to his application for letters patent of the United States hereinafter mentioned and not in public use or on sale in this country for more than two years prior to his said application, and not abandoned by him prior to his said application, and not patented or caused to be patented by him or his legal representatives or assigns in any foreign country upon an application filed more than twelve months prior to the filing of his said application in this country. And that being such original, first and sole inventor, said Langmuir did on the said twenty-eighth day of October, 1915, make application in due form of law to the Commissioner of Patents of the United States for letters patent for such invention and duly swore to the specification thereof and requested the Commissioner of Patents to issue to him any letters patent which might be granted on his said invention, and then and there in all respects complied with the necessary conditions and requirements of the statutes of the United States in such case made and provided, and duly assigned said invention and application and the letters patent to be issued pursuant to said application by proper assignment in writing duly executed and delivered to the plaintiff, General Electric Company. That thereupon such proceedings were had with respect to the said invention and application that on the twenty-third day of October, 1917, Letters Patent No. 1,244,217 were duly issued to said plaintiff for said invention and on said application in conformity with the requirements of the statutes in such case made and provided. And the plaintiff brings here into court a duly authenticated copy of said letters patent and prays that the same may be taken as part of this bill.

Fourth.—That on and prior to the eleventh day of August, 1921, Irving Langmuir, of Schenectady, New York, was the original, first and sole inventor of certain new and useful improvements in Electron Emitting Device and Method of Preparation, not known or used by others in this country before his invention or discovery thereof, and not patented or described in any printed publication in this or any foreign country before his invention or discovery thereof, or more than two years prior to his application for letters patent of the United States hereinafter mentioned, and not in public use or on sale in this country for more than two years prior to his said application, and not abandoned by him prior to his said application, and not patented or caused to be patented by him or his legal representatives or assigns in any foreign country upon an application filed more than twelve months prior to the filing of his said application in this country. And that being such original, first and sole inventor, said Langmuir did on the said eleventh day of August, 1921, make application in due form of law to the Commissioner of Patents of the United States for letters patent for such invention and duly swore to the specification thereof and requested the Commissioner of Patents to issue to him any letters patent which might be granted on his said invention, and then and there in all respects complied with the necessary conditions and requirements of the statutes of the United States in such case made and provided, and duly assigned said invention and application and the letters patent to be issued pursuant to said application by proper assignment in writing duly executed and delivered to the plaintiff, General Electric Company. That thereupon such proceedings were had with respect to the said invention and application that on the tenth day of March, 1925, Letters Patent No. 1,529,597 were duly issued to said plaintiff for said invention and on said application in conformity with the requirements of the statutes in such case made and provided. And the plaintiff brings here into court a duly authenticated copy of said letters patent and prays that the same may be taken as part of this bill.

Fifth.—That by virtue of the said several assignments and of the grant of the said several letters patent, as above set forth, the plaintiff became on the date of grant of each of said several letters patent and that it has ever since been and now is possessed of and vested with the full and entire right, title and interest in and to each of said several inventions and letters patent.

Sixth.—That the said defendant, the DeForest Radio Company, has been, since the grant of said letters patent as aforesaid and prior to the execution of this bill of complaint, at Wilmington, Delaware, and elsewhere within the United States, and still is without license or permission of the plaintiff and in infringement of said letters patent practicing and causing to be practiced the inventions in said several letters patent, and each and every thereof, set forth and claimed, and has been and still is making, using and selling or causing to be made, used and sold electron discharge apparatus prepared, employing, containing and operating in accordance with the inventions in said several letters patent set forth and claimed, all to the plaintiff's great damage.

Seventh.—That the said defendant has been duly notified of said letters patent and of its infringement thereof in violation of the plaintiff's rights thereunder.

Eighth.—That the said defendant is prepared and ready to continue said infringement, and unless restrained therefrom the plaintiff will suffer great and irreparable damage from such unlawful acts of said defendant, and that said defendant has derived and received and still is deriving and receiving from said infringing acts great gains and profits.

WHEREFORE, plaintiff prays that an accounting be taken of the profits received by said defendant and the damages suffered by the plaintiff in the premises; that said defendant and its officers, servants, agents, employees, workmen and confederates may be perpetually restrained and enjoined by the decree and injunction of this Court from directly or indirectly infringing upon plaintiff's said several letters patent or any thereof; that said defendant may be decreed to pay the costs of this suit and may also be enjoined and restrained as aforesaid during the pendency of this suit; and that the plaintiff may have such other and further relief as to this Honorable Court may seem meet.

GENERAL ELECTRIC COMPANY.
By (Sgd.) FRANCIS C. PRATT,
Vice-President.

(Sgd.) SAMUEL OWEN EDMONDS,
(Sgd.) WM. G. MAHAFFY,
Solicitors for Plaintiff.

(Sgd.) SAMUEL OWEN EDMONDS,
Of Counsel for Plaintiff.

STATE OF NEW YORK, }
COUNTY OF SCHENECTADY, } *ss.:*

FRANCIS C. PRATT, being duly sworn, deposes and says that he is a Vice-President of General Electric Company, the plaintiff named in the foregoing bill of complaint; that he has read said bill of complaint and knows the contents thereof; that the same is true of his own knowledge save in so far as the same is therein stated to be upon information and belief, and as to those parts he believes it to be true. And he does further depose and say that he verily believes said Irving Langmuir to have been the first, original and sole inventor of the several inventions in said Letters Patent Nos. 1,244,216, 1,244,217 and 1,529,597 set forth.

(Sgd.) FRANCIS C. PRATT.

Subscribed and sworn to before me, this twenty-third day of April, 1926.

(Sgd.) HELEN ORFORD,
(Seal) *Notary Public.*

AMENDED ANSWER.

(Filed May 1, 1926.*)

In the United States District Court,
for the District of Delaware.

General Electric Company, Plaintiff, v. *The DeForest Radio Company,* Defendant.	No. 598. In Equity.

The answer of the DeForest Radio Company, defendant herein to the bill of complaint of the General Electric Company. The defendant, answering, says:

1. This defendant denies each and every allegation contained in paragraph "Second" of the bill of complaint except that it admits having seen what purports to be a copy of Letters Patent No. 1,244,216, dated the twenty-third day of October, 1917.

2. This defendant denies each and every allegation contained in paragraph "Third" of the bill of complaint except that it admits having seen what purports to be a copy of Letters Patent No. 1,244,217, dated the twenty-third day of October, 1917.

3. This defendant denies each and every allegation contained in paragraph "Fourth" of said complaint, except that it admits having seen what purports to be a copy of Letters Patent No. 1,529,597, dated the tenth day of March, 1925.

4. This defendant has no knowledge of the matters set forth in paragraph "Fifth" of the said bill of com-

---

*Amendment to answer filed October 28, 1926.

plaint, and therefore denies the same, and puts plaintiff to its proof.

5. This defendant denies each and every allegation contained in paragraphs "Sixth," "Seventh," and "Eighth" of the bill of complaint.

This defendant further answering the said bill of complaint avers contrary to the allegations therein contained.

6. That the said patentee, Langmuir, was not the first inventor of or discoverer of any material or substantial part of the thing patented, but that the same was known to and used in this country by others than Langmuir, before his alleged respective invention or discovery thereof or more than two years prior to his application for the respective Letters Patent of the United States therefor, as follows:

Lee DeForest, of and at Palo Alto, California;
G. E. Lamonte of and at San Francisco, California.

7. That the said patentee, Langmuir was not the original or first inventor or discoverer of any material or substantial part of the respective thing alleged to be patented, but that the same had been patented and described in printed publications in this and foreign countries before his alleged invention or discovery thereof, or more than two years prior to his application, of which full information of the patents and publications defendant is not at present possessed, but begs leave to add hereto by proper amendment.

8. That the things claimed or sought to be claimed in the respective Langmuir patents do not constitute lawful subject matter for a patent; that the things patented were not lawfully patentable in view of the prior

art, and in view of what was commonly known to those skilled in the art, and in view of the prior invention, knowledge and use in this country, full information of which defendant is not at present possessed, but begs leave to add hereto by proper amendment.

9. That the things claimed or sought to be claimed in the said Langmuir patents do not constitute patentable invention requiring reward by way of a grant of letters patent within the meaning and intent of the United States Patent Stattutes.

10. The things claimed or sought to be claimed in the said respective Langmuir patents do not constitute lawful subject matter for a patent in that they are mere aggregations of unrelated elements.

11. That the things attempted to be patented in said respective Langmuir patents have been in use or on sale for more than two years prior to the respective applications for letters patent by certain persons, firms, corporations or associations, including:

Western Electric Company of and at New York, New York.

General Electric Company of and at Schenectady, New York, and divers persons, firms, corporations or associations, complete information of which this defendant is at present not possessed, but begs leave to add thereto by proper amendment.

12* The thing or things alleged to be patented by patents Nos. 1,244,217 and 1,529,597 had been previously patented to the same party in interest, namely, the General Electric Company, plaintiff herein, in patent No. 1,159,307 applied for March 20, 1914, and issued November 2, 1915, in the name of William C. White, assignor, as illustrated, solely as examples, in claims 4 and 6 of said White patent, wherefore, plaintiff made election as to inventorship of the subject matter of said patents Nos. 1,244,217 and 1,529,597; is estopped from asserting that White is not the first inventor thereof; and patents Nos. 1,244,217 and 1,529,597 are, therefore, void.

---

*Paragraph 12 added by amendment October 28, 1926.

Wherefore, this defendant denies each and every allegation of the bill of complaint, save those admitted or as to which it states it is without knowledge, and this defendant denies that the plaintiff is entitled to the relief prayed for or to any relief, and therefore prays to be hence dismissed with its proper costs of this action and with such general, further and affirmative relief as to the court may seem just.

THE DeFOREST RADIO COMPANY.
By (Sgd.) Darby & Darby,
Attorneys.

(Sgd.) E. E. Berl,
(Sgd.) Darby & Darby,
Solicitors for Defendant.

(Sgd.) S. E. Darby, Jr.,
(Sgd.) Thomas G. Haight,
Of Counsel.

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *DeForest Radio Company.*

In Equity. No. 589.
On Langmuir Patent
No. 1,558,436.

In the U. S. District Court, Wilmington, Delaware

Monday, October 11, 1926, at 10 o'clock A. M.

Before:

HON. HUGH M. MORRIS,
U. S. District Judge.

Appearances:

HUBERT HOWSON, ESQ.,
SAMUEL OWEN EDMONDS, ESQ.,
ALBERT G. DAVIS, ESQ.,
ALEXANDER D. LUNT, ESQ.,
WILLIAM G. MAHAFFY, ESQ.,
Of Counsel for Plaintiff.

THOMAS G. HAIGHT, ESQ.,
SAMUEL E. DARBY, JR., ESQ.,
WILLIAM R. BALLARD, ESQ.,
CARL A. RICHMOND, ESQ.,
WARD, GRAY & WARD, ESQS.,
Of Counsel for Defendant.

General Electric Company v. *DeForest Radio Company.*	In Equity. No. 598. On Langmuir Patents Nos. 1,244,216, 1,244,217, 1,529,597.

Appearances:

Hubert Howson, Esq.,
Samuel Owen Edmonds, Esq.,
Albert G. Davis, Esq.,
Alexander D. Lunt, Esq.,
William G. Mahaffy, Esq.,
Of Counsel for Plaintiff.

Thomas G. Haight, Esq.,
Samuel E. Darby, Jr., Esq.,
Ward, Gray & Ward, Esqs.,
Of Counsel for Defendant.

PROCEEDINGS.

Mr. Mahaffy: If the Court please, there are two cases set for trial today, General Electric Company against DeForest Radio Company, Nos. 589 and 598.

The Court: Both against DeForest?

Mr. Mahaffy: Both against DeForest Company. Case No. 589 is on one patent.

The Court: What is that patent?

Mr. Mahaffy: No. 1,558,436.

The Court: And the other?

Mr. Mahaffy: And the others are No. 1,244,216 and No. 1,244,217——

The Court: More than one in the second suit?

Mr. Mahaffy: Three patents in the second suit, and one only in the first.

The Court: And the second patent in the second suit is what?

Mr. Mahaffy: No. 1,244,217 and Patent No. 1,529,597. I understand it is agreed between all parties that the two cases shall be tried together under the caption of the two cases.

The Court: It is so ordered.

Mr. Mahaffy: If your Honor please, Mr. Albert G. Davis, Mr. Hubert Howson, Mr. Samuel Owen Edmonds are of counsel for the General Electric Company, the plaintiff in each of these cases, and Mr. Gray is not here, and has asked me if I would move the admission of Judge Haight for the defendant; also Mr. Darby, Mr. Carl A. Richmond and Mr. Ballard. I believe that is all.

The Court: Are counsel the same in each suit?

Mr. Mahaffy: In each suit.

[Note: Opening statements not printed.]

After Recess.

PLAINTIFF'S PROOFS.

Mr. Howson: The plaintiff offers in evidence officially printed copy of the Patent No. 1,558,436, dated October 20, 1925, issued to the plaintiff as assignee of Irving Langmuir for electrical discharge apparatus and process of preparing and using the same.

(Received in evidence and marked "Plaintiff's Exhibit No. 1." *See Volume IV, Plaintiff's Exhibits, page 1.*)

Mr. Howson: Plaintiff also offers in evidence officially printed copy of Patent No. 1,244,216, dated October 23, 1917, issued to the plaintiff as assignee of Irving Langmuir for electron discharge apparatus and method of preparation.

(Received in evidence and marked "Plaintiff's Exhibit No. 2." *See Volume IV, Plaintiff's Exhibits, page 11.*)

Mr. Howson: Plaintiff also offers in evidence officially printed copy of Patent No. 1,244,217, dated October 23, 1917, granted to the plaintiff as assignee of Irving Langmuir for electron discharge apparatus and method of operating the same.

(Received in evidence and marked "Plaintiff's Exhibit No. 3." *See Volume IV, Plaintiff's Exhibits, page 16.*)

Mr. Howson: Plaintiff also offers in evidence officially printed copy of Patent No. 1,529,597, dated March 10, 1925, granted to the plaintiff as assignee of Irving Langmuir for electron emitting device and method of preparation.

(Received in evidence and marked "Plaintiff's Exhibit No. 4." *See Volume IV, Plaintiff's Exhibits, page 20.*)

Mr. Howson: I ask the reporter to place upon the record this stipulation of September 21, 1926, entitled in both of these cases, which, with your Honor's permission, will be tried together, under these four patents just offered in evidence.

(The said stipulation is as follows:)

Stipulation

It having been agreed by counsel that these two causes may be tried together, the Court consenting, it is stipulated and agreed by and between counsel for the respective parties in these cases, but for the purposes of these cases only, as follows:

1. That printed or photographic copies of patents and publications may be offered in evidence and used with the same force and effect as certified copies, subject to correction, if error shall appear, and the dates of filing appearing on

patents and dates and places of publication appearing upon publications so offered may be taken as *prima facie* correct, but subject to correction.

2. The incorporation of plaintiff and defendants as pleaded in the bill may be taken as proved.

3. Defendant admits that since the grant of the Langmuir patent in suit No. 1,558,436, and prior to the filing of the Bill of Complaint herein it manufactured and sold within the United States of America vacuum tubes the same in all substantial respects of construction, combination material and operation as the tubes accompanying this stipulation and which are severally marked Plaintiff's Exhibits 5, 6, 7 and 8, Defendant's Tubes, Exhibit 5, being what is commercially known as DeForest Type H Rectifier, and Exhibit 6 what is known as DeForest Type H Audion, while Exhibits 7 and 8 are what are known as DeForest DV5 vacuum tubes. And defendant admits that these several tubes Exhibits 5, 6, 7 and 8 are defendant's manufacture.

4. Defendant admits that since the grant of the Langmuir patent No. 1,558,436, in suit, and prior to the filing of the Bill of Complaint in suit No. 589, defendant issued and published the circular letter and leaflet of which copies accompany this stipulation marked Plaintiff's Exhibits 9 and 10, respectively, Defendant's Circular Letter and Defendant's Leaflet.

5. Defendant admits that in at least some of the 'D V' vacuum tubes which it manufactured and sold within the United States of America since the grant of said Langmuir patent No. 1,558,436 and prior to the filing of the Bill of Complaint in case No. 589 (that is, defendant's tubes commercially identified by the Letters 'D V' with the number '2', '3' or '5' as the case might be, and of which the above mentioned Plaintiff's Exhibits 7 and 8 are typical examples), defendant used filament wires of tungsten containing ap-

proximately one-half of one per cent. of thoria: that the spool of filament wire accompanying this stipulation and identified by the date '10/6/24' and the initials of S. O. Edmonds and S. E. Darby, counsel for plaintiff and defendant respectively, is a sample of such filament wire, the same having been procured by defendant from P. R. Mallory and Company, Inc., of Portchester, New York, and that defendant used in others of its said D V vacuum tubes wire not procured from said P. R. Mallory & Company, Inc., but which wire was substantially the same in all respects as said wire procured from said P. R. Mallory & Company, Inc.: and that the coating on the inside of the glass bulbs of its said D V vacuum tubes of which plaintiff's said Exhibits 7 and 8 are examples, is magnesium deposited by vaporization in the course of manufacture of the tubes.

6. It is further stipulated that plaintiff may offer in evidence in this case the testimony of D. Ruotolo given in the suit of General Electric Company v. DeForest Radio Company et al., in Equity No. 561, in this court appearing on pages 32 to 60 of plaintiff's record in said suit, and such offer shall be with the same force and effect as if said witness had been duly sworn and examined in this case.

(Sgd.) Howson and Howson,
Of Counsel for Plaintiff.

(Sgd.) Samuel E. Darby, Jr.,
Of Counsel for Defendant.

Sept. 21, 1926.

Mr. Howson: We charge infringement of all the claims of the first of these patents, No: 1,538,436, but we particularly call your Honor's attention to the following as typical examples of the claims to be considered: Nos. 1, 2, 4, 6, 7, 9, 11, 20, 21 and 22.

Of the second patent No. 1,244,216, we charge infringement of all the claims excepting claims 8 and 9.

Of the third patent No. 1,244,217, we charge infringement of claims 1 and 4.

Of the fourth patent No. 1,529,597, we charge infringement of claims 12, 13, 18, 19, 21 and 22.

I understand that the defendant admits infringement of all the claims of the patents charged and reserves the right to contend that as to certain things——

Mr. Darby: As to the first patent we admit infringement of all the claims as charged. As to the second patent we admit infringement of the terms of the claims. In the third patent the same is true. As to the fourth patent we admit infringement of the claims.

The Court: All of said conditions are reserved so far as the validity is concerned.

Mr. Darby: Absolutely. I admit notice of infringement of the first patent No. 1,558,436, on January 26, 1926. We acknowledge notice of the infringement of the other three patents prior to this suit in Delaware.

JOHN V. L. HOGAN.

John V. L. Hogan, called as a witness on behalf of the plaintiffs, being duly sworn, testified as follows:

Direct Examination.

By Mr. Howson:

Q. 1. Please state your occupation, your age, and your residence.

A. I am a consulting engineer, age thirty-six, residence, Forest Hills, Long Island.

Q. 2. You may state your familiarity with the radio art in a general way.*

---

*For answer see Record, page 131.

Mr. Darby: We will admit Mr. Hogan's qualifications as a patent expert and as an expert in radio matters. Mr. Hogan has prepared a typewritten statement of his qualifications and what not, and I rather take the position that as long as we admit it it is not necessary.

The Court: It is no longer in issue, I take it, unless the qualifications become essential and then it may be spread upon the record.

By Mr. Howson:

Q. 3-4. Mr. Hogan, have you studied and do you understand the several patents in suit which have been offered in evidence referred to colloquially as 1, 2, 3 and 4?

A. Yes, I have studied all of the patents and I believe I understand them.

Q. 5. As a preliminary to the consideration of those patents, will you tell us something of the elementary facts about the construction and operation of radio tubes generally and their purposes and use?

A. Yes. The vacuum tube that has become so prominent in radio and in a number of other arts is mechanically a very simple thing. When we look at it we see nothing but a glass tube and the electrodes within that tube and electrical connections from the electrodes to the outside.

There may be two electrodes or there may be three electrodes or in some special cases there may be more, but in any event, the structure is extremely simple.

When we take up the operation of the tubes and consider the electrical matters involved, and particularly the electro-physical matters involved, we find that the whole series of effects is exceedingly complex, so much so in fact that the vacuum tube in its various forms has been the subject of a vast amount of study for a great many years.

The first practical radio tube was the Fleming valve. Before it was applied to radio it was old as a rectifier, that is to say, as a device which can be used for converting alternating current to direct current at low frequencies.

It was never practically used as such a power rectifier so far as I have been able to find, although it had laboratory uses for that purpose, and the reason that it obtained no practical work-a-day uses was that it was incapable of handling the amounts of power that are common in the ordinary electrical industrial arts.

That limitation did not work against the tube as a radio detector, however, and so when Fleming recognized the radio use of the tube about 1904, and commenced to introduce it into the radio field, it did attain practical utility for that purpose. The immediate detection of the radio waves is of course a type of operation that involves extremely minute currents, voltages and amounts of power.

If I may refer to this Fig. 1, which is a graphical illustration of the Fleming valve or of a two-electrode tube generally, perhaps I can make a brief description of the device a little clearer.

The rectangular vessel shown is usually a cylindrical glass bulb, that is to say, the vessel indicated by the rectangular form of line on the drawing is usually a cylindrical bulb such as that which is used in the ordinary electric light. It is seen that on the left of this diagram, in hairpin shape, is a filamentary electrode marked a, and at the right within the bulb is shown an anode or plate electrode marked b.

The filament is the cathode in devices of this type and is shown in this illustration as connected into the circuit, of a battery marked c, which battery supplies current for the heating of the filament, usually to a point of substantial or bright incandescence.

The anode or plate b may actually take a number of different forms in practical devices. It may be a small piece of metal in flat plate-like shape; it may be a cylinder of sheet metal surrounding the cathode a, or it may be a wire electrode either in filamentary hairpin shape or strung back and forth over its supports—all three of those structures and some variations of them have been used.

Edison discovered some time in the 1880's that in an electric incandescent lamp a current could be measured flowing between the incandescent filament itself and an additional pole or plate-like electrode which he inserted into the tube especially for the study of that particular effect. As a result of that discovery and his announcement of it, and also of his proposal to use a tube so constructed as a voltage regulator or indicator, the current passing through a tube evacuated of its original content of atmospheric air, for instance, has come to be known as the Edison effect.

Edison recognized that the current flowed only in one direction, but so far as I know made no application of that observation to the rectification of alternating currents and certainly made no application of the effect in radio use as did Fleming. There was no radio at the time of Edison's experiment.

In this tube we now know that the heated filament a gives off electrons, that these electrons are elementary negative electrical charges, they are looked upon as so-called atoms of negative electricity, and we know that when a circuit is completed between the anode of such a two-electrode tube such as shown in Fig. 1 and the cathode, as for instance by connecting a wire from the terminal of b through a second battery back to the filament circuit, we know that the electrons may flow from the filament across the space and back through that circuit and battery to the filaments so completing an anode or plate circuit for the device.

We also know that the negative current will flow most easily, the flow of electrons will flow most easily from the cathode to the anode within the tube or outside of the tube from the anode to the cathode. For that reason when a battery is put in a plate circuit to produce a flow of electrons through the tube, that is to say, to pump electrons through the tube by reason of the battery's electromotive force, the positive terminal of the battery is connected to the anode b, and the negative terminal to the filament a, so that the negative potential of the battery will repel the negative electrons through and out of the filament to the plate whence they will return to the battery through the wire circuit.

It might interest your Honor for me to note at the moment that the currents in terms of industrial currents are small. We customarily speak of the currents in these tubes as measured in microamperes which are millionths of one ampere or milliamperes which are thousandths of one ampere, and while those currents are small compared to industrial currents they are large compared to the current represented by a flow of a few electrons.

For example, to get an electric current of one microampere, that is to say, one millionth of one ampere, we have to have about six million million electrons passing through the circuit per second.

Fleming found in applying this tube to radio that the impressing of a radio frequency electromotive force, such as is developed in the receiving circuit of a radio receiver, upon the two electrodes of his tube would give a partial rectification of the resulting alternating current. He found that there would result, in other words, a current which flowed to a larger extent in the normal direction of high conductivity through the tube than in the other direction.

He was able to use that rectified or converted alternating current to operate an indicator such as a galvanometer which could not be operated directly by the radio frequency currents which the arriving waves could set up of their own force.

The next important practical step in the development of the vacuum tube in radio was DeForest's addition of the third electrode or grid. A tube of this sort is shown in Fig. 2 where it will be recognized that the cathode or filament a, the anode or plate b and the filament battery c, as well as the representation of the tube itself is the same as in Fig. 1, which I have just discussed.

In addition to those elements, Fig. 2 shows the grid or screen-like third electrode d interposed in the space between the cathode a and the anode b. The diagram also shows the completed anode circuit from b to the filament by way of a telephone indicator f and a plate or anode battery e, thus returning to the filament.

Wires g and h are also shown connected to the grid d and to the filament.

The flow of electrons from the filament to the plate is the same, speaking generally, in this type of tube as in the two-electrode tube, but that current through the space can be affected as to its amount by the potential, the electric voltage, to which the grid d is charged at any particular instant.

It was found that for some purposes it was more effective to apply this input or driving voltage to the grid than to the filament, that is to say, to develop that potential between the points g and h, than to apply it directly to the plate and filament as would be done in the case of the Fleming valve.

The use of the third electrode as a terminal of the input circuit in that way in general gives a larger control of the current passing through the plate circuit than could be had from the same potential applied directly to that circuit and consequently the three-electrode tube within its limitations, whatever they may be for the particular structure, ordinarily is better suited as a radio detector than the Fleming valve or two-electrode tube. It is also useful as an amplifier.

There are a number of principles that apply to both the two and the three-electrode tubes. For instance, in the matter of the filament. Here we have a simple conductor having connected to its terminals a battery. That battery is capable of applying a certain electric voltage to the terminals of the filament and consequently is capable of forcing a certain definite electric current through the filament.

The voltage across the filament terminals multiplied by the current which that results in, passing through the filament, gives a measure of the power consumed in the filament, and if the pressure is measured in volts and the current in amperes the product gives the power in watts, so that one may determine the power consumption of the filament of such a tube, whether of the two-electrode or three-electrode type, in that simple way.

A watt, as your Honor doubtless recalls, is an electrical unit of power and is rather small from the industrial viewpoint, because it is about 1/750 of a horsepower.

The voltage applied to the tube and the current that results also give a measure of the filament resistance, and when I say "applied to the tube," in this case, I mean to the filament terminals. The resistance of the filament under any particular condition is determined then by dividing the voltage or the potential in volts by the resulting current in amperes, which will give us the resistance of the filament in ohms. In that way we can determine the filament resistance for any particular condition.

As a matter of fact, the filament in the usual tube, as in the usual electric lamp, has a different and higher resistance when heated than when it is cold; and the ratio of the two resistances, that is to say, the resistance with operating current at a high current flowing, and the resistance with the perhaps smallest measureable current flowing, or at least a small current flowing, gives an indication of the material* of the filament which is sometimes very useful.

That relation connects up the temperature of the filament with the voltage applied to it and it is entirely feasible to determine the temperature of the filament in any of these devices as measured by the voltage applied to it. The relation is usually a simple and continuous one and depends simply on the fact that as the voltage is increased more current is forced through the filament and therefore more energy is expended in the filament and therefore the filament becomes hotter as the temperature is higher.

We can tell what the temperature of any calibrated or measured filament is simply by measuring the voltage across its terminals. It has been customary in the use of vacuum tubes to provide a regulating resistance in series with the filament battery, so that the voltage applied to the filament could be controlled by the user and thus the temperature of the filament changed.

Further, with relation to both the two and three-electrode tubes, it is recognized that the higher the temperature of the filament the more easily electrons break through the surface, so to speak, or, putting it more directly, the more rapid will be the emission of electron current for practical purposes.

There is some difference between metals and in some cases an astonishing difference between the possible emission at a certain temperature.

If in either of these tubes, that of Fig. 1 or of Fig.

---

*Changed from "temperature" to "material" when typewritten record was corrected.

2, there is a moderately high potential applied to the anode b, so that its positive charge will draw over through the vacuum tube all of the electrons that are emitted by the filament, then by measuring the current flowing through the anode circuit, one can determine what is called the saturation emission of the filament at that particular temperature.

The filament at a certain temperature can emit a certain number of electrons per second. If all of those electrons are forced to pass through the circuit, then a measurement of the corresponding current flow is of course a measurement of the total or saturation emission of that particular filament at that particular temperature.

If under this same saturation condition, that is, with sufficient voltage to draw all of the electrons through the circuit, one increases the temperature of the filament, then of course a new value for saturation is obtained because at the higher temperature the filament is able to emit more electrons per second and a larger current flows which establishes a new value for the saturation current. It is a definite value for a given material at a given temperature, although many times the measurement of the saturation is difficult because of complications brought in by other effects.

If we are given in a vacuum tube of this sort, either the two or three-electrode type, a reasonable supply of electrons, more electrons than we need to carry the current that we propose to use, we can then study how the plate current, the current through the plate circuit or anode circuit, varies as the potential applied to the anode is changed. Of course, if there were not enough electrons we could not make that study because as soon as the plate potential would reach a value that would pull all of the electrons away from the cathode, we would at once be limited by a lack of electrons.

But assuming that there are enough electrons available, that is to say, that the filament is operated at a sufficiently high temperature, and that the proportions of the tube are right, we may vary the voltage of the plate measured with respect to the filament and then as a result of each voltage we may measure the current flowing through the plate circuit, which will be, of course, the electron current.

That is entirely different from the temperature relation of which I have spoken a moment ago. In the other case we are measuring the plate current as it changes when the filament temperature is varied, but for a given plate potential which is high enough to draw all of the electrons away from the filament. In this instance we are supplying instead of a surplus plate potential, so to speak, we are supplying a surplus temperature (more than enough electrons), and we are finding out how the electron current or the current through the circuit varies as we change the plate potential.

In general, the plate current in the old tubes will increase uniformly as the plate voltage is increased up to a value of about twenty or twenty-five volts. Then the potential applied to the plate will ordinarily result in drawing over the electrons with sufficient velocity to produce ionization of the residual gas within the evacuated tube.

That ionization is a conduction effect that is produced in a gas when electrons are passing through the gas with a high enough speed or velocity, and consequently a high enough energy; so that when they collide with gas molecules, they will disrupt the molecules by knocking out electrons already forming part of the molecules, and thus give the molecules which have suffered from the collision, the opportunity, I might say, to display a positive charge.

The atom or the molecule is looked on as a tiny solar system having a positive nucleus at the center, like a sun, or two suns, in the case of the molecule and circling around those, a group—not always a group—but one or more electrons, which take the place of planets in our solar system.

The positive charge of a nucleus, the sun at the center, is balanced by the negative charges of the electrons in the neutral molecule, and it exhibits no electrical effects, though it floats around in the space within the tube.

When one of the electrons is knocked out by collision with a fast-flying electron from the filament, then the positive charge at the center, the positive sun predominates, and the entire molecule exhibits a unit positive charge.

It is that development of an electrical effect that is called "ionization," and it is that which may happen when an electron passing through a partially evacuated space attains a velocity corresponding to that which could be given to it by the effect of a voltage of the order of twenty or twenty-five volts.

Of course, in the case of simple ionization, where we had a neutral molecule and a flying electron, after the collision we have two electrons and a positively charged ion.

The effect of ionization may be to increase the conductivity of the gaseous space, and that increased conductivity will ordinarily be shown up when we increase the plate potential, the filament to plate battery voltage, by an excessively rapid increase in the rate of current flow; that is to say, as we go from five volts to twenty-five volts, or thereabouts, we get a more or less uniform and gradual increase of plate current; but from the voltages of that order on up, if there is ionization, the current will increase far more rapidly, and the change of rate will be evident as a general rule.

If the ionization produced by the rapid driving of the electrons through the space, is very large, is very intense, that is to say, if the space current is fairly high, and if the voltage is sufficiently high, the ionization may attain so large an amount that it can actually be seen, or its effect can actually be seen as a blue glow within the vacum tube. You can not see ionization within a tube; no visible effect is produced by the ionization of the residual gas, until that ionization occurs at a rapid rate, a very intense rate. In fact, in the case of the practical audion tubes at so high a rate that the tube is tremendously overloaded and far beyond its point of normal use.

The two-electrode tubes, as I think I said, have been used practically, and to a substantially practical extent, as radio detectors. They have also been used by the power rectifiers, and within recent years the use of the two-electrode tube as a power rectifier; that is to say, as an industrial or practical converter of alternating current to direct current, has been very extensive.

The three-electrode tubes have been used largely as radio detectors, as amplifiers, both of telephone and radio currents, and as generators of alternating current for sending messages, particularly in connection with radio transmitting stations, and in carrier current telegraphy or telephony on wires, which has sometimes been called "wired wireless."

There are also special uses of these vacuum tubes, such as the limitation of power in protective devices, or regulating devices, and also very extensively the production of X-rays.

Mr. Howson: I will offer in evidence at this point the tubes and other articles that are referred to in the stipulation, which I ask to be spread upon the record. I offer this tube, the defendant's rectifier tube, referred to in the stipulation as "Plaintiff's Exhibit No. 5," two-electrode tube.

(Received in evidence and marked "Plaintiff's Exhibit No. 5.")

MR. HOWSON: I offer in evidence as Plaintiff's Exhibit No. 6, the three-electrode tube of the defendant, referred to in the stipulation.

(Received in evidence and marked "Plaintiff's Exhibit No. 6.")

MR. HOWSON: I offer in evidence as Plaintiff's Exhibits No. 7 and 8, the two DeForest D. V. tubes referred to in the stipulation and identified by those numbers.

(Received in evidence and marked respectively "Plaintiff's Exhibit No. 7," and "Plaintiff's Exhibit No. 8.")

MR. HOWSON: I may mention that these tubes, Exhibits Nos. 5 and 6, are known as type H tubes.

I also offer in evidence the circular of the defendant referred to in the stipulation as Plaintiff's Exhibit No. 9.

(Received in evidence and marked "Plaintiff's Exhibit No. 9. *See Volume IV, Plaintiff's Exhibits, page 28.*)

MR. HOWSON: I offer the accompanying leaflet of the defendant as Plaintiff's Exhibit No. 10.

(Received in evidence and marked "Plaintiff's Exhibit No. 10." *See Volume IV, Plaintiff's Exhibits, page 29.*)

MR. HOWSON: I offer in evidence as Plaintiff's Exhibit No. 11, the figure one diagram referred to by the witness, diagram of the two-electrode tube, and I offer in evidence as Plaintiff's Exhibit No. 12, the figure two diagram, diagram of the three-electrode tube.

(Received in evidence and marked respectively "Plaintiff's Exhibit No. 11," *see Volume IV, Plaintiff's Exhibits, page 31,* and "Plaintiff's Exhibit No. 12." *See Volume IV, Plaintiff's Exhibits, page 32.*)

By Mr. Howson:

Q. 6. Mr. Hogan, I will ask you now to turn to this first patent No. 1,558,436, and will get you to state as specifically as you can, what you understand to be the principal characteristics of the thing set forth in that patent.

A. Probably the simplest and completest way to answer that question is to run through the specification and comment on the various portions in an order that will tie them together.

The invention is said at page 1, line 10, to relate to electrical vacuum discharge devices, and to comprise devices in which the electrical current is carried by negative charges, called electrons, emanating from the cathode independently of gaseous ionization, such as occurring, for example, in the ordinary Roentgen tube.

In answer to the last question I discussed briefly what this gaseous ionization which Langmuir is avoiding, amounts to, and the Roentgen tube mentioned here is the ordinary old art gas X-ray tube, which depended for its conduction upon gaseous ionization within the evacuated vessel. Continuing at line 17, Dr. Langmuir says that his present invention:

> ". . . comprises improvements in electron-discharge apparatus which make possible a high load capacity and operation with the highest voltages. . . ."

In that connection, I spoke of the difficulty with the Fleming valve in its original form as an industrial device, and the fact that it had attained no use in that field, though it did operate as a laboratory rectifier. The same type of low load limit, both in power and voltage, was found in the most successful prior art vacuum tube devices, namely, the audion. Its normal operating potential on the plate was between twenty and thirty volts, although occasionally it was run a little higher.

A typical audion would have so much ionization at thirty volts, that, when the plate current was increased to a point which passed even 300 microamperes, the tube would show a blue glow.

Now, that allows us to compute the maximum power in the plate circuit, because just as in the filament circuit, the power is the product of the voltage times the resulting current, and if we have thirty volts and multiply that by 300 microamperes (it is the same as 0.3 milliamperes, or the same as 0.0003 amperes) then we find 0.009, or nine-one-thousandth of a watt, as representing the plate power at the time when the tube was grossly overloaded and exhibiting extreme ionization. There was tremendous variation among the tubes, but that sort of operation was characteristic of a good average audion tube of the time, and in making that statement I am speaking from my own experience with those tubes.

On page 1, line 34, Langmuir says:

> "In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas."

And he then goes on to refer to the old Geissler tubes and the Roentgen X-ray tubes and the Crookes tubes, through which conduction was accompanied by ionization.

In the next paragraph, beginning at line 47, he points out that the passage of an electric current across a tube, ordinarily involves the movement of negative charges called electrons, which, under the influence of the impressed voltage, pass from the cathode to the anode, through the vacuous space. That, your Honor will recall as paralleling the description I gave of the general old art tubes. The specification continues:

> "If these electrons when moving above a certain velocity collide with gas molecules, they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions."

Then, in the next part of the specification, Dr. Langmuir sets forth some of the disadvantages and characteristics of the mixed electronic and ionic discharge, which I may summarize in four points: First, erratic and non-retroducible action. Second, disintegration of the cathode; third, production of a blue glow which may prevent operation; and fourth, the heating of the cathode by space current; and of course those four points are additional to the low power limit, the low load limit already referred to.

On line 70, he refers to the ionization being produced by definitely determinable voltages that are different for different gases, and he states that in the case of the gases such as nitrogen and hydrogen and oxygen and argon, helium and neon, they are of the order of magnitude of from fifteen to twenty-five volts.

I thought it might be convenient to have those voltages in the record at this point, and so I will tabulate them:

For nitrogen,	16.9 volts.
Hydrogen,	13.3 volts.
Oxygen,	15.5 volts.

Argon,	15.1 volts.
Helium,	25.6 volts.
Neon,	16.7 volts.

Those values are collected from several different authorities, but I think that they are right, and if there is any series of later measurements that shows that they should be corrected, that anybody can find, I will be glad to have the new figures.

The reference to ionization voltages is at page 1, line 76, at the end of the paragraph to which I have been referring, and which I identified by its first line.

In the next portion of the specification, the paragraph beginning at line 77, Dr. Langmuir describes and discusses the audion and the Fleming valve, as being incandescent cathode devices involving gas ionization.

At the end of page 1, he points out that he knows of no prior discharge devices operating in a practical usable manner and without substantial ionization effects with currents as great as about one-tenth of a milliampere, and voltages as high as about forty volts. He then continues on page 2, line 4, saying that:

> "In devices made in accordance with my invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas."

And in the balance of that paragraph, and in fact, for a farther portion of that page, he sets forth some of the resulting characteristics that accompany or characterize the pure electron discharge to which he refers; that is to say, the discharge which is characterized by absence of or negligible gas ionization; and rather than read the specification complete on that point, I have tabulated those seven resulting characteristics.

First, that the cathode is not heated by the space current, page 2, line 9.

Second: That a blue glow does not appear, page 2, line 10.

Third: That glass fluorescence does not appear, page 2, line 11.

The Court: What is that?

The Witness: Glass fluorescence is a visible effect, often olive green in appearance, such as one saw in the old X-ray tubes of the Roentgen type.

Fourth: That when a sufficient quantity of electrons is provided, that is to say, when the cathode is hot enough to avoid saturation at the voltage concerned, the plate current of a simple tube, involving the invention, will vary as the 3/2 power of the plate voltage. That is described briefly at page 2, lines 13 to 19, and I will return to the matter of what the 3/2 power is, in a moment.

Fifth: This characteristic is that the current in the plate circuit does not vary when the filament temperature is changed, provided that there is a plentiful supply of electrons; that is to say, that the operation is in the region termed "below saturation." That is referred to at page 2, lines 96 to 104.

Sixth: The discharge is independent of the residual gas pressure after that pressure has been reduced to a certain value which value will depend upon the particular structure and the particular use.

That is referred to at page 2, lines 105 to 110.

Seventh: That the discharge is regular and that the variations in the discharge, the purposed variations in the discharge with changes of applied electromotive force, and with the temperature of the filament, and so on, are reproducible changes, regular changes that will occur the same way, time and time again. That is referred to at page 2, lines 111 to 114.

The first three of these resulting characteristics, that is to say, that the cathode is not heated by the space current and the blue glow does not appear, and the glass fluorescence does not appear, are so simple that it probably would not be profitable to discuss them now.

The fourth item as to the variation of plate current with the 3/2 power of the plate voltage under the condition which requires the cathode to be hot enough to supply plenty of electrons, should be considered a little farther; that is a delicate test, a metrical test for ionization in a simple type of tube. The patent points out at page 2, line 19, to line 76, how this variation may be applied to the tubes of the patent, and also points out at lines 51 to 56, page 2, that the 3/2 power variation may be complicated, or as it is stated in the patent more or less masked by other simultaneous effects going on in a tube having a more complicated structure.

Before we got into that I think it might be worth while to consider what the 3/2 power is from a simple numerical viewpoint. It is not a power that one encounters every day, as one does squares and cubes and square roots; but it was an exact relation to those every-day powers of numbers; and of course, we have also to bear in mind that the 3/2 power is a power in the mathematical sense and has nothing whatever to do with electrical or mechanical power or with the power limitation of the tube. It is simply a double use of the same word in our language.

I thought that the simplest way to get a correct conception of what the 3/2 power is, as a matter of numbers, would be to look at a table of numbers varying in accordance with several powers; and to this end I have prepared table No. 1. In the left-hand column are the integers from 1 to 10, and then in the succeeding columns, the five powers of those simple numbers which we are likely to encounter. In the first column is the number itself; in the second column headed "Square Root" is the square root or one-half power of each of the numbers in the first column. For instance, the square root of four is given as two, and the square root of nine is given as three, as we all recognize. In the third column headed "First Power," the numbers are repeated because each number is the first power of itself. Skipping the fourth column, which is the 3/2 power column, and taking the fifth column, we have the second power or square of each number, and there it is seen that the square of two is four and three is nine, as one ordinarily recognizes them. The third power or cube comes in the last column.

Now, the 3/2 power is the one and one-half power or the square root of the cube; that is to say, the one-half power of the third power, the one-half power——

THE COURT: Square root of the cube?

THE WITNESS: Yes.

THE COURT: Cube of the square root, is it not?

THE WITNESS: It is the same thing exactly. It does not matter which we do first. It is like four times two or two times four. It is accurate to state it either way, your Honor, and it may be stated as the 3/2 or as the one and one-half power or 1.5 power, without difference. Now, these numbers, your Honor will see from an inspection of the table, lie between the first power and the second or square for each number, as one would expect from the value of the exponent being one and one-half. If we set up a circuit, a tube circuit, and arrange matters—I do not know whether we could or not,—but if we did arrange matters so that the current varied as the square root, that is to say, the one-half power of the voltage, and then if we set the voltages successively at one, two, three, four, and so on, and measured the corresponding currents, they would come out 1, 1.4, 1.7, 2, and so on, in accordance with this square root column; or if not those even values, they would come out definite multiples of them, because they would be proportional to them. Similarly, if the current varies as the first power, they would follow the voltage readings. As the square, they would follow the figures given in the fifth column of this table.

Now, I have plotted on a sheet of paper (co-ordinate paper) which I have labelled as Chart A, of Table 1, some of the values of this little Table 1 the simple powers of numbers, on arithmetic co-ordinate paper. Here the square root or one-half power is the lowest curve and we may see that the square root of 4 is 2, and that the square root of 9 is 3, simply by tracing the co-ordinates on the paper.

Similarly, I have drawn the first power or linear relation in which the straight line, on ordinary co-ordinate paper is shown, I have also drawn the one and a half or three halves power and I have drawn the second power or square and the third power or cube for these same numbers; so that one may get from this chart a visual idea of how these curves shape out on ordinary co-ordinate paper.

It is interesting to see that in these power series the first or linear gives the natural straight line curve or the linear curve; and that is how it got its name, because when plotted on ordinary equal spaced co-ordinate paper, the first power does come out as a straight line of varied position or varied slope.

Now, further, it is characteristic of these numbers which are related in a power series, that is to say, which are proportional to the powers of the numbers originally considered, that when their logarithms are plotted, or when they are plotted on ordinary logarithmic co-ordinate paper, they come out as straight lines, whose slope varies with the power, and in order to make that clear I have re-plotted the data of this table 1 as chart B of table 1 entitled Simple Powers of Numbers on logarithmic paper. Here we have as the first curve, the one for the square root. The first power is the second curve from the bottom, the one and one-half power is the third, the second is the fourth, and the third power or cube is the fifth.

Your Honor will note that in each of these cases the line is straight but that the slope changes as the power increases, so that we have a definite slope corresponding to the 3/2 power.

These changes in the form of the curve result from the changes in the distribution of the numbers on logarithmic paper, because the lengths both horizontally and vertically of logarithmic paper are made proportional to the logarithms of the numbers. In other words, at the left we have zero, at the middle ten and at the right one hundred. We can check any of these curves against the tabulation as before. Taking for instance 9 as the number, we run up and go across on the square root curve to 3, which is the square root of that. For linear relation we take ten and go up and to the left at ten. Similarly with the cube we may take three and go up and intersect the cube curve and go over to 27, which is the 3d-power or cube of 3.

The utility of logarithmic paper used in that way—perhaps I should not say the utility, but one very important utility is that if we plot some data involving an unknown relation and draw a line through the points representing the individual readings, and if that line comes out straight, we know that the two variables involved are related according to some power relation. That is, that one is necessarily proportional to some power of the other, and more than that, by determining the slope of the line, we can find what power connects the two sets of numbers. For instance, if we did not know that this second curve was linear, we could measure the vertical distance here of perhaps three inches, and then the corresponding horizontal distance of three inches, and take the ratio between those measurements and the resulting slope of one gives the first power. Similarly, if we take the 3/2 power curve, we could measure down perhaps six inches and crossing at the same point we get a corresponding measurement of four inches, which would be a ratio of 6 to 4, or 3 to 2, giving us the 3/2 power.

In that way the exponent can be determined directly from a plot on logarithmic paper and that is why physicists use that paper so much, one of the biggest reasons.

Now, as to what such data may show about the discharge in a vacuum tube. That is discussed in the patent particuarly on pages 2 and the first part of page 3. Putting it very briefly, a tube using the Langmuir discharge of the patent will in general show a variation of plate current in accordance with the 3/2 power of the plate voltages at voltages that are materially above the ionization range, which I outlined a moment ago.

A tube that has an amount of gas sufficient for its particular conditions of use and configuration to contribute by its ionization materially to the carrying of the discharge and thus to remove the tube from the pure electron category, will ordinarily show a complete voltage characteristic (that is to say, a curve between the plate current and the plate voltage), with a definite upward trend, away from the 3/2 line, as soon as the ionization potentials are reached or exceeded. Page 3, lines 29 to 58, take up that matter and of course bring in the essential limitation that there must be enough electrons; that is characteristic of this discussion. The last part of the paragraph at the middle of column one on page 3, and the paragraph immediately below that, ending at line 58, is a well-condensed and extremely good statement of this whole situation, and I wish to refer to it particularly. The matter carries over to page 5, beginning at line 102, where there is a further discussion of the residual gas (left in a tube when it is sealed off, or which has come from the walls of the tube or from the electrodes) and what it will do in the way of producing irregularities is taken up.

In this section of the patent, toward the end of page 5, and carrying over to page 6, Langmuir points out the difference between the irregularities produced below saturation (that is to say, when there are plenty of electrons), that are due mainly to the disturbing effect of the resulting positive ions upon the space charge, that is, when gas is present; and on the other hand, irregularities in the saturation region where the electrons are all being drawn away from the cathode, which are due ordinarily to changes in the rate of emission, *i. e.*, changes in the rate of emission of electrons from the cathode.

Now, here is a reference to the space charge, which is mentioned in the discussion of the 3/2 power relation on page 2, and particularly on page 2, at line 111 to page 3, line 8, at page 2, line 124, Langmuir says:

> "This last mentioned phenomenon, the current limiting the effect of the electric field of the electrons on each other, termed the 'space charge effect,' is discussed and analyzed by me,"

in the papers to which he refers, and

> "is the basis of the 3/2 power law referred to."

That last reference is page 3, line 6.

Now, if we determine and plot the plate current against plate voltage relation for a tube of the patented type, it is perfectly clear that as the voltage is increased indefinitely, some voltage will "use up" all the electrons or will carry over all the electrons given off by the filament at the given temperature—or all it will emit.

In other words, there will be some voltage which at some particular filament temperature will result in saturation, and of course, though we have a variation of the plate current as the 3/2 power of the plate voltage, and it will come out as a straight line with a slope 3/2 when plotted on logarithmic paper, there will be a certain reduction in slope (and particularly at low filament temperatures) where there will no longer be enough electrons emitted to permit the current to increase in accordance with the 3/2 power law or in fact, with any other law.

At that point where the electrons are all "used up" the curve will depart from the 3/2 power law or slope and bend over to a practically horizontal position with increase of voltage, because as the voltage goes on up the tube is saturated and all the electrons are being used and the current is not being increased, which it would have to do to follow the law of increase.

I mention that because the plot or graph drawn between practical determination of the plate current and the plate voltage often shows a bend of that sort off to the right and horizontally at the top, and because I want to divide that type of plot into two portions, the one being the space charge portion (that is the straight sloping part of the curve), and the other the saturation portion, which comes at the top and indicates that all the electrons are being used up.

To follow this 3/2 power variation, then, we must have plenty of electrons, we must be below saturation, and we must have substantially no ions to neutralize or to offset the electron charges.

Now, we may consider the other characteristic that is frequently drawn to show the condition of the discharge within the tubes, and that is the relation of the plate current as the filament temperature is varied.

Your Honor will recall that I mentioned in connection with the preliminary discussion of tubes the two types of characteristic, (1) variation of plate current with plate voltage which is that which we have now been discussing, and which shows as its straight sloping portion the 3/2 power law and beyond that goes off flat into saturation. This second is a totally different type of curve, although sometimes one characteristic will look like another characteristic though it is of a different kind.

This type, the type I now wish to consider, is the graph which shows that variation between plate current vertical and filament temperature horizontal. That curve will have to be taken under a standard condition of plate voltage, and if we take a relatively low plate voltage in a tube of the first patent we will find that as the filament temperature is increased the emission increases and therefore the plate current increases, because the plate voltage is strong enough to draw over all the electrons given off by the filament up to a certain point.

In other words, the tube remains saturated up to a certain temperature for a particular voltage, and if we plot the curve we find that the plate current increases as the temperature increases, and rapidly as the temperature increases, until saturation is reached. At that point—saturation is reached all the time—I will have to change that. It is saturated up to the point where the electrons in the space produce among themselves a mutual repelling effect that is so strong that the particular voltage, the particular plate voltage which we assume, is unable to pull more away from the filament.

That then gives us a flat part of the curve between temperature and plate current which is on this type of curve, the space charge portion. In other words, the space charge and the saturation portions are interchanged in the two families of curves. If on this second family, that is, the filament temperature curve, we increase the plate voltage and then begin again, the tube remains saturated, all the electrons are being drawn over, as the temperature increases to a certain higher point (and practically in a practical device the same curve is followed for saturation up to a higher point). Then the space charge shows a potential which is so great that the new positive potential assumed for the anode can pull no more electrons and once more we go off into a flat space charge portion.

Of course, as we go from tube to tube, we may have complications which will change the absolute flatness of the space charge portion, we may have a transition from the saturation to the space charge portion in that type of curve, or in the other type of curve we may have a transition from the space charge to complete saturation,—in fact, we usually do. It does not go by abrupt changes.

The Court: Suppose we take a five minute recess.

(After a short recess.)

A. (Continued). These two metrical tests based upon the regular performance of the pure electron discharge, free from ionization, give a critical and accurate measure of the type of discharge in any particular tube.

A rough test such as the gas fluorescence or the blue glow test will not give a precise idea of the tube condition or the discharge condition. The blue glow, for instance, appeared in the DeForest tubes when they were overloaded and was proof positive that, when the blue glow was visible, the tube was very intensely ionized; but before a blue glow will appear, that is to say, at lower currents and lower voltages, and above ionization voltage, there was often a region of fairly considerable extent in which ionization in very substantial amounts was going on as would be shown by a 3/2 power measurement and yet there was no blue glow visible.

Wherever we have blue glow we have ionization, but we do not have blue glow wherever we have substantial ionization. Moreover in the part of the characteristic in which there is ionization that is contributing to the operation of the tube which is above ionization potential and yet which is below the blue glow point, the DeForest audions were in general the most sensitive. That was as a general rule the best place to use them.

Now, returning to the specification, the portion beginning on page 3, line 82, and extending through two paragraphs has to do mainly with the utility of the invention. In that part of page 3, Dr. Langmuir points out that he may use voltages far above the ionization voltages with currents that are literally thousands of times greater than the curents at which devices of the old art were usable without substantial positive ionization.

The next part of the specification at page 3, line 105, and continuing over to page 4, line 59, is a description of the construction of the forms of tubes illustrated in the drawings of the patent. In that I would like to call attention only to the very end of the second column on page 3, which points out that the grid is wound around a glass frame and that the turns of the wire forming the grid are closely adjacent to each other and are closely adjacent to but of course, out of contact with, the filament or incandescent cathode.

That type of grid construction is very different from the grid of the DeForest tube of the old art and is a sort of a grid that is particularly desirable in a space charge tube, that is to say, a tube of the sort here. It is a type of grid which gives strong control of the plate current and produces therefore a large amplification.

The portion of this general section of the specification beginning at page 4, line 12, describes the three-electrode tube and that beginning at page 4, line 33, describes the two-electrode tube, and also points out that in some cases it is desirable to use a plate shaped anode instead of the wire anode or filamentary anode which is shown in connection with Fig. 1 of the patent. The plate shaped anodes are shown at 20 and 21 of Fig. 2.

The next portion of the specification beginning at page 4, line 60, and continuing through that page and over into page 5 has to do with the preparation of the device, the mechanical or constructional features having already been described.

This detailed statement of the steps which Langmuir took in building these first pure electron tubes is very complete and very interesting. I am not going to go through it in detail, but I am simply going to summarize it by saying that it is important to include heating of the glass tube, of the filament, and of the metal electrodes to an extent and for a time that will make it practically impossible for any of those elements to give off further gas in the later and continued later operation of the tube in service.

Second, that while these treatments are being carried on, it is important to remove by the best exhaust means available substantially all of the gases that are evolved from the various parts of the bulb or that were originally free within the bulb, and to keep them out.

How far that evacuation has to go in terms of pressure is not at all material. The important thing is to carry it to a point beyond which it is unnecessary to go in order to avoid the harmful ionization effects.

Of course, as in any manufacturing process there is a factor of safety; there is a series of precautions which should be observed simply out of abundant precaution, so that if one determined for a particular type of tube fair operation was had at a certain pressure, it would not be good manufacturing practice to put those tubes through the factory for that pressure and no lower. It would be much better to evacuate further than is necessary so long as that is not a tremendously costly operation.

Langmuir says at page 5, line 3, that

> "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionization by collision will take place at the given working voltage and current."

And that is the foot rule by which any particular design of tube should be measured. As an example he gives a few hundredths of a micron. A micron is a millionth part of a meter and an atmosphere is 760 millimeters of mercury column pressure indication or about three-quarters of a meter.

One micron then is one one-thousandth of a millimeter mercury pressure and the fraction stated, approximately a few hundredths of a micron, would be represented in millimeters of mercury as .00001 to .00003 or .00004.

There then come on page 5 some references to other applications beginning at line 35, the circuits, shown at the lower part of the drawings in Fig. 4 and Fig. 5 are described. The first of these is for detecting electromagnetic waves in radio telegraphy, that is to say, it shows the use of a pure electron tube as a detector, and Fig. 5, described beginning at line 75, shows the tube for the production of alternating currents from direct currents, that is to say as a generator of electrical oscillations.

There are of course other uses of the discharge, typical of the patent. I have mentionel telephony amplification, X-ray work, and so on, and in all of those the features of the new art tubes, using the pure electron discharge and avoiding the positive ionization, that stand out above all other features are the uniformity of operation and the high load capacity.

Tubes which have these outstanding advantages have the other features and characteristics that I have described, but those are the two things that have made the tremendous commercial advance as the result of this invention.

I think that answers your question, Mr. Howson.

Mr. Howson: I will offer in evidence the table of powers of numbers which the witness produced and referred to.

(Received in evidence and marked "Plaintiff's Exhibit No. 13." *See Volume IV, Plaintiff's Exhibits, page 33.*)

Mr. Howson: I offer in evidence the Chart A of the table of Exhibit 13, produced and referred to by the witness.

(Received in evidence and marked "Plaintiff's Exhibit No. 14." *See Volume IV, Plaintiff's Exhibits, page 34.*)

I offer in evidence Chart B of the table of Exhibit 13, produced and referred to by the witness.

(Received in evidence and marked "Plaintiff's Exhibit No. 15." *See Volume IV, Plaintiff's Exhibits, page 35.*)

Mr. Howson: May I ask your Honor's permission to ask Mr. Edmonds to continue the examination since it relates to the patents in the case in which he is interested.

The Court: In the absence of objection you may proceed.

By Mr. Edmonds:

Q. 7. Mr. Hogan, will you now turn to the Langmuir patent in suit No. 1,244,216 and say what you find to be the characteristic features of the vacuum tube set forth in that patent?

A. This second patent in suit describes the invention as relating to electrical discharge devices operating with a pure electron discharge and as comprising a novel cathode material and the method of its preparation.

The characterization of the invention appears at page 1, line 10, and is immediately followed by a reference to Langmuir's previous application, Serial No. 795,610, which resulted in the first patent in suit here.

This particular invention has to do with the cathode or filament in such a pure electron tube. The third paragraph of the specification running down to line 28, gives some of the characteristics of the pure electron tubes that I have discussed in connection with the first patent.

Then beginning at line 29, Dr. Langmuir points out that various refractory materials such as platinum, carbon, tungsten and molybdenum have been used as cathode materials and that it has been found that the emissivity of electrons of these various materials while differing in some degree is of the same order of magnitude.

We might also include tantalum in the list of refractory materials that have been used as cathodes in these vacuum tubes, and the three, tantalum, tungsten and molybdenum, may be classified as highly refractory metals used for filaments.

Langmuir continues at line 36, pointing out that he has discovered that the electron emissivity of pure thorium, the metal thorium, is of an entirely different order of magnitude than the emission of refractory materials theretofore used in electrical discharge devices.

He points out at line 40 that in order to get the high emissivity characteristic of thorium it is not necessary that the electrodes should consist entirely of thorium, and he explains that when thorium or a thorium compound is added to one of the highly refractory materials such as tungsten and the metal is given a preliminary heat treatment in high vacuum, the electron emission in the high vacuum is tremendously increased.

He points out at line 49 that the increase emissivity is not due to the presence of thorium oxid in the way calcium oxid and other oxids have been used on the so-called Wehnelt filament, that is, painted on the surface of a platinum bar or put on by dipping into a solution and allowing the solution to dry, thus giving a coating of calcium or other oxid material applied to the surface of the platinum.

He says that this high emission of thorium is a property of metallic thorium on the surface of the cathode, and the phrase "on the surface of the cathode" in this connection refers to the atomic layer of thorium on the surface of the cathode and not to a layer painted on, so to speak.

He then describes (beginning at line 56), the apparatus which is suitable for preparing and utilizing a thoriated cathode for this high emission purpose, and describes (beginning at line 71) the Fig. 1 arrangement in detail.

In Fig. 1 the anode is produced by vaporizing tungsten from one filament on to the inside wall of the vacuum tube itself, the tube being connected to a pump through a freezing bath shown at the bottom of Fig. 1 which may contain liquid air or even an ice and salt mixture. Either of those expedients would be sufficient to prevent mercury or other vapors from the pumping system from getting back into the tube which is being evacuated, and this is a very simple proposition.

Beginning at line 87, he points out that preliminary evacuation is followed out by usual methods of producing high vacuum, including baking, and that a final stage of evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtained by its use, and he characterizes that as about one one-thousandth micron.

Beginning at line 95, he states that while the apparatus is still on the pump, the filaments are heated and then the apparatus may be sealed off. It may be immersed in liquid air and the filament aged by further heating for about a half an hour to a temperature of 2400 to 2500° K.

Putting the tube in liquid air will of course condense any condensible gases within the tube and hold them trapped to the wall. It is a step of exceeding caution.

Then the filament 3 is incandesced and vaporized and by that process produces a gas-free coating of tungsten on the inner surface of the glass tube, that is to say, the filament is actually burned out or vaporized rapidly in the tube and the particles of vaporized tungsten travel across and rest on the cold wall of the tube in a tungsten film which may be used, by connecting through the wires 12 and 13 of Fig. 1, as the anode.

It is a method of preparing a gas-free anode which Langmuir has described in another application that was co-pending with this one.

Another result of that vaporizing of tungsten is to remove additional traces of gas from the inside of the tube, so that a very clean tube is produced.

Page 2, line 19 describes how the filament 2 may be prepared and is a brief summary of the preparation of a thoriated tungsten filament, that is to say, the metal tungsten filament containing a small percentage of thorium oxid or thoria.

He points out that the percentages of thoria may vary. The actual wires used in vacuum tubes have thoria contents from half of one per cent. to one and one-quarter per cent. or thereabouts.

He points out at line 33, that the percentage of the thorium compound in the cathode makes a little difference within the limits he states, and little difference in the maximum electron emission which may be obtained under the best conditions, but that the desired active condition of the filament may be reached and maintained with greater ease if there is a larger rather than a smaller amount of thoria in the filament.

Beginning on page 2, line 43, he describes heat treatment of the thoriated cathode which in the case of Fig. 1 is now filament 2, filament 3 having been used up to take care of the vacuum and to deposit the tungsten anode upon the surface.

He first heats this filament to a high temperature and points out that that has no marked effect on the subsequent electron emission, that is to say, if one simply heated the filament to a high temperature of 2900° K. or absolute and then went ahead and used it, that prior treatment would have had no real effect upon the later emission of the filament.

It is not enough to bring about this thorium emission to which the patent is directed. It does clean any foreign materials from the surface of the filament and puts it in good shape for the further treatment. It also has the effect of reducing some of the thorium oxid or thoria to thorium metal within the interior of the filament.

The second step described begins at line 49 as incandescing the filament to somewhere within the range of about 2000 to 2400° K. and it is said that by this temperature treatment some change is produced in the cathode which enormously increases its electron emitting property under the condition described.

He says further at line 54,

> "The greatest activity is obtained between about 2200 degrees to 2300 degrees K. and the treatment at this temperature is usually continued for about one minute, but even outside of this range a marked change is produced."

That step is what we ordinarily call activating the filament.

It is described beginning at line 59 by the statement that a concentration of metallic thorium or of some other oxidizible thorium material takes place on the surface of the material so that the filament may then be used as a cathode at a temperature below this forming or activating temperature. In other words, having a reserve of thorium metal within the filament structure, produced by the reduction of the thorium oxid or thoria, the activating treatment preferably at 2200° or 2300° K. brings out some of that thorium metal by a diffusion process to the surface of the filament as stated at line 62, and there forms this atomic layer of pure clean thorium held to the clean tungsten surface of the filament.

At the top of the second column, line 66, Dr. Langmuir points out that with a filament thus prepared he has obtained at temperatures of about 1300° to 1380° K. substantially the same electron emission per square centimeter as with a pure tungsten filament at about 2000° K.

The difference in temperature there, from 1300° to 2000° does not look so very much as a mere matter of numbers, but when we remember that the emission goes up with tremendous speed as the temperature increases we can see what that gain in emission amounts to.

He says that preferably the thoriated cathode is operated at about 1700° or 1800° K. at which temperature its life is indefinitely long, page 2, line 71.

Also he points out at page 3, line 31, that it is possible to operate a refractory thoriated cathode at temperatures between 2000° and 2200° K. for a long time without destroying its high electron emission. Actually the filaments are used between those two ranges at from 1950° to 2000° K., and one picks out that temperature by reason of a balance between the most emission that you can get (in other words, the hottest temperature that is safe), consistent with a long life of the atomic thorium surface on the filament.

The next portion of the specification, beginning at page 2, line 75, describes what happens to an activated thoriated filament, if it is heated to a very high temperature, for example, to 2800° K., after the atomic layer has been formed.

He says that some change, apparently a distillation of the film of thorium from the surface takes place that is to say, the thorium is evaporated off at this high temperature and no longer is there to produce the high electron emission; and he says that the electron emitting power of the cathode as the result of that high temperature treatment falls to the same order of magnitude as the pure metal, ~~that is~~ to say, the tungsten itself.

That is exactly what will happen if one has this atomic layer of thorium (which evaporates more and more rapidly, of course, as the temperature increases), and if one increases the temperature to 2800° and thus evaporates the thorium from the surface.

He also points out that if you give a pure tungsten filament this schedule of heat treatment, of activation, it has no effect upon its electron emissivity. He has in his specification, therefore, proof of some unusual effect taking place in this thoriated filament and that effect is best explained by the explanation given in the specification which I have elaborated to a small degree.

He points out that active thorium material may be transferred by distillation to an adjacent surface, that is, it is not simply a dream that the thorium is there; it can be transferred. He points out beginning at page 2, line 100, that one of the most striking proofs that the active surface filament is not due to the effect of the thoria, that is, the oxid, as in the case of the Wehnelt cathode, which depends on the calcium oxid, is furnished by the effect of a minute trace of oxygen on the behavior of the cathode. At line 105, if in the same way a trace of oxygen is admitted the electron emission immediately falls as low or even lower than the low value observed when a cathode of pure tungsten is slightly oxidized.

Here we have this exceedingly delicate layer of a sensitive material, thorium, easily attacked by oxygen and a very slight trace either of oxygen or of an oxygen carrying vapor, like water vapor, allowed to reach that filament. It will destroy it very, very promptly and bring the emission down to that normal for the pure tungsten filament. He points out, beginning at line 120 on page 2, that cathodes containing only a small amount of thorium compound are deleteriously affected and that disintegration of the surface will be produced by positive ion bombardment, and that in this respect they may be extremely sensitive.

From that point of view, it is necessary to use the non-ionizing vacuum and space charge conditions of the first patent in suit, in order not merely to get the stability and high power capacity of a pure electron discharge but also to protect this delicate thorium surface from bombardment by positive ions, that bombardment having the effect of driving the thorium atoms from the surface. He refers again at page 3, line 15, to the presence of the skin of thorium and compares that with metallic thorium, and the properties of both, by showing a very high electron emissivity at a given temperature as compared to tungsten; but he points out there that difficulties are encountered with the use of metallic thorium as a cathode material, due to its relatively low melting point, and its susceptibility to oxidation. The melting point of thorium metal is just about the operating temperature of these thoriated tubes, that is somewhere in the neighborhood of 2000° K.

I think that the later measurements have shown the atomic layer of thorium held on the tungsten surface of an activated filament of this kind, has an even slightly higher emission than thorium metal would have, if it could be brought to the same temperature. That is due to some peculiar activity of the atomic layer so far as anybody can tell now.

Page 3, line 24, describes in greater detail the diffusion to which I referred in connection with the 2200° to 2300° treatment described on page 2, at line 55. Here it is stated that at the temperature range of 2000 to 2300 K., the active thorium is slowly diffusing to the surface from the interior of the metal. The paragraph continues:

> "As the temperature is raised a point is reached where the distillation of thorium from the surface exceeds the rate at which the metal diffuses to the surfaces."

And then comes the statement which I referred to a moment ago as to the possibility of operation for a long time at 2000°, with the note that there is some diffusion at this operating temperature. Some thorium of course is being evaporated from the surface of the filament, but some is being replaced, and the differential action continues and gives the long life of an activated filament. Beginning at line 41, page 3, follows a specific description of Fig. 2, which has plate-shaped anodes instead of the film anode on the inside of the tube, and is a rectifier. The use of the thoriated filament and the activation stage is much the same in this description. Beginning at line 87, Dr. Langmuir points out that it is not absolutely necessary that the thorium should be introduced into the body of the metal during the process of manufacture, and describes a distillation method of putting a thin layer of thorium on the surface of a filament, but that is not used in a practical process, either by plaintiff or defendant, so far as I know. It would result in getting a film of thorium on the surface. If too much thorium were deposited on the filament, it would immediately vaporize off at the vaporizing temperature of 2000, the operating temperature, except as to the atomic layer which will remain there held by the affinity of the tungsten atoms.

The Court: But not indefinitely?

The Witness: But not indefinitely, no. It would require either renewal from inside or outside. That, I think, is enough reason to endorse the use of the diffusion process, which is the one pratically adopted by everybody making this type of tube or filament.

The remaining part of the specification is a short paragraph beginning on page 3, line 112, which points out that an important thing is not to bombard this cathode with ions, and that therefore if you are operating at voltages below ionization voltages, where ions can not be produced, then you do not need to worry so much about the vacuum, in so far as ionization is concerned; but, of course, you must still have a tube which is exceptionally free from oxygen or water vapor, which would attack the thorium, if present even in a very minute degree.

Incidentally, the partial pressure of oxygen, or of water vapor, to which one must go in order to have a long life for a filament of this sort, is a much lower pressure—that is with respect to a practical embodiment, the vacuum must be very much better than it need be with the 3/2 power patent. It is an exceptionally severe treatment that is necessary (from the point of view of getting a pure electron discharge), if you are to attain a freedom from oxygen and water vapor which is sufficient to preserve the sensitive thorium filament surface for a reasonably long life. I think that covers the second patent, Mr. Edmonds.

United States District Court,
Wilmington, Delaware,
Monday, October 18, 1926,
10 o'clock A. M.

THIRD DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

John V. L. Hogan, resumes the stand.

Direct Examination (Continued).

By Mr. Edmonds:

Mr. Edmonds: May I recall to your Honor that at the close of the last session I was directing the attention of the witness to the second Langmuir patent in suit, No. 1,244,216?

The Court: The thoriated patent?

Mr. Edmonds: The thoriated patent; yes, sir.

Q. 8. Mr. Hogan, will you refer for a moment to the baking step, as stated, between lines 95 and 100 of the first page of the specification of the No. 1,244,216 patent, and explain that step more fully?

A. The portion to which you refer reads:

> "While the apparatus is still on the pump the filaments 2, 3, are heated to a temperature of about 2900° K. (absolute) for a short time and the envelop 1 is baked out in an oven at a temperature of about 360 to 450 ° K."

The K. representing the Kelvin or absolute scale. 350° Kelvin is 87° C., which is below the boiling point of water and 450° Kelvin is 177° C., which is a low heat, not much above the boiling point of water, not double the boiling temperature in any event. On the other hand, 400 to 500° C., corresponding to 673 to 773° Kelvin, covers the range at which the glass wall of an incandescent lamp heated while on the pump is likely to suck in because the glass softens sufficiently so that it cannot withstand the external pressure, I think it is perfectly clear that this statement of 360 to 450° Kelvin as a baking temperature is an error, and that it is intended to represent 360 to 450° C. That change of scales corresponds to lamp practice, and, particularly in view of the fact that the lower temperature is below even the boiling point of water, I feel sure that any lamp man in reading the patent would understand this temperature range to refer to the C. scale, rather than the Kelvin scale, as it appears in the printed text; in fact, the first time I read that, I did not notice the Kelvin at all. I simply took the figures as representing the C. figures.

Q. 9. Would the skillful lamp man have so understood that reference to the temperature scale at the date of the patent?

A. Yes, I feel sure of that.

Q. 10. Referring now to the step of heating the thoriated cathode to about 2900° K. as covered by lines 42-43 of the second page of the specification, is this step a necessity in the preparation of a vacuum tube, in accordance with the disclosure of this patent?

A. No. It is not an essential step. It is a helpful step in that it has the cleaning and reducing effect of which I spoke in discussing the patent. It adds to the reserve of reduced thorium metal within the filament, but if it is omitted and the activating treatment, the essential activating treatment, that is explained beginning at line 49, page 2, is included, the high emission characteristic of the thorium atomic layer will be had even though the first step is omitted; that is to say, the cleaning step.

Q. 11. Will you now state the characteristic features of the vacuum tubes described in the two remaining Patents Nos. 1,244,217 and 1,529,597?

A. Taking up first the specification of 1,244,217, the invention is defined at page 1, line 10 and thereafter as relating to electrical devices having an electrode consisting at least in part of thorium and having at a given temperature an electron emission per unit surface materially greater than the emission of a refractory metal such as tungsten at the same temperature independently of and in the absence of positive ionization.

Then follows reference to another application of Langmuir, Serial No. 851,095, which became the second patent in suit on the thoriated high emission filament.

The specification continues at page 1, line 23, pointing out that in the preparation of these devices, that is to say, the thoriated filament devices, great care must be exercised to remove the last traces of oxygenous gases, particularly water vapor, and precautions must be observed not to evolve water vapor from the bulb walls during the operation of the device.

Continuing at line 29:

> "In accordance with my present invention, I have improved the above-described device and also rendered easier the preparation of the same by providing in the envelope a quantity of a vaporizable reagent of low vapor pressure capable of preventing the oxidation of thorium. I prefer to use for this purpose an alkali metal, such for example, as potassium."

Then follows a description of the figure of the patent including the thoriated tungsten filament, as to which at line 69, page 1, a reference is made to Patent 1,082,933.

Beginning at line 79, the evacuating process is characterized, the statement being:

> "The preliminary evacuation of the envelop is carried out by the usual methods of producing a non-striking high vacuum, which includes baking out the envelop to remove water vapor."

The phrase "non-striking high vacuum" has been used frequently in the art to define a vacuum in which ionization was minimized, "striking" being a throw back, so to speak, to the old phrase of "striking" an arc and being based on the analogy between the ionized discharge and an arc.

The final stage of evacuation is described as preferably utilizing a high-grade pump, such as the Gaede molecular, and then beginning at line 97, is given a description of the distillation of the vaporizable reagent to be used from a side chamber in the specific illustration of Fig. 1 into the tube itself by way of one or two subordinate side chambers, the use of which results in a purification of the vaporizable reagent.

This description of the introduction of the vaporizable material into the bulb carries over to page 2, the last step being in the first few lines of page 2 to the effect that a very small amount of this reagent is introduced into the main envelop 1. Sufficient potassium in the specific example given here is distilled into the tube to form a visible film over part of the inside of the tube wall and the vapor permeates the tube space when the tube is hot and produces an active film which may not be thick enough to be visible, but yet is a film over practically all the wall of the inside of the tube.

The next paragraph of the specification, beginning at line 11, page 2, describes the activating of the thoriated cathode and follows the second patent in suit in that particular.

At line 24 there is a statement as to the appearance of a concentration of metallic thorium or of some other oxidizable thorium material, on the surface of the filament, to which I have already referred.

Beginning at line 30, page 2, the patent states that

> "the presence of the reducing agent in the main receptacle maintains the thorium reduced in spite of traces of water vapor which may be liberated from the glass. In any event, the high electron emissivity of the thoriated cathode is more easily secured and maintained in the presence of the reducing agent than without it."

It will be recognized that the use of a potassium film in this way provides an active oxygen absorbing material within the same tube that contains the activated thorium surfaced filament. Traces of oxygen or of water vapor which would oxidize the thorium surface are taken up by the film of potassium on the surface of the bulb before they attack the thorium and they are held on the highly oxidizable potassium surface and prevented from attacking the thorium.

The result of providing a film of material of this sort is to protect the easily oxidizable thorium surface and thus to make it available for a long period of use without the likelihood of its destruction by traces (and very minute traces) of either oxygen or water vapor which might be produced either by condensation or directly from the walls of the tube in use.

Your Honor may recall that I pointed out the very, very small quantities of oxygen or of water vapor that would destroy the thorium and yet would be entirely insufficient to destroy the space charge operation in accordance with the first patent. This is a sort of superprecaution for the protection of the particularly delicate and particularly highly emissive thorium surface.

The specification continues at page 2, line 38, with a discussion of the action of the filament at the various temperature ranges and then at line 60, points out that the vapor pressure of potassium, sodium or other alkaline metal at room temperature is so low that objectionable positive ionization of its own vapor during the operation of the pure electron device is negligible and that the vapor pressure of the oxidization products of the alkaline metal have no perceptible vapor pressure.

It will be recognized, of course, that if the vapor pressure of whatever material were used to protect the filament were sufficiently high it might under the action of high voltages become ionized just as a gas would become ionized and in that way destroy space charge operation and possibly bombard the filament, not only to the extent of removing the thorium by bombardment but perhaps even disintegrating the filament as a result of the heat produced by this ionic bombardment.

The portion of the specification that I have just read points out that at room temperature the vapor pressure of the alkaline metals is so low as to be unobjectionable. As a matter of fact, it is at ordinary room temperature in the case of potassium very far below 1/1000 of a micron so that one need have no fears as to the vapor pressure of potassium itself so long as room temperature is maintained under operating conditions. That refers back incidentally to page 1, line 33, where the vaporizable reagent is stated as having a low vapor pressure, and of course, that means a low vapor pressure under the conditions of use. The remainder of the specification beginning at page 2, line 78, has to do with the possible uses under carefully controlled conditions of a device filled with an inert gas such as argon, but that is a feature that is not utilized by the defendant here and so I will not discuss that part of the specification.

Turning to the fourth patent in suit, 1,529,597, we find the invention characterized at page 1, line 10, as comprising an improvement in the electron emitting cathode of the type described in the prior patent 1,244,216 and 1,244,217. Those are the second and third patents in this suit.

The description of the third paragraph of page 1, beginning at line 14, parallels the descriptions that I have already given of the second and third patents, pointing out, for example, (1) the use of the cathode containing the metal thorium distributed throughout its mass, (2) the preparation of such a thoriated cathode by an addition of the material capable of increasing its electron emissivity, such for example, as thoria and (3) the treatment so that the active material in a finished device, according to all indications, consists of metallic thorium, or at least of a lower oxide of thorium than thoria. Beginning at line 31, Dr. Langmuir points out that the cathode prepared according to the methods set forth in the No. 1,244,216 patent, the second patent here, is commonly known as a thoriated cathode, and that it is very sensitive to traces of oxidizing gas in the bulb, as for example, to small traces of water vapor which may be given off from the walls of the bulb during the normal operation of the device. He then points out that in order to prevent loss of activity of the cathode, as he describes in the '217 patent, the third patent here, beneficial results are obtained by the admission to the bulb of a small amount of alkali metal, such as potassium or sodium, or of a hydrocarbon compound—but a hydrocarbon compound is not used here.

The next paragraph of the specification has to do with another aspect of the invention covered by this fourth patent in suit, that of carbonizing; and since that is not involved here, so far as I know, I will skip the parts of the specification referring to it.

Beginning on page 1, line 63, the specification states that:

> "In accordance with another feature of my invention my improved cathode is used in conjunction with a non-carbonaceous reducing agent which is provided in the bulb as for example, a highly oxidizable metal."

The next dozen lines refer to the deleterious effects of positive ion bombardment, and the way in which the beneficial effect of thorium may be largely or entirely destroyed by such bombardment, and then at line 75 occurs the following:

> "Although the alkali metals are entirely satisfactory as agents to remove deleterious gases when the operating temperature of the bulb is only moderately above room temperature, as in the case of radio receiving tubes, these alkali metals have a sufficiently high vapor pressure at the operating temperature of power devices in which cathodes of the thoriated type are used to become ionized at higher voltages and to cause removal of the active film of thorium from the cathode by bombardment."

That points out the danger of ionization, which occurs when such reducing agents as potassium are used under conditions in which the bulb may become relatively warm with respect to normal room temperature, the reason being, of course, that the vapor pressure of the reagent increases rapidly with temperature; and if the temperature goes up to a substantially higher value than that of the ordinary room, the pressure will also go up to a value where the ionization under high voltage may be sufficient to damage the filament; that is to say, the activated filament. An amount of ionization that would not heat and disintegrate a pure tungsten filament will be sufficient to affect very seriously the operation of the highly sensitive thoriated filament.

The specification continues at line 88 to the effect that it is advantageous in many cases to provide a device containing a cathode of the thoriated type with a material having an affinity for gases, such as magnesium, for example, which, at the operating temperature of the device has substantially no vapor pressure. There is a reference to the specific material of certain of the claims which has the protecting power that is necessary for the care of the thoriated tungsten filament, and yet does not have a high enough vapor pressure to produce ionization under normal operating voltages, even at a temperature somewhat higher than room temperature.

The patent then describes, beginning at line 99 of page 1: An incandescent cathode rectifier or two-electrode tube prepared in accordance with this use of magnesium. The figure of the patent illustrates a heating coil within the tube, marked 11, having within it a small quantity of magnesium, which magnesium, while the tube is being exhausted, may be vaporized by heating the small coil.

Let me say first, that almost all of the second page has to do with the carbonizing feature of the invention, but at the bottom of the second column beginning at line 120, Dr. Langmuir points out that to prevent ionization of residual gases or vapors, he prefers to introduce a reagent having a lower vapor pressure than the alkali metals, such, for example, as an alkaline earth metal such as magnesium, calcium, strontium or the like. He then describes the use of the small heating coil within the tube, and states a preference for metallic magnesium. Beginning at the top of page 3, column 1, this description of the treatment is continued, and it is pointed out that by heating, some of the magnesium is volatilized and deposited on the inner surface of the bulb, which is then sealed off. Beginning at line 7, he indicates the fact that the sealing off process may result in driving out a small quantity of gas from the heated glass where the constriction is made, makes it desirable to heat the filament a second time, and so volatilize the small additional quantity of magnesium in order to combine chemically with what ever gas may have gotten into the bulb during the sealing off operation.

Then beginning at line 16, page 3, is the statement:

> "The film of magnesium, or other equivalent metal, on the walls of the bulb will combine with any water vapor or oxygen which may be given off by the bulb, or any other parts of the device during its operation, and thereby prevent an oxidation of the active thorium material upon the surface of the cathode."

Your Honor will recognize that that is the same type of protecting action with respect to the sensitive thoriated filament that was provided by the potassium or alkali metal film on the third patent, but that in this instance we have a film which will not produce a harmful vapor, even though the tube is heated somewhat above room temperature. The metal magnesium is not as active normally for the absorption of oxygen or water vapor as is the alkali metal potassium, and it is somewhat astonishing that the reduced effectiveness of magnesium, its reduced affinity (in the popular phrase), for oxygen can be made up by using a large area of the clean vaporized magnesium metal on the inside wall of the tube, and at the same time the advantage of lower vapor pressure obtained.

The next portion of the specification beginning at page 3, line 24, describes the cleaning of the tungsten cathode at the high temperature and beginning at line 28, the activating of the thoriated cathode, and it is pointed out that the operation at the activating temperature of about 2200° absolute causes the active thorium product to come to the surface of the cathode, where it will be effective in increasing the electron emission during the operation of the device. That, your Honor, will recognize as the diffusion from the interior of the thoriated tungsten filament to produce the atomic layer on its surface. The specification goes on at line 38 to say:

> "As explained in my prior patents, a temperature materially higher than the activating temperature will result in the thorium being volatilized from the surface of the cathode. A fresh supply can be produced and caused to accumulate upon the surface by again activating or 'forming' an electrode at about 2200° K."

The normal operation below 2200 or even as high as 2100 is described, and the statement is made that under those conditions, the electron emission stays constant, that of course, referring to the balance between the evaporation rate which takes the thorium away from the cathode and the diffusion rate, which brings it to the surface of the cathode; and as I think I pointed out in connection with the second patent in suit, the adjustment of the operating temperature is governed by the desire to get the highest emission consistent with a long life of the filament. I think that covers both of the patents, Mr. Edmonds.

Q. 13. Will you state briefly, Mr. Hogan, what personal contact with the vacuum tubes of the sort we are here discussing and their use, you have had?

A. I have bought and used and measured a great many types of vacuum tubes for a number of years, both in radio and in the other fields, and I have been familiar with tubes utilizing the inventions of these four patents, both by observation and by my own use for a good many years.

Q. 14. Do you know whether the plaintiff is and has been making and selling vacuum tubes constructed in accordance with the teachings of these four patents to which you have referred?

A. Yes; I have tested and used the tubes, using the four inventions here in suit and made by the plaintiff, for some time, beginning in the war period, the pliatrons and the kenotrons, that is to say, the three-electrode tubes and the two-electrode tubes, utilizing the invention of the first patent in suit which were available and used by me, and from late 1920 the types of tubes characterized, or perhaps I should say, exemplified by the UV-201 tube which were on the market; and I used and tested a good many of these tubes and the similar tubes, all of which used the invention of the first patent in suit. From early 1923, I have used tubes of the sort represented by the UV-199 and the UV-201-A, which utilized the inventions of all four of the patents in suit. The three tubes to which I have specifically referred, that is to say, UV-201, the UV-199 and the UV-201-A are so-called general purpose tubes, convenient for radio and telephone amplification, and for radio detection. The UV-201 tube of late 1920 and thereafter, had a tungsten filament using five volts filament potential and one ampere of current, or consuming in the filament about five watts under normal adjustment. The later tubes, dating from early 1923, and involving the thoriated cathode, the highly emitting cathode, included the 201-A, which used the same voltage (namely, five volts), on the filament as did the UV-201 but used only one-quarter of an ampere instead of one ampere and consequently had a power consumption of one and one-quarter watts instead of five watts. The UV-199 thoriated tube uses only 0.06 ampere at three volts on the filament, or eighteen-one-hundredths of a watt as the filament power. I have also seen and used much larger tubes made by the plaintiff under the first patent, including the UV-207, which is a commercial tube having a power capacity of 20,000 watts, 20 kilowatts operating with a plate voltage of about 15,000 volts. The tubes using the pure electron discharge of the first patent from the date of their first availability to the public, have superseded all the other tubes that were available and since tubes using the inventions of all four patents have been available; that is to say, since the first part of 1923, the thoriated tubes have become tremendously used for all ordinary purposes, such as detection and amplification in radio, and the rectification of alternating current for power supply in radio sets.

Q. 15. Is the tube which I now show you a sample tube known as UV-199, such as made by the plaintiff under the patents in suit?

A. Yes, this is a typical dry cell tube of the UV-199 type, made under the four patents in suit, and having the small filament power consumption to which I referred.

Mr. Edmonds: UV-199 tube is offered in evidence as Plaintiff's Exhibit No. 16.

(Received in evidence and marked "Plaintiff's Exhibit No. 16.")

Mr. Edmonds: And I will offer separately the data sheet accompanying the tube as Plaintiff's Exhibit 16-A.

(Received in evidence and marked "Plaintiff's Exhibit No. 16-A." *See Volume IV, Plaintiff's Exhibits, page 36.*)

By **Mr. Edmonds**:

Q. 16. What is the tube which I now show you, Mr. Hogan?

A. This is a UX-201A tube having a quarter ampere five-volt filament. The designation used in my second previous answer was UV-201A which has to do only with the form of the base. The tube is the same. This particular tube was obtained by me from the stock room of the General Electric Company at Schenectady on September 1st and was marked at that time with my initials. It is a tube using the inventions of all four of the patents in suit.

Mr. Edmonds: The 201A tube identified by the witness is offered in evidence as Plaintiff's Exhibit No. 17.

(Received in evidence and marked "Plaintiff's Exhibit No. 17.")

Mr. Edmonds: And the data sheet accompanying it as Plaintiff's Exhibit 17-A.

(Received in evidence and marked "Plaintiff's Exhibit No. 17-A." *See Volume IV, Plaintiff's Exhibits, page 37.*)

Mr. Edmonds: The plaintiff offered in evidence the other day Exhibit No. 8, the DeForest DV-5 tube. I think that the data sheet accompanying the tube should be offered as an exhibit as well and I accordingly do so, offering this sheet as Plaintiff's Exhibit 8-A.

(Received in evidence and marked "Plaintiff's Exhibit No. 8-A." *See Volume IV, Plaintiff's Exhibits, page 27.*)

By Mr. Edmonds:

Q. 17. Mr. Hogan, I will ask you inasmuch as in these exhibit tubes the interior construction cannot be seen because of the cloudy effect of the film on the inside, whether you have had prepared drawings illustrating the internal construction of both the 201-A and the DV-5?

A. Yes, I have here drawings of each of those tubes that were made under my direction some time ago. The plate of each tube is the rectangular box-like structure and in each of the drawings has been cut away in part so as to expose the grid and the filament.

Q. 18. Your answer referred to both?

A. Yes, I treated them generally and not in detail.

Mr. Edmonds: The two drawings produced by the witness are offered in evidence, one illustrating the General Electric tube 201A as Plaintiff's Exhibit 18.

(Received in evidence and marked "Plaintiff's Exhibit No. 18." *See Volume IV, Plaintiff's Exhibits, page 38.*)

Mr. Edmonds: And that representing the DeForest tube DV-5 as Plaintiff's Exhibit 19.

(Received in evidence and marked "Plaintiff's Exhibit No. 19." *See Volume IV, Plaintiff's Exhibits, page 39.*)

Mr. Edmonds: That is all.

Cross-Examination.

By Mr. Darby:

XQ. 19. In your direct examination I think you mentioned the hot to cold resistance ratio as serving or as being capable of serving as a guide to determine the material of the filament, at least I understood you to say material, and on page 46 of the record it says it gives an indication of the temperature of the filament. Which is correct?

A. The sentence ending seven lines from the top of the transcript, page 46, should end "gives an indication of the material of the filament which is sometimes very useful."

XQ. 20. In other words, the word "temperature" as it now stands is incorrect?

A. That is right. That is to say, material is correct.

XQ. 21. Is that hot to cold resistance ratio method of ascertaining the material of the filament considered to be fairly accurate?

A. I think it is accepted generally.

XQ. 22. Prior to the summer of 1912, had you ever used an audion for any purpose other than as a detector?

A. I think not. I have no present recollection of any use of an audion other than as a detector prior to 1912 summer, except the attempts to use a grid audion as a telephone amplifier which both Dr. DeForest and I made in 1906 and 1907. Because it did not work and we could not make it work at that time—I assume you do not want a reference to that.

XQ. 23. And with reference to these 1906 attempts to use the audion as an amplifier, you say that you could not make them work?

A. No, we could not get any amplification at that time.

XQ. 24. Was that because of blue glow effect?

A. I do not know why it was.

XQ. 25. When was the first time that you were personally familiar with the use of the three-electrode audion as an amplifier as distinguished from a detector?

A. I think the first time I saw an audion used as an amplifier was in Dr. DeForest's demonstration at his Institute of Radio Engineers' paper, the date, I do not recall, but I think it was January, 1913; perhaps you can check me on that.

XQ. 26. I think that is the approximate time. And you had never heard of its use as an amplifier as distinguished as a detector prior to that time?

A. No, that is not correct. Even as far back as 1906 and 1907, I had heard of its possibility so to speak——

XQ. 27. I did not ask you about the possibilities. I was asking about its use.

A. I did not understand. You mean its successful use as an amplifier?

XQ. 28. Yes.

A. No, I do not think I had heard of it before then unless some indirect comments as to use on the Pacific Coast by DeForest had been repeated to me. I cannot recall that distinctly. Of course, I was familiar with DeForest's 1907 patents, I think that is the date, on the three-electrode tube as an amplifier but I had never known anybody to make it work up to 1912 or 1913.

XQ. 29. Several times in your direct testimony you made reference or used the expression "harmful ionization." Just what did you mean by that expression, harmful ionization in connection with the three-electrode audion tube, for example?

A. I might have meant either of two things. Harmful ionization would be ionization that would substantially reduce the life of the sensitive thoriated cathode in one case, that is to say, with reference to the last three patents, or with reference to the first patent, harmful ionization would be that which would interfere with the operation of the device in such a way as to produce a low power limit or affect its uniformity of operation or otherwise produce difficulties.

XQ. 30. Then you intended to include by that expression affecting a low power limit?

A. Yes, I think that would be a distinctly harmful effect of ionization.

XQ. 31. You make that conditioned upon the power limit that you desire?

A. Yes. Of course, if you have no desire to use more than one microwatt then the capability or incapability of a particular device to go to one watt will not trouble you.

XQ. 32. And adhering to that latter case, then what would you mean by harmful ionization having eliminated the lower power limit?

A. That which would affect the cathode or that which would interfere with the operation of the tube, particularly with respect to the uniformity of its operation.

XQ. 33. You are now of course well familiar with the use of the three-electrode audion as an amplifier?

A. Yes.

XQ. 34. And you are familiar with the use of the three-electrode audion as an amplifier such as are used in the wire telephone lines?

A. Yes, although I have not great familiarity with the details of the telephone company's plant.

XQ. 35. What practical effect would harmful ionization have upon an audion amplifier such as, for example, as is used in the telephone line?

A. The worst immediate effect would be as to uniformity of operation, which would make continued adjustments necessary and would interfere with the replacement of one device by another, that is to say, when one tube burned out and another were put in an amount of ionization that would interfere with uniformity of operation would make it necessary to readjust throughout the circuit to take care of the substitute tube. In addition to that, if ionization were still greater it might introduce, probably would introduce distortion to some extent and the further increase of ionization would give a type of operation that was progressively worse as the intensity of the applied electromotive force increased, that is to say, a tube might operate moderately well, passably well, on small impulses but would go bad either by blue glow or by extreme distortion if the intensity of the impulses applied were increased.

XQ. 36. Then I understand from your last answer that when blue glow occurs the tube goes bad?

A. As a rule, yes. That is to say, it does not go bad permanently, but——

XQ. 37. You can no longer operate it while the blue glow is present?

A. The blue glow condition is not a good operating condition for a normal design of tube. I have seen tubes operate practically with a shade of glow, but usually, that is an indication of severe overloading.

XQ. 38. What happens if you increase the voltage after the blue glow occurs; that is, the plate voltage, after the blue glow occurs in a three-electrode audion?

A. You are likely to burn up the filament by ionization, though that will not inevitably follow.

XQ. 39. What effect will it have on the practical operation of the tube, would it cease to function as an amplifier, would you say?

A. Ordinarily it would, yes. That has been my experience.

XQ. 40. Do you agree with the statement contained in lines 90 to 92 of the Langmuir Patent Number 1, that ordinarily the gas ionization in the audion begins to be important somewhere between twenty and thirty volts?

A. Yes, that has been my experience with the old art audion.

XQ. 41. And has it been your experience that around thirty volts you have obtained blue glow?

A. In many cases, though not always. Some audions I have had would not show blue glow with small filament emission at higher voltages than 30, even as high as 50, but on higher filament emission those same tubes would show a blue glow at about 30 volts. There is no arbitrary blue glow voltage; it is a function both of the emission from the filament and the plate voltage.

XQ. 42. What are the respective emissions that you have referred to in your last answer?

A. They were within the operating range. I cannot give them to you specifically. Even in the 30-volt case it was not necessary to push the filament to such brightness that it was likely to be burned out any minute.

XQ. 43. And if you were operating a tube just below the ionization voltage in the normal use of the tube you are familiar with prior to 1913, and you increased the plate voltage above 30 volts, to say 70 or 80 volts, what would have happened?

A. It would depend on the filament emission. I have had tubes which would stand as high as 70 or 80 volts without showing blue glow when the filament was dimly lighted, but when it was brightly lighted it would go into blue glow considerably below that point.

XQ. 44. Are you referring to some tubes in addition to the ones you have mentioned in the preceding answer when you said you were operating as high as 50 volts?

A. No, I have no specific recollection of one tube as against another tube, but I do recall measurements that I think ran as high as 100 volts without blue glow and with very small emission.

XQ. 45. Will you please think very carefully, because we have had 50 and 70 and now 100? Were there any more voltages you have used above that point?

A. I cannot remember specific voltages, Mr. Darby, but I do know that I have used voltages which varied from 10, I do not believe I ever went below 10, for satisfactory operation, and up to as high as 70 or 80 and probably even 100. I do not think I have ever used voltages higher than 100 on any of the old art tubes, and I do not think I have operated under voltages even as high as that.

XQ. 46. Did you operate the tubes that you were using voltages as high as 70 and probably 100 as you have stated, or was your answer limited to the fact that you have used that much voltage without obtaining blue glow?

A. The latter is correct. Those same tubes which would stand as high as 70 volts or thereabouts without glow would not operate well with the small emission that was necessary in order to let them stand that voltage. As soon as I came to normal emission, normal filament temperature, then I operated at the low voltages of around 25 to 30, at which point the bulbs were most sensitive both as detectors and amplifiers.

XQ. 47. Then will you agree with me on the general proposition that from a practical viewpoint in the tubes that you are familiar with prior to 1913, that if you employed a voltage, say roughly twice the value of the ionization voltage, they were not practically good in operation?

A. No, I do not think I can accept that as a general statement, Mr. Darby, because the tubes vary. I would not be able to exclude operation at even 40 or 50 volts because one might be able to get practical operation——

XQ. 48. I am not asking you what one might do; I am asking you about your own experience, please.

A. In my own experience all the audions I have had from the DeForest Company up to 1914 or thereabouts——

XQ. 49. I am confining it to 1913.

A. I think I purchased no tubes during 1913, although I may have had some. I did get some from Dr. DeForest in 1914, and those tubes were of the same type he demonstrated in 1913 and I know that all of them were most sensitive in the range of around 30 volts. Now, what kind of operation I could have gotten either above or below, I am not sufficiently clear to say.

XQ. 50. That is, you did not attempt it or you do not recall?

A. I think that both things are true. No, I beg your pardon. I did attempt it but I do not recall it. I say that simply on the basis of probability because I have no definite recollection of having tried the voltages. I know that I did make a practice of using all the variables to get the best operating conditions.

XQ. 51. It is true, is it not, referring to the Langmuir Patent No. 1, that Langmuir nowhere makes any reference in that patent specification to the use of a so-called audion as an amplifier and confines his mention of the audion to its use as a detector?

A. I had not noted that point but I see the text with reference to the audion at page 1, line 81, says: "This device has been used as a receiver for radio-telegraphy." Perhaps he had in mind only the detecting use although amplification was well known prior to October, 1913, when this application was filed.

XQ. 52. Amplification was well known prior to that time?

A. Why, yes. I think that DeForest's paper of January, 1913, was an announcement of amplification in a practical way that was known widely.

XQ. 53. What was the current that you employed with the audion tubes that you operated prior to 1913, do you recall?

A. Filament current or plate current?

XQ. 54. The filament current.

A. No. In the first place, I have no recollection of having used tubes prior to 1913, except in 1906 and 1907, and I do not remember those.

XQ. 55. Will you please refer to this patent No. 1? It is a fact is it not, that generally speaking up to line 100 of page 3, the patent is directed to a statement of object of invention and the differences between devices containing the invention of the patent and devices not containing the inventions of the patent and ways of telling them apart, is not that in a general way correct?

A. Yes.

XQ. 56. Then beginning at line 101, page 3, with the words "Before describing the method of preparing my new type of apparatus, I will describe the structure of the apparatus illustrated by Figs. 1 to 3" and from there on until line 60, page 4, is a description of the drawings, is that correct?

A. That is correct.

XQ. 57. Then beginning line 60, begins a description of the evacuation steps?

A. The evacuation and preparation in general, yes.

XQ. 58. And the first step mentioned is heating the walls of the tube and in general the most approved methods of incandescent lamp exhaust, is that correct?

A. The sentence reads beginning at page 4, line 60, "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used."

XQ. 59. And his next step of evacuation referred to in the specification is a Gaede molecular pump, which he states removes vapors as well as gases, is that correct?

A. I do not understand that to be an additional type of evacuation necessarily, but the next reference is a reference to a Gaede molecular pump.

XQ. 60. Then as I understand your last answer, that is not an additional step but it may be an alternative step, is that correct?

A. Alternative to what? To incandescent lamp exhaust?

XQ. 61. Yes.

A. Yes, or it may be made part of the exhaust. I mean I do not want to break this into steps as indicated by your question.

XQ. 62. My question as I believe I framed it, was not so much as indicating it in steps, as to mentioning the types of the exhaust. Listen to this question. May be it will straighten it out: The next type of exhaust that is mentioned in the specification is chemical evacuating means such as electrically vaporized calcium or magnesium; is that correct?

A. The statement is that chemical evacuating means such as electrically vaporized calcium or magnesium, may also be used.

XQ. 63. The next thing that is mentioned in the specification which refers to the elimination of air or gas, is that the electrodes may be heated; is that correct?

A. Yes, that is correct.

XQ. 64. And it describes one method of freeing the electrodes of gas or air by the term "bombardment of the electrons"; is that correct?

A. That is correct.

XQ. 65. And with respect to the bombardment he mentions the use of the voltage impressed between the filament and the anode, and states that this bombardment may be repeated with "increasing voltages"; is that correct?

A. Yes,

XQ. 66. And then he states at line 125, on page 4, in effect, that after electrodes have been freed of occluded gas by the bombardment process, that the electrodes will not again readily take up air or gas; is that in effect what he says?

A. The statement is: "After the metal has been freed from occluded gas reabsorption of gas will not readily take place even though it is exposed to the air or other gases."

I do not think that limits it to freeing by bombardment, as your question implies.

XQ. 67. Does that mention any way of freeing the electrodes of gases in the specification other than that bombardment?

A. Yes, the wire anode heating by passing a current through it is shown.

XQ. 68. The wire anode?

A. Yes.

XQ. 69. That is on Figure 1 of the patent?

A. That is correct.

XQ. 70. And that wire anode structure is not incorporated in the Plaintiff's Exhibits Nos. 16 and 17, is it?

A. That is correct; it is not incorporated in either of those tubes.

XQ. 71. Now, do I understand from you that the bombardment treatment is alternative to the heating treatment?

A. Why, bombardment is heating, Mr. Darby.

XQ. 72. Bombardment is heating?

A. Yes.

XQ. 73. You can not bombard without heating, and free the cold electrode of gas?

A. You can not get the cold electrode really free of gas and usefully free of gas without heating.

XQ. 74. By "useful" you mean that you can not get it so free that the gas which the electrode subsequently gives off would cause appreciable ionization in the operation of the tube?

A. I mean that you will heat the anodes by bombardment or otherwise if you want to get them free of gas, to a practical extent. If the anodes were not heated at all, the amount of gas evolved would certainly be small, compared to that which we have to take out to make practical tubes today.

XQ. 75. Then you can heat the electrodes to a sufficient degree of temperature to free them of gas without bombardment, could you not?

A. Yes.

XQ. 76. Then the next passage of the specification which follows the passage we have just been considering states:

> "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower," and then——

A. Won't you finish the sentence?

XQ. 77-78. —"but no definite limits can be assigned." That is correct?

A. Yes.

XQ. 79. And a little lower, around line 12, appears the statement:

> "When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance."

That means, does it not, to state it in a different way, that when the anode is farther away from the cathode, such as an incandescent filament, you have got to have a higher vacuum in the tube than if the anode was closer to the filament; is that correct?

A. All other conditions being the same, yes.

XQ. 80. The statement appearing in the specification assumes all other conditions being the same, does it not?

A. That is my belief.

XQ. 81. All right. And the next paragraph refers generally to voltages that may be handled, at least, currents with very high voltages that may be handled with electron discharge apparatus thus provided with gas-free pretreated anode and makes reference to another application; is that correct?

A. Yes.

XQ. 82. The next paragraph describes a use of a device constructed in accordance with the invention in connection with the circuit arrangement of Figure 4; is that correct?

A. Yes, sir.

XQ. 83. The next paragraph refers to Figure 5, which illustrates a form of feed-back circuit for making the tube act as a generator of continuous oscillation; is that correct?

A. That is correct.

XQ. 84. And the last paragraph on page 5 refers to, generally speaking, differences in operating characteristics of devices constructed in accordance with the invention as compared with devices which operate with gas ionization; is that, generally speaking, correct?

A. I think that is a general statement of it, yes.

XQ. 85. And the last paragraph of the specification prior to the introduction of the claims and appearing at the top of page 6, is, in a few words, Langmuir's definition of positive ionization; is that correct?

A. Yes. It says:

> "The positive ionization herein referred to is that positive ionization which occurs as the result of collisions between electrons and gas molecules in the space between the electrodes and causes," and so forth.

I think that could be called a definition although it is not the complete definition as given elsewhere in the specification.

XQ. 86. Were you familiar with Dr. Langmuir's paper on the high vacuum which I think was published in December, 1913, at or shortly after the time that it was published?

A. What was the title of that paper, Mr. Darby?

THE COURT: Is this the paper (indicating)?

MR. DARBY: The December, 1913, paper; I think that is it, your Honor.

XQ. 87. The December, 1913, paper?

A. This is the paper published in the *Physical Review* of December, 1913, entitled: "The Effect on Space Charge and Residual Gases of Thermionic Currents in High Vacuum," by Dr. Langmuir. I do not remember when I first saw that, but I do know that I did not hear it presented. I think I must have read it within six months or a year after its publication.

XQ. 88. You think that you did read it within six months or a year?

A. Yes, sir.

XQ. 89. You certainly had read it prior to 1919?

A. I think so.

XQ. 90. What type or material of filaments have been used in audion tubes since 1906, according to your personal knowledge or information?

A. Tantalum, tungsten, oxide-coated filaments, and highly emitting filaments, such as thoriated tungsten. There may have been some molybdenum filaments used, but I am not sure.

XQ. 91. You know, do you not, that each of these filaments that you have mentioned, have been used as filaments in incandescent lamps?

A. I do not believe the oxide-coated Wehnelt filament has ever been used as a lamp filament, and I know that the thorium-coated filament, that is to say a filament having an active surface of thorium such as described in the second patent here, is not used, and could not be used in an incandescent lamp.

XQ. 92. But you do know that thoriated tungsten filament, in which thoria is added to the slug before it is sintered, as likewise described in the second patent, has been used as incandescent filament in lamps?

A. Oh, yes, that is used tremendously because of the non-offsetting property of the thoria. The point I make is that the different use of thorium——

XQ. 93. I know the point. I think you have answered my question. You have also stated your own point. How long, to your knowledge, has the thoriated tungsten filament been used as a filament in incandescent lamps?

A. I do not know when I first heard of that, and I am afraid I cannot give you a definite answer. It certainly has been a matter of several years.

XQ. 94. Has it been as early as 1910?

A. I do not know.

XQ. 95. You have testified that you have examined defendant's audion tubes or the defendant's tubes alleged to infringe in this action?

A. I do not know whether I testified so, but that is the fact.

XQ. 96. You have; did you have any difficulty in being able to tell whether or not they, in your opinion, embodied the invention of this high vacuum patent, or did you examine them with that thought in mind?

A. I had no trouble in making tests of them which demonstrated that they did.

The Court: Is this a convenient point for recess?

Mr. Darby: Yes, sir.

(After a short recess.)

XQ. 97. Read the last question and answer. (Record repeated as recorded.) That is, that they did contain the invention of this Patent No. 1?

A. Yes.

XQ. 98. What tests did you make?

A. 3/2 power characteristic measurement and a three-electrode test, the so-called gas test.

XQ. 99. And as the result of those two tests alone, you concluded that the defendant's audion tube embodied the invention of this Patent No. 1?

A. Not alone, Mr. Darby.

XQ. 100. What other tests—I asked you a minute ago what other tests you submitted them to?

A. I told you what tests I made. The other features that I considered were the regularity of operation, the reducibility of the results observed during those same two tests, and the fact of steady operation at high voltages and high emission.

XQ. 101. But you do not consider them to be tests?

A. Not in the sense that I understood your question.

XQ. 102. You have examined tubes manufactured by the Western Electric Company and used by the Telephone Company in their wire line transmission system, have you not?

A. Yes, I have examined and used a number of those tubes.

XQ. 103. And those vacuum tubes embody the invention of this high vacuum Patent No. 1, do they not?

A. A good many of them do.

XQ. 104. Do you know of any of them that are used in their wire transmission systems that do not?

A. I think the intent is to use them in that way and I suppose that the practical tubes do use the invention, but I have had samples of their tubes which showed obvious signs of ionization.

XQ. 105. Did they show ionization or did they show what you have termed harmful ionization?

A. I do not know. I made no tests to distinguish.

XQ. 106. Then you could not tell whether or not they had harmful ionization or not?

A. I think these particular tubes did.

XQ. 107. You heard Mr. Davis in his opening statement refer to the Cooper-Hewitt litigation, did you not?

A. I think he referred to it, yes.

XQ. 108. And that litigation you are familiar with, are you not?

A. Yes.

XQ. 109. And in essence that litigation was based on a licenes contract between Peter Cooper Hewitt and the Western Electric Company, and Peter Cooper Hewitt claimed that the three-electrode vacuum tubes used by the telephone company, the American Telephone & Telegraph Company in their line transmission systems as telephone relays and repeaters came within the terms of the Cooper Hewitt patent; is that correct?

A. I think that would be correct if you would specify the patent as to which he complained and also I think that the license was to the American Telephone & Telegraph Company, although it may have been to the Western Electric.

XQ. 110. And all of the Cooper Hewitt patents which were involved in that litigation were mercury vapor devices, were they not?

A. I think that is not a complete statement. The four Hewitt patents referred to alternative constructions using cadmium and alloys in place of mercury. Perhaps the figures and the specific illustrations in all four patents were based on mercury. I think that is correct. That is, I think they were. But I think that the specification referred to other than mercury devices.

XQ. 111. But they were all gas devices, were they not?

A. There was a good deal of dispute in that case as to the differences between gases and vapors but I think they were all devices that as specifically shown in the patent specifications involved the use of a substantial vapor or gas pressure.

XQ. 112. And operated because of ionization?

A. That was the question. The Court decided that the Telephone Company devices did not depend upon ionization and that the devices upon which Hewitt had based his patents did depend upon ionization and the Court put them into two distinct classes.

XQ. 113. And the devices of the Telephone Company were these so-called hard tubes containing the high degree of vacuum?

A. They were three-electrode vacuum tubes, but I do not believe the record ever brought out what the hardness of vacuum or degree of vacuum was. There were some tubes of the Telephone Company in that case that showed blue glow and the matter was never resolved as to whether those were defective or not.

XQ. 114. And you testified as an expert in that case for the plaintiff, did you not?

A. That is correct.

XQ. 115. You were asked Q. 13 in that case:

> "Q. 13. What is the difference between the use of the 'audion' type of device as a detector in wireless work and as an amplifier in telephone circuits?"

This is your direct examination, and you answered:

> "A. There are several important distinctions, not the least being that the range of frequencies involved are widely different. In radio or wireless telegraphy the detector must produce responses to electric disturbances of so-called radio frequency, which comprehends the alternating voltages or currents of from approximately 20,000 cycles per second to several millions of cycles per second. In telephonic amplification, such as concerns us in this case, the frequences

invariably lie within the audible range of from about 20 cycles per second to 15,000 or perhaps 20,000 per second—the average frequency of telephonic work being in the neighborhood of 800 or 1200 cycles per second.

Another important distinction lies in the fact for telephonic amplification the action of the vacuum tube must be distortionless, and consequently that the increase of outgoing current due to application of a positive impulse must be equal to the decrease of outgoing current which results from the application of an equal negative impulse. In other words, there must be no change in the amount of variation depending upon the polarity of the applied variations from the transmitter, but these repeated currents must be an undistorted replica (of course, increased as to the volume) of the original disturbances.

An entirely different condition holds in the use of these vacuum tubes for detectors in wireless telegraphy, inasmuch as it is of no value merely to amplify the received electromagnetic waves unless some other detecting mechanism is provided. The audion used as a radio detector not only amplifies but also rectifies or distorts the currents produced by the received signal waves so that they will be capable of operating an indicator such as a telephone receiver which is necessarily limited in action to much lower frequencies than those of the radiant waves themselves."

You so testified?

A. Yes, that appears in the record and I think that is a proper transcript of my testimony.

XQ. 116. Then you were asked in cross-examination:

"XQ. 479. Do you know what extent or degree the space inside of defendant's tube is evacuated; that is, what the pressure there is?

A. No; I have experimented with tubes produced by defendant and found indications of variation, but I do not know in figures the value which is assigned as a manufacturing standard, if that is what you mean.

XQ. 480. In the operation of defendant's devices as amplifiers in its wire telephone circuits, and with the voltages, and so forth there used, does it make any difference what the pressure in the tube is?

A. I think the action will certainly be governed quantitatively at least by the pressure of the gas within the tube; that is to say, the gas pressure along with other constants of contour and geometrical arrangement should be chosen to meet the particular conditions of voltage and whatnot concerned in the application desired.

XQ. 481. With the particular voltages and whatnots that the defendant actually does use would the defendant's tubes operate irrespective of the pressure that is in the tubes?

A. I think you are begging the question somewhat. If you mean that we are to hold constant everything except pressure and then to change that, I can answer that the operation will depend quantitatively at least upon the pressure within the tube.

XQ. 482. Do you not know whether or not they will operate in just the same way no matter whether their pressure is what it is or whether it is higher?

A. I believe the general statement and general belief is that for any given voltage applied to the plate of one of these tubes the pressure should be reduced to a point found best by experiment, and that that is a convenient manufacturing limit to set in the production of the device. If the voltage is changed I believe that the pressure is also changed to correspond."

You so testified?

A. I believe that is a correct transcript. I believe so, yes.

XQ. 117. That was your honest belief at the time it was given?

A. Yes, and is now.

XQ. 118. Then you were asked in rebuttal direct examination:

> "Q. 513. Considering the operation of defendant's vacuum tube, here in controversy, and the mercury vapor tubes such as shown in the Hewitt patents that have been referred to, is it the fact that ions alone are the current carriers in either of these two tubes, or that electrons alone are the current carriers, or what is the fact in that regard?–
>
> A. I believe the fact is necessarily that both ions and electrons, under the definitions which have been advanced are involved in the passage of current in both kinds of tubes. The proportion will vary from tube to tube and under varying conditions, but some current will necessarily be carried by each type of carrier, and under the entire range of conditions which we have been considering in this case.
>
> Q. 514. In Q. 38, of this direct examination Prof. Millikan testified that one of the defendant's amplifiers does not work any differently, if there is less pressure than that actually present. Please state your opinion on that point and give your reason.
>
> A. Mr. Millikan qualified his answer to Q. 38 by assuming that the pressure must be reduced sufficiently low so that the residual gases played no part in the action of the tube, and he would be probably correct if that assumption were carried out actually. As a matter of fact, however, the current must be carried in part by the ions within the tube, even at the small pressures specified by Dr. Millikan and Mr. Snook. As the pressure is reduced there will necessarily be less current carried by the gas or by the electrons, this, of course, being again effected by the voltage applied to the tube. The amount of current carried by the gas ions as compared to that carried by the electrons will change gradually with the voltage and exhaustion, just as Prof. Millikan indicated this morning, increasing as the gas pressure increases and as the

voltage across the tube increases. There is no sudden point at which one lets go and the other takes hold, so to speak."

You so testified?

A. Yes.

XQ. 119. Again Q. 518 you were asked this question:

"Q. 518. Considering Prof. Millikan's answers to Qs. 46 and 47, comment on his opinion as there given?"

And I call your attention to Prof. Millikan's answer to these questions, which were as follows:

"Q. 46. If in the normal operation of the defendant's devices the filament were made hotter by an intentional increase in the battery current heating it, would the current flow from the filament to the plate be altered?

A. No, not in general.

Q. 47. What does that signify as to whether gas or vapor takes any part in the operation of the device?

A. That also shows that you have got what we call a space charge around the filament, and the space charge is a charge which is due to one kind of carriers alone. These carriers are, in general negative electrons though if positive carriers were present alone they would produce similar effects. The reason that the increase in temperature of the filament does not increase the current is that we always heat the filament sufficiently hot so that under the conditions there is an over-supply of electrons about it anyway, many of the electrons actually emitted probably returning to the electrode because of the repulsion of those already in the neighborhood of the filament. It is from this charged space about the filament that changes in the potential of the grid cause a changing number of electrons to flow to the plate independently of the number of electrons tending to come out of the filament. Thus there is an oversupply of electrons anyway, more than is needed to produce the currents corresponding to the part of the characteristic at which the device must be operated, so that slight changes in the temperature of the filament play no role in the phenomenon.

If, however, gases are present, then the positive ions destroy that space charge and you will begin to get hot spots developing in the filament, and more rapidly with a high temperature filament than with a low temperature filament, because the bombardment of the filament by the positive ions is greater the more of them are formed."

Those two questions were the questions and answers of Prof. Millikan that you were asked to consider in Q. 518 that was asked you, and to which you answered as follows:

"A. So far as my observations of the practical devices produced by the defendant company go, Dr. Millikan's statement that increasing filament temperature would not increase the plate current under conditions of operation, is not correct. I have taken a series of measurements shown by my sketch 20, which is a graph plotted between the filament current in amperes and the plate marked in milliamperes for defendant's audion type tube 101-B, series No. 1829 which is like the Plaintiff's Exhibit 4 in this case. This shows that as the filament current is increased the plate current increases up to a filament current of 1.45 amperes, which is considerably higher than the filament current normally used, according to the data supplied by the defendant.

The operating point in relation to plate current is indicated in the diagram as 8 milliamperes, and this plate current is secured with a filament current of 1.07 amperes and the operating voltage of 130. The curve and my tests show that the normal operation of this tube was at a point where increasing the filament current, and consequently increasing the filament temperature, would increase the plate current and vice versa.

In this connection I might comment on the space charge generally and say I do not disagree with Dr. Millikan's general statements as to that. The point I wish to make is that the production of the space charge effect in one of these tubes is not sudden, but is a matter of the relative rates of electron emission from the filament and the electron consumption within the tube's circuit. The amount of space charge varies with the tube's design and the chosen points of operation.

Dr. Millikan's answer to Q. 143, I believe, limited his earlier statement by requiring gas ions to be present 'in large quantities' in order to destroy the space charge, and I think this is correct. The important fact is, as I see it, that some gas ions being present will neutralize some electrons, or vice versa, and consequently some of the space charge effect will be removed. The existence of a measurable space charge does not deny the existence of any positive ions or of any ionization, because the production of the space charge effect is gradual and it does not appear abruptly at some point where there are ions on one side and are not any on the other."

You so testified?

A. Yes, that is correct.

XQ. 120. And that is still correct?

A. Yes. Do you want my comment on it?

XQ. 121. Again you were asked Q. 525:

"Q. 525. Consider Prof. Millikan's answer to Q. 62 and state your agreement or disagreement with him?"

Prof. Millikan's question and answer 62 is as follows:

"Q. 62. Does the characteristic, no matter what it may be, whether rising or falling, and whether it is the potential current characteristic or resistance-current characteristic, have anything to do with the operation of the Telephone Company's devices as amplifiers, that is, is amplification dependent upon their having one or another characteristic?

A. No, they work on an entirely different principle."

After considering those questions your answer to Q. 525 was:

"A. Looking at the audion device from the operational and effective practical viewpoint, I must disagree with Prof. Millikan's statement. The operational characteristic shown by my sketches, Exhibits 53 and 54, show that there is a falling electromotive force with increase of current insofar as the cause and effect relations are concerned. That is an entirely proper relation of input potential and output current, Prof. Millikan's implications to the contrary notwithstanding. It is a use which has been made extensively in connection with audion work and it is the only true index of the real operation of the device. The simple plate current, plate voltage characteristic to which he refers is ample if one is considering the plate circuit alone, but that circuit alone does not show the action of the device, and all of Dr. Millikan's answers based upon it should be taken with that point in mind.

The details of the construction are different in the Defendant's devices from that shown in Patent 781,001 in some particulars, but the ultimate effects are of the same kind, and I cannot agree that 'they work on entirely different principles.'"

You so testified?

A. That is correct.

XQ. 122. That is still your testimony?

A. Yes.

XQ. 123. In the last question that I asked you with reference to Q. 518 the answer referred to sketch 20. Is the sheet that I show you, the graph that I show the sketch 20 referred to?

A. Yes, that is Plaintiff's Exhibit 52, printed at page 504a.

MR. DARBY: I would like to have this graph marked for identification.

THE COURT: Let it be marked.

(Received and marked "Defendant's Exhibit A for Identification.")

XQ. 124. You were asked Q. 540 in your direct examination in rebuttal:

> "Q. 540. Please consider Professor Millikan's answer to question 145 and state your opinion on the matter."

And the next question asked you is 541:

> "Q. 541. Answer a like question, please, with reference to Professor Millikan's testimony in answer to question 147, having in mind the subject matter of question 146."

Referring to Professor Millikan's question and answer 146 and 147, it was:

> "Q. 146. Are you familiar with the so-called audions, containing a plate, a grid and a heated filament, which DeForest put out and which have been used as detectors in wireless work?
>
> A. I am.
>
> Q. 147. How do they differ from the telephone company's devices here in controversy? My question is not directed to the uses of the devices or the circuits in which they are used, but to the devices themselves.
>
> A. They both contain a heated filament, a grid, a plate, a variable potential on the grid acting to control the flow of current between filament and plate but the telephone company's devices are much more highly evacuated than are most audions, and they must be, for the reasons which I have already indicated. In fact, they are evacuated to such a degree that the residuary gases play no part in the operation."

After considering those two questions and answers of Professor Millikan, your answer was:

> "A. In regard to the relation of defendant's vacuum tubes and the audions of DeForest, I believe that the residual gases must play some part in the operation of both and that the magnitude of the part played in either will be determined by the particular design, voltage and exhaustion used, and that there is no strict line of demarcation between them.
>
> Tubes made by the defendant's company amplify, and audion tubes made by DeForest amplify, and I do not think that you can set one of them on one side of the fence and say, 'They are audions' and the others on the other side of the fence and say 'they are defendant's vacuum tubes which are quite different things.'"

You so testified?

A. Yes.

XQ. 125. Referring to Patent No. 2, do you know whether or not the filaments of the defendant's audions are subjected to the temperature treatment specified in this patent?

A. I do not know of my own knowledge, but I understand that——

XQ. 126. If you do not know of your own knowledge—all right, go ahead, pardon me.

A. But I understand that the cleaning step is omitted in the factory and that the activation step is used. Operation of the tubes would confirm that understanding, that is to say, I think it all checks up.

XQ. 127. It is your understanding that the temperature treatment for activation is used?

A. Yes.

XQ. 128. And your testimony that you have given with respect to No. 2 is based on that understanding?

A. I think the testimony would not be affected by that understanding but of course I had it in mind.

XQ. 129. I understood you to testify, referring to page 2, and the paragraph beginning at line 42, that the step of heating the thoriated cathode to about 2900° K. for about one minute was not a necessary step in your opinion?

A. That is correct. That is what I called the cleaning step, which also results in the reduction of some thoria and thorium.

XQ. 130. Do you find anything in the patent which states that that is not a necessary step?

A. The statement beginning at line 43 that this treatment of the filament at a temperature of 2900° has no marked effect on the subsequent electron emission of the cathode when at a lower temperature, but appears to be desirable for purifying the surface of the cathode.

XQ. 131. And the next sentence reads: "The cathode is then incandesced within the range of about 2000° to 2400° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described." Is that correct?

A. Yes. You have read the patent.

XQ. 132. What are some of the alkali metals?

A. Sodium, potassium, lithium and caesium.

XQ. 133. Would you say that magnesium is an alkali metal?

A. No.

XQ. 134. Would you say that calcium, strontium and barium are alkali metals?

A. No. The four are alkali earth metals.

XQ. 135. Whenever you volatilize magnesium it inevitably forms a film on any container in which it is volatilized, does it not?

A. Well, that is a natural consequence, I think.

XQ. 136. That is a natural consequence, and the same would be true with calcium, would it not?

A. I think so. Of course, I am assuming a cold wall. If there were no cold wall, if the wall were heated, there would be no deposit.

XQ. 137. That is, if the wall were heated to a temperature higher than that necessary to volatilize the magnesium?

A. I do not know just what temperature would prevent a film from forming, but there would be a differential rate between the tendency to deposit and the tendency to evaporate, and above some temperature for some particular conditions, there would be no film formed. I just want to make it clear that my answer though stated briefly, was complete.

XQ. 138. Magnesium has an affinity for oxygen, has it not?

A. Yes, I suppose every element has to some extent. Magnesium is oxidizable, though not highly oxidizable. You can leave magnesium open to the air, for instance, in the way that you could not do, for instance, with potassium and sodium.

XQ. 139. If I vaporize magnesium in an enclosed container, even though the container was heated, would the magnesium form a film on the walls of the container when it cooled down?

A. I think so unless it is deposited in a solid mass in the bottom, or something of that kind; you have not definite enough conditions to cover all possibilities.

XQ. 140. Can you contemplate any possible condition whereby magnesium was flashed in a closed container, it would consolidate the bottom in one mass?

A. Why, suppose the bottom of the container were cool, and the walls were hot. Then the magnesium would all go to the cool spot, and you would have no coating on the wall.

XQ. 141. Your answer was based on the assumption when I said the enclosed container was hot, that I meant part of it was cold?

A. I do not remember the form of your question.

XQ. 142. But if the entire container was hot, it would not consolidate into one lump down at the bottom, would it?

A. If there were no cold place, either in the container or inside the container, there would be no tendency for the magnesium to deposit.

XQ. 143. And when the container started to cool off, it would deposit in the form of a film on the wall?

A. Wherever it cooled.

XQ. 144. Magnesium takes up water vapor, does it not, when it is volatilized?

A. Yes.

XQ. 145. And when you say you volatilize magnesium the colloquial expression is that you "flash" it; that is correct, is it not?

A. I have heard that word used.

XQ. 146. And when you flash magnesium, it takes up water vapor, it takes up oxygen, and does it take up anything else in the ordinary rarified vacuum, or rarified space within the vacuum tube?

A. Yes, I think when it is hot or vaporized, it will take up nitrogen, and I think it will also take up the oxygen compounds, such as carbon dioxide or carbon monoxide.

XQ. 147. I think you stated a minute ago—I do not want repetition, but I want to make sure that it is clear, that magnesium, calcium, strontium and barium are all——

A. Alkali earth metals.

XQ. 148. Alkali earth metals, as distinguished, I believe you said, from just alkali metals?

A. I think that is the usual chemical nomenclature.

XQ. 149. Now, taking the case where a vaporizable reagent is employed in the proposed container such as an audion tube, and it forms a deposit on the wall of the tube, in the form of a film, would not such a reagent maintain the vacuum in the tube by taking up any gases that were evolved from the walls or the electrodes within the tube?

A. It would depend upon what the reagent was. If it were an oxidizable substance, as represented by the highly oxidizable potassium, for instance, or the less easily oxidizable magnesium, then even with a cold film in the tube, it will hold oxygen molecules that strike it, or the water vapor molecules that strike it. They will go into oxides or hydroxide, and it will probably hold the oxygen compounds in that film form.

XQ. 150. What other vaporizable reagents do you know of which would do the same thing?

A. I do not know of any that would do the same thing.

XQ. 151. Calcium?

A. Oh, yes, of those families, that is in the patents. As I pointed out in connection with the fourth patent, it indicates calcium as like magnesium, and the third patent indicates sodium, I think, as of the potassium group. I think calcium and magnesium would not be different in kind, in that action.

XQ. 152. Then would you say that you did not know of any other than magnesium or potassium; you mean you do not know of any other than those in the same group with them?

A. No. I misunderstood your question a moment ago. You asked me generally as to the film, and I said the film would have to be of a kind that would hold these gases, and then you asked me what other kinds I knew, and I thought you said that would not hold those gases.

XQ. 153. Let me make it clear what other vaporizable reagents other than potassium or magnesium would maintain the vacuum when deposited in the form of a film in a container?

A. Well, I am sure they parallel——

XQ. 154. Other than magnesium and potassium?

A. Parallel magnesium, I am certain calcium would work, or a calcium-magnesium combination. I do not know of my own experience, whether strontium or barium would work, although they are in the same chemical group. I do not know how effective they would be with respect to the others. In the alkali metal group, I should expect sodium to work or a sodium-potassium combination.

XQ. 155. Would you go so far as to say that you would expect all of the metals in the same groups to work, not confining it to your knowledge, understand?

A. I do not think it would be fair to say that I would *expect* them to work, because I do not know enough about them.

XQ. 156. I say not merely using your own knowledge.

A. Yes, and I have given you what I would expect from those which I have used or those with which I have some familiarity. I might say, I know of no reason to doubt the similar action of the others.

XQ. 157. I hand you a number of patents, and I ask you to look over them, because I want to ask you some questions in connection with them. You probably are familiar with all of them. Will you please look those over?

Mr. Darby: It will probably take Mr. Hogan a minute or two. I think it is my last line of the examination; it will take him a minute to do so, if you will allow him to retire from the stand, if your Honor will allow him to examine them.

The Court: Possibly there may be some re-direct which will take a few questions. That is the simplest way perhaps, to let him examine them. Probably it would not be well to call another witness until after re-direct.

RE-DIRECT EXAMINATION.

By MR. DAVIS:

RDQ. 158. Mr. Hogan, during the cross-examination, Mr. Darby spoke to you about some questions which were asked of Professor Millikan in this suit, which Dr. Hewitt brought against the Telephone Company, and I had the impression at one point that you wished to add some statement, but he was not at that time willing that you should add it. Have you any such statement of that kind you wish to make now?

A. No, I do not remember the point except I think it had to do with the practical test of one of the Telephone Company's devices, wherein the question was whether at the operating point of filament potential or voltage, the plate current remained constant, with an increase of filament temperature, or whether the plate current increased with an increase of plate temperature. The point that comes to my mind now, the point I was going to make was to tell Mr. Darby that the operating point of that curve was below the point at which the curve became flattened off, and that both portions, that is, the sloping portion and the flat portion, were shown in the curve which he introduced as an exhibit. That operating point, as I remember it, was defined by data obtained from the Telephone Company.

RDQ. 159. So that in operating these tubes as detector, on what part of the curve do you work?

A. In operating an audion as a detector, you are not very much worried about where you work, so long as you get the maximum sensitiveness, and that may come about in several different ways, usually by incipient ionization.

RDQ. 160. Let us drop that for a moment and consider where we work with a tube of the patent in suit, the first patent, what part of the curve do you work?

A. Always on the space charge part, for the sensitive amplification and good control by the grid.

RDQ. 161. Why don't you work on the saturation part of the curve?

A. Because you have not enough electrons available to take care of the increase of current that would be necessary for amplification. The tube is not sensitive in that condition.

RDQ. 162. Suppose we have a tube which saturates at 100 volts, it is a tube of the issue; you have a voltage of 60 on the tube, plate voltage, and you change that to 70, what effect qualitatively and not quantitively, would that have on the current?

A. An increase of the plate current. There are plenty of electrons available for the increase.

RDQ. 163. But if the same tube was at 120 volts if you increase it to 130, what effect do you have on the plate current?

A. If your plate voltage is already so high that it has drawn all the electrons, of course there can be no further plate current for increase in the voltage. You have filament limitation, emission limitation.

RDQ. 164. Now, in working, the tubes as amplifiers, do you work on the saturation part of the curve?

A. No.

RDQ. 165. On what part?

A. The space charge part.

RDQ. 166. Now, in your testimony, I mean in your cross-examination, you spoke of an audion to which you applied about 70 volts plate voltage, and a low filament current, and therefore, as I understood, a low emission, and you said you could not operate or did not operate it under those conditions. Why could you not operate it as a detector or amplifier under these conditions?

A. The practical point was that it was not sensitive and of course the reason for the lack of sensitiveness was that the high voltage and low emission saturated the tube.

RDQ. 167. That is, will you just state, to be sure it is fully understood, why it is at low current a lower voltage will saturate?

A. A low filament temperature involves small emission of electrons per second. Therefore, small voltages will draw all of the electrons to the plate and saturate the tube.

RDQ. 168. We refer to the first patent in suit. I have not seen the transcript of your testimony this morning, and I may misquote you or my brother, but I will try not to, but if I do I hope to be corrected. I was under the impression, Mr. Hogan, that you were asked whether there was any action other than a detector action disclosed in the patent in suit. Did you make such a statement?

A. As I recall the particular question, Mr. Davis, it was whether the description of the old art audion at page 1, beginning about line 77, referred to the use of that old art audion as a detector—of course——

RDQ. 169. What kinds of utility are disclosed in Figures 4 and 5 of the patent in suit?

A. Detection, amplification and oscillation as the result of amplification.

RDQ. 170. In discussing your testimony on page 311, where you made a correction, in order to have all the facts before us, I would like to ask you this question: If you have a known filament, say tungsten, and know the range of temperature through which it is carried, by some change, can you or can you not predict the change in its electric resistance?

A. You can.

RDQ. 171. Now, if you did not know what the material was but found on carrying it through a certain range that it had the same range as tungsten, I judge your testimony to mean that you could identify this as tungsten. Suppose, on the other hand, you knew the material and knew the range of change of resistance, could you or could you not thereby get the temperature through which it had been carried?

A. If your material had been checked as to temperature co-efficient, that is to say, the change of resistance with temperature, and if you knew the dimensions, you should be able to calculate a change of resistance from a change in temperature or vice versa.

RDQ. 172. You were asked with reference to the suit which Dr. Hewitt brought against the Telephone & Telegraph Company. Were you familiar with the decision of the District Court in that case?

A. Am I familiar with it?

RDQ. 173. Yes.

A. Yes, that is to say, I read it some time ago.

RDQ. 174. I hand you Volume 272, Fed. Rep., opened at page 194, and ask you what that decision is?

The Court: 272 Fed. Rep., 194?

A. That is the decision in this particular case.

RDQ. 175. The decision of the lower Court?

A. Yes.

RDQ. 176. That was his Honor, Judge Mayer, was it not?

A. Yes.

RDQ. 177. And in the same volume at page 392, what do you find?

A. The decision on appeal of this same case, by the Circuit Court of Appeals for the Second Circuit.

RDQ. 178. This opinion was written by Judge Hough, was it not?

A. I believe so.

RDQ. 179. Did you see the briefs in that case?

A. I think so.

RDQ. 180. I note on page 199 Fed. Rep., Judge Mayer's decision:

"On the question as to the character of the space within defendant's bulb—i. e., whether it contains gas or vapor—the answer is that there is substantially no air, gas or vapor therein. The defendant's tubes are exhausted to such a degree that the pressure remaining in them balances a mercury column of only one one-hundred-thousandth of a millimeter, or less, which is one seventy-six-millionth part of ordinary atmospheric pressure, or about one five-millionth part of a pound."

Do you remember whether or not that statement is in accordance with the testimony given by the defendant's experts in that case?

Mr. Haight: I object to that, if your Honor please.

A. I do not remember that.

Mr. Haight: It is manifestly improper.

(Discussion.)

Mr. Davis: I will frame the question this way:

RDQ. 181. Did or did not the fact witnesses of the Telephone Company, the defendant in that case, testify that their pressure was one one-hundred-thousandth of a millimeter in the tube?

Mr. Haight: I object to that.

The Court: Is not that the same? My thought is, Mr. Davis, if that was the fact, the record is in evidence, and the best evidence, and probably the only evidence of that fact, and that this would permit a conclusion of the witness probably to be drawn from what he considered to be the evidence of these witnesses.

(Discussion.)

Mr. Davis: If your Honor please, I will now ask, in view of the nature and extent of the cross-examination, that I may be permitted to repeat to the witness the second question asked on his direct examination as to his qualifications.

THE COURT: You may do that, because in thinking the question over I think I was wrong in ruling it out even after admission on the ground that even admitting the qualification of the witness it is still pertinent to inquire how well he is qualified and not whether he is merely qualified, and on that ground I will reverse my former ruling and will permit the question to be asked.

By MR. HOWSON:

Q. 2. You may state your familiarity with the radio art in a general way?

A. I have been a student of radio continuously since I began as an amateur in 1904. For about seven months in 1906 and 1907 I was laboratory assistant to Dr. Lee DeForest, working under his immediate direction on experimental investigation and development of the Fleming valve and the audion as a radio detector and telephone amplifier, as well as on radio telephone apparatus. After leaving him in 1907, I continued experimental work in my own home laboratory and at various commercial radio stations. In 1908 I entered the Sheffield Scientific School where I studied in an electrical engineering course, and at the same time carried on experimental work in graduate research laboratories. I left Sheffield in late 1909, and proceeded to Brant Rock, Massachusetts, which was the high power experimental radio station of the National Electric Signaling Company, Professor Fessenden's company. I joined that company at that time as telegraph engineer, and I remained with that company in successive positions as telegraph superintendent, chief of operating and inspection, Chief Research Engineer, Commercial Manager, and finally as Manager, until the fall of 1921. During that time the company was reorganized, and its name changed to International Radio Telegraph Company, but the general organization and personnel remained the same. In that period I did a great deal of experimental work, as well as practical operating and testing of a wide variety of radio telegraphy and radio telephony apparatus, both transmitting and receiving, and throughout all the work, both with the Fessenden companies, and before, I investigated and used a great many forms of receivers and detectors, including vacuum valves, audions and mercury vapor devices. From 1917 to 1919 I was associated with Peter Cooper Hewitt on experimental and patent work in connection with his vacuum tube developments, and I assisted in his license litigation against the telephone company. A little later I supervised (for the International Company) the design, testing and manufacture of X-ray machines and in this way became acquainted with the problems involved in the use of the old forms of Roentgen tube as well as with the performance of the modern Coolidge X-ray tube. In the fall of 1921 I opened my own office as consulting engineer, and since then have specialized in radio. In addition to that experience record I may say that I have kept in close touch with the literature of the art as published, including the patents, and I have also made a number of inventions in radio, on which patents have been issued to me. I have become a Fellow and past president of the Institute of Radio Engineers, and served as chairman of that body's standardization committee for a number of years. I am a member of the American Institute of Electrical Engineers, and of a number of other scientific bodies, and I also have been called to Washington several times by Secretary Hoover, to serve in his Radio Advisory Conference.

In general I am familiar, by personal investigation and experiment, with the design, manufacture and use of many types of evacuated tubes in both radio and line communication and in their application to other electrical systems. I have made a number of patented inventions in the electrical arts. I have also published a book on radio entitled "The Outline of Radio," which has gone through two editions.

Mr. Haight: We do not expect to ask you every question that Mr. Darby can think of, but I prefer not to tell you at this time what we should like to ask you.

Mr. Davis: I would like to call attention to a stipulation which has been made an order of the Court by your Honor's signature, which I have read in my opening argument but which I should like to read again in order to have it in the printed record of the case.

"United States District Court
District of Delaware.

General Electric Company
v.
The DeForest Radio Company } Equity No. 589

Stipulation

It is stipulated and agreed, the Court consenting, that during the taking of defendant's proofs at the trial of this case, defendant and plaintiff will jointly offer in evidence printed volumes being the transcript of record in the Court of Appeals of the District of Columbia, January Term, 1924, Patent Appeal Docket No. 1680, Langmuir v. Arnold, appeal from the Commissioner of Patents, Interference No. 140,380, and upon such offer all testimony and other evidence and other proceedings by or for Arnold in said interference and in the Arnold patent application involved therein are to be considered as evidence duly taken and presented on behalf of defendant in this suit, and all testimony and other evidence and other proceedings by or for Langmuir in said suit and in the Langmuir patent application involved therein are to be considered as evidence duly taken and presented on behalf of plaintiff in this suit.

(Signed) WILLIAM G. MAHAFFY,
HOWSON & HOWSON,
Counsel for Plaintiff.

E. E. BERL,
SAMUEL E. DARBY, JR.,
Counsel for Defendant.

April 30, 1926.

So ordered Hugh M. Morris, U. S. Judge."

MR. HAIGHT: What is the point that you make, Mr. Davis?

MR. DAVIS: I make no point. I simply read it into the record.

THE COURT: Mr. Howson filed it.

(Discussion.)

AFTER RECESS.

MR. DAVIS: If your Honor please, during the recess we have had an opportunity to find out what these patents are which were handed to Mr. Hogan, and Mr. Hogan has various matter which he wants to look at from time to time other than these patents, and we can not quite see why he should be examined about them. They seem all to be patents taken out by Dr. Hull, one of the chemists employed at the General Electric Company, on applications filed after the filing, if I am not mistaken, of the application for the patent in suit, and perhaps it might be proper to ask my friends on the other side to indicate the reason why they think it proper to ask Mr. Hogan to read them.

The Court: Well, then, will you have Mr. Hogan take the stand? They may or may not want to put the questions to him now.

Mr. Davis: Now, Mr. Hogan.

John V. L. Hogan, resumes the stand.

Re-Cross-Examination.

By Mr. Haight:

RXQ. 182. I direct your attention to the following patents issued to the General Electric Company on the following dates. Will you hand those to him, Mr. Davis? (Patents handed.)

No. 1,387,984, August 16, 1921;
No. 1,313,187, August 12, 1919;
No. 1,313,188, August 12, 1919;
No. 1,385,873, July 26, 1921;
No. 1,291,527, January 14, 1919;
No. 1,280,769, October 18, 1918;
No. 1,313,112, August 12, 1919.

The first five on the applications of Albert W. Hull, of the General Electric Company's staff, and the latter two on the application of Dr. Langmuir and J. H. Paine, respectively, and ask you whether each of these patents does not relate to high vacuum tubes or vessels?

Mr. Davis: To which I object, as immaterial, so far as we now see it.

The Court: These patents were issued after each of the patents in suit?

Mr. Haight: Before.

The Court: Before any of the patents in suit?

Mr. Haight: Before the high vacuum patents. I do not know the dates of the others.

The Court: That is what your question is directed to, the high vacuum patent?

Mr. Haight: Yes, sir.

The Court: You are not asking him about——

Mr. Haight: As part of the prior art.

Mr. Davis: They were all applied for, if your Honor please, after the application for the first patent in suit, to which I understand this cross-examination is directed.

(Discussion.)

The Court: Well, I overrule the objection to the present preliminary question.

Mr. Haight: Can you answer that, Mr. Hogan, without examining the patents?

The Witness: What is the question now? (Question repeated by Mr. Haight.) No, I could not answer that without reading the specifications over, at least briefly. I think they do, but I have not looked at them critically.

RXQ. 183. Well, then, passing that question for the moment, I will ask you the second one: You find in each of these patents, do you not, the following references to blue glow as a test for high vacuum?

Patent No. 1,387,984, page 1, line 47:

"The envelop 1 should preferably be exhausted to such a degree of vacuum that when potentials of the magnitude desired for operation are applied to the electrodes there will be no visible manifestations of gas ionization such as blue glow."

Mr. Davis: Is that the first one?

RXQ. 184. I will just put them all in one and save a little time. Patent No. 1,313,187, page 1, line 94:

"The envelop 5 should preferably be exhausted to such a degree of vacuum that when potentials of the magnitude desired for the operation of the device are applied to the electrodes there will be no visible manifestations of gas ionization such as blue glow."

Now, Patent No. 1,313,188, page 1, line 67:

"The envelop 5 should preferably be exhausted to such a degree of vacuum that when potentials of the magnitude desired for the operation of the device are applied to the electrodes there will be no visible manifestations of gas ionization such as blue glow."

Patent No. 1,385,873, page 1, line 105:

"The receptacle 1 is preferably exhausted to such a degree that with any operating voltage which may be employed the flow of current between the electrodes is not accompanied by any visible manifestation of gas ionization such, for example, as blue glow."

Patent No. 1,291,527, page 2, line 5:

"The receptacle 1 is preferably exhausted to such a degree that with any operating voltage which may be employed, the flow of current between the electrodes is not accompanied by any visible manifestation of gas ionization, such for example, as blue glow."

Patent No. 1,280,769, page 1, line 55:

"By the term 'electron discharge device,' I mean to imply an exhausted envelop containing at least two electrodes, one of which is provided with means for causing it to emit electrons, the degree of vacuum in the envelop being such that with any voltage which may be applied to the electrodes the flow of current from the electron emitting electrode to the other electrode or electrodes will take place without any visible manifestations of gas ionization, such, for example, as blue glow."

Patent No. 1,313,112, page 2, line 10:

"The receptacle 1 is preferably exhausted to such a degree that with any operating voltage which may be employed the flow of current between the electrodes is not accompanied by any visible manifestation of gas ionization, such for example, as blue glow"——

Mr. Davis: If your Honor please, if I may omit to object to that question without by doing so binding myself to something later, I shall be glad to have the question answered if my brother wants it answered.

The Court: If you object, I shall sustain the objection. If you do not, it goes in. I shall sustain the objection if made on this ground, that I think Judge Haight, if this question were permitted, would be enabled by the way in which he put his question, to put on record certain statements made in the specification of certain patents. Now, those statements, I assume, are intended by the defendant to indicate a contradiction or a denial to a greater or lesser degree of some statement made in direct or cross-examination by Mr. Hogan.

Now, my thought with respect to that matter is that what the defendant is attempting to do is not different in this patent case, from what a like effort would be in the ordinary suit in equity, or suit in law, where the statements are involved in some documentary evidence. Our practice here, so far as I am familiar with it, would be roughly this—"that you have testified,"—so and so. I call your attenton from line A to K, 10 to 20 pages, one patent so and so, patented at a certain time to a certain person, to lines 15 to 45, page 3 of patent No. so and so, granted to a certain person, and ask you whether in view of the statements therein contained, you desire to adhere to or modify your testimony to which I have directed your attention.

Now, then, he says yes or no. Suppose he says no. Then if the document intended to lessen the weight to be given to his testimony is admissible in evidence, that would be rebuttal testimony and would not be put in here by way of cross-examination, nor would the contents of the document be spread upon the record, before the document itself is properly offered or admissible in evidence.

Mr. Haight: I had thought it did not make a great deal of difference. I rather think that in the manner of framing the question, that your Honor's method is the usual and may be the proper one; but I do not think it made a great deal of difference whether I directed the witness's attention to the specific provisions of the patent to which I referred, or whether I referred to it by letter, and so forth, and then put it in later.

The Court: Technically, what is the difference, except that you might fail to follow up in your case, when your case opens, a denial on the part of this witness, with an offer of these patents, because you have already the portions that you care about, you have them already of record; so that I am not concerned with the form except that sometimes where we do not adhere to form, it is difficult to see where the lines of substance run.

Mr. Davis: That is what we are talking of, your Honor, so that I make the objection simply because, while I have not the slightest objection to this particular statement, I do not know what they will open.

The Court: I will sustain the objection, but if the question is put along the lines I have indicated, do you object to that? Probably it is not fair to ask of Judge Haight, because I intended by that ruling to indicate——

Mr. Davis: That is to say, if your Honor please, I see no reason why Judge Haight cannot ask the witness whether the certain lines of a certain patent do not make it to him desirable that he should qualify his testimony.

Mr. Haight: There are two or three other questions I want to submit to the witness before I come to that.

The Court: I sustain the objection to the present question.

Mr. Davis: And the paragraphs read by Judge Haight are not in the record?

Mr. Haight: Do you mean physically in there?

Mr. Davis: They are not in the record as evidence that these patents contain——

Mr. Haight: I do not want them physically in there if his Honor thinks they should not be in there.

The Court: It does not make any difference. It will not appeal to me unless they are in there properly, so that you might as well strike them out if you want to.

Mr. Davis: I do not care, your Honor.

RXQ. 185. I direct your attention to Patent No. 1,387,984, page 1, lines 47 to 52 inclusive; 1,313,187, page 1, lines 94 to 100 inclusive; 1,313,188, page 1 lines 67 to 74 inclusive; 1,385,873, page 1, line 105 to line 5 on page 2, inclusive; 1,291,527, page 2, lines 5 to lines 11, inclusive; 1,280,769, page 1, lines 55 to 66 inclusive; 1,313,112, page 2, line 2, and ask you whether or not blue glow is not in the passages to which I have directed your attention referred to as a test of ionization or high vacuum as the case may be?

Mr. Davis: We make the same objection.

The Court: Sustained.

Mr. Haight: I do not know how I can put the question to him that your Honor has in mind unless I ask him that.

The Court: What I had in mind was this: You have directed his attention to certain passages. Now, will you read them. Will you tell me whether or not those passages lead you to reaffirm your previous statement as to what was said about blue glow or do you care in view of those passages to modify those passages?

Mr. Haight: I have not completed. I want to ask him another question before that, and that is whether or not he finds in the patent any other test than blue glow.

The Court: But as I see those two questions, they are putting the patents of record, that is, you would have him assert that the patents constitute a denial of his own testimony.

Mr. Haight: I am going to follow it up and ask the very question that your Honor mentioned.

The Court: If I see the thing right it is this, you have a witness on the stand who makes a certain statement in direct or cross-examination. Let us assume that you disagree with that statement and you think that these patents constitute some evidence that that statement is erroneous. If you call his attention to those patents, it seems to me the only thing you can ask him to say is whether he adheres to his prior testimony having seen those patents or whether he cares to modify it and suppose he adheres to the testimony that he has given, then the only thing it seems to me that the defendant can do is to offer those patents in evidence as some evidence, that the fact is not as asserted by the witness.

Mr. Haight: All right, I will follow that course.

The Court: Do not understand me that I will admit those patents when you offer them or that I will not admit them.

Mr. Haight: I thought your Honor would admit them.

The Court: Maybe, but I am not sure. I have not even passed on that question yet, because I think the objection made by Mr. Davis will then have to be considered.

Mr. Haight: Your Honor overrules the present question?

The Court: I overrule the question as now put, yes.

By **Mr. Haight**:

RXQ. 186. You have read, Mr. Hogan, the parts of those patents to which I have referred in the last preceding question, have you?

A. That is correct.

RXQ. 187. Will you please look at those patents and see whether or not there are any tests for the determination of high vacuum or ionization referred to in those patents other than the passages to which I have referred?

Mr. Davis: Same objection.

The Court: That is the same question.

Mr. Haight: I understand that. I want to get the record entirely clear on that.

The Court: Objection sustained.

By **Mr. Haight**:

RXQ. 188. Now, Mr. Hogan, having read those passages to which I have referred, do they in any way change the statements made by you on your direct examination to the effect that blue glow was simply a rough test of ionization?

THE COURT: Won't you have that question repeated? I think I would not understand exactly what you want there.

(The stenographer repeated the last question.)

MR. HAIGHT: That is not right, of course.

RXQ. 189. Do they lead you to change the statement made in direct examination to the effect that blue glow is simply a rough test of ionization?

MR. HOWSON: May I show him that?

MR. HAIGHT: He knows what it is.

A. There is no reason to change that statement, Judge Haight. May I say that that is not all I said about blue glow.

RXQ. 190. The record will speak on that. That is all I want. You said that there is no reason to change?

A. Yes.

RXQ. 191. Would that be your answer upon the assumption that there is nothing in any of these patents to which I have directed your attention in the way of a test for ionization other than blue glow?

A. Yes, though I think the matter should be explained more fully to have it clear.

RXQ. 192. I do not want any explanation at all. I want you to tell me whether or not your answer would be the same if upon examination of those patents you found no other reference to a test for ionization other than blue glow?

A. Yes, the answer would be the same for the surrounding circumstances.

MR. HAIGHT: That is all. May I have those patents marked for identification?

(Received and marked "Defendants' Exhibits B, C, D, E, F, G and H for Identification.")

RE-DIRECT EXAMINATION.

By **MR. DAVIS:**

RDQ. 193. Is there anything you wish to add to the statement you have already made?

MR. HAIGHT: I object to that. This witness is being cross-examined and I have asked him the question which your Honor indicated that I should ask him and it called for a yes or no answer and I think that that is as far as the witness can go.

THE COURT: I think the question as put is not a proper question.

THE COURT: I understand that you now formally and finally rest.

MR. DAVIS: We have rested. This is an aftermath.

(Witness excused.)

MR. HAIGHT: I think the time has arrived when Mr. Howson and Mr. Darby should offer the record under the stipulation.

THE COURT: Not necessarily. You may offer it at the last minute.

DEFENDANT'S PROOFS.

MR. DARBY: I would like to offer in evidence the sketch 20 referred to in the cross-examination of the witness Hogan and marked Defendant's Exhibit A for identification.

THE COURT: From the record——

MR. DARBY: It is Plaintiff's Exhibit 52 in the record of Hewitt against the American Telephone & Telegraph Company in the Southern District of New York and opposing counsel agree that I may furnish a photographic copy of this page.

(Received in evidence and marked "Defendant's Exhibit 1." *See Volume V, Defendant's Exhibits, p. 1.*)

E. LEON CHAFFEE.

E. LEON CHAFFEE, called as a witness on behalf of the defendants, having been duly sworn, testified as follows:

DIRECT EXAMINATION.

By MR. DARBY:

Q. 1. Please state your name, age, residence and occupation.

A. Name, E. Leon Chaffee; age, forty-one; residence, Cambridge, Mass.; occupation, professor of physics at Harvard University.

Q. 2. Will you please state briefly the qualifications that you possess both with respect to education and experience which qualifies you to testify as an expert in this case?

A. I took my undergraduate course at Massachusetts Institute of Technology. From that institution I received the degree of S. B. in 1907. I immediately entered the graduate school of arts and sciences of Harvard University and received in 1908 the degree of A. M. in physics and in 1911 the degree of Ph. D. in physics.

I was very soon, in one or two years, appointed on the faculty of that institution and have been there ever since, progressing to the grades of assistant professor and associate professor through professorship which I now hold.

I have for four or five years been giving a course in vacuum tubes and my experimental work during the period after receiving my doctor's degree has been largely concerned with vacuum apparatus and I have exhausted and tested during that time a large number of thermionic vacuum tubes so that I feel reasonably familiar with the evacuating processes that are used. I am a Fellow of the American Academy of Arts and Sciences, a Fellow and past vice-president of the American Institute of Radio Engineers and a member of the American Physical Society and several other minor societies. I believe that answers your question.

Q. 3. Has your vacuum tube work included work in connection with the three-electrode type of vacuum tube?

A. Almost entirely it has, yes.

Q. 4. Have you read the four patents involved in this suit as well as the file wrappers of those patents?

A. I have read them.

Q. 5. Will you in a few words state with reference to the patent No. 1, namely, No. 1,558,436, what you understand the object of the invention to be and how the objects are attained as set forth in the patent?

A. As I understand it the object of this patent No. 1 is to produce a thermionic device, a practical thermionic device which I can explain perhaps in these words. The alleged invention to my mind comprises an electron discharge tube with a little better vacuum than existed in the three-electrode devices, for instance, such as the DeForest detector tube at the time of about 1913. I think that answers your question.

Q. 6. Will you please state how the objects are attained in the patent?

A. The objects, as I understand them, are attained by evacuating the vessel to a slightly higher vacuum, as I stated in the answer to the previous question and that evacuation was accomplished by means which were fully described in the art previous to the year 1913 and which were well known at that time.

Q. 7. Did you understand the three earmarks or means of identifying a device containing the invention of this Patent No. 1?

A. I believe I do understand them.

Q. 8. And those three earmarks consist of what?

A. I may not recite these earmarks in the order in which they were previously given.

Q. 9. That is immaterial.

A. One earmark as I remember is the flat top curve which is obtained by plotting the space current vertically against the temperature horizontally. That is, I believe, spoken of as the flat-top temperature curve. If I remember correctly another earmark is the 3/2 power law and the third earmark is that the discharge shall be independent of the gas pressure. I might say that the first earmark which I stated is sometimes known as independent of the cathode temperature.

Q. 10. Have you in literature available here in court instances in the prior art which disclose discharge devices which recite one or more of those earmarks as characteristics of the device described?

A. Yes.

Q. 11. Will you please refer to the prior literature, I thought perhaps chronologically would be a more convenient way of handling the subject, and describe the disclosures in the literature and point out the pertinency thereof with respect to the issues here involved.

A. I would like to say for the benefit of your Honor that I have collected a list of references which are pertinent to the present case. Most of the references do have to do with the production of high vacuum. Your Honor will notice that as I describe these various references the methods of obtaining high vacuum may be broadly divided into two. We have methods of obtaining high vacua by purely physical means such as pumping and baking the walls and then we have methods which depend upon chemical action, which we term the chemical methods.

I will endeavor as I go through these references to point out the most salient points. I would like to begin with a reference to an article published in *Nature* by a correspondent of that magazine who reports on a lecture given by Sir James Dewar.

Q. 12. Will you give the date of that publication?

A. Yes, I was just looking for it. The date of the publication is July 15, 1875, and the title of the article is "Charcoal Vacua." I refer to this because this is one of the first references to the possibility of obtaining high vacua by the application of liquid air to cooling charcoal contained in the vessel to be evacuated or in a vessel which is connected to the vessel to be evacuated.

Q. 13. May I interrupt there, Professor Chaffee?

A. Yes.

Q. 14. How does this method of obtaining vacua by employing charcoal and liquid air compare with the methods known today, the later methods, as to the degree of vacua obtainable?

A. I was coming to that but will state at this point that the degree of vacua which is obtainable by this method is, I believe, as great as is obtainable by the modern methods in use today. To that point I will refer in just a moment.

In order to indicate the degree of vacuum which Dewar obtained in his experiments, he made use of a discharge tube, an ordinary two-electrode discharge tube of the type called Geissler tubes sometimes used in lecture demonstrations, and upon this tube he impressed a very high voltage and observed that no discharge took place through the tube.

I will quote from this article:

> "Two wires, one-quarter inch apart in one of Tait and Dewar's exhaustion tubes would not allow a spark to pass although a powerful coil was employed."

From what I have gained from experience and knowledge, that indicates certainly that there is a pretty good vacuum in the device.

In this connection I would like to refer to an article by Scheel and Heuse. This article does not chronologically follow but is pertinent at this point. The title of the article is "Tests of the methods used for producing high vacua," in the *Physikalische Zeitschrift*, Volume 29, pages 46 to 50, 1909. This article describes tests which were conducted in the Reichanstalt in Germany to determine the degree of vacuum procurable by various methods of exhaust, and among those that are listed I find this statement:

> "Charcoal and liquid air" gives a vacuum of .000007 millimeters of mercury.

I might add at this point that there are various methods of specifying or measuring the pressure in an evacuated chamber. In order to avoid confusion I will translate all of the numerical measures of vacuum into microns of mercury. I believe your Honor is familiar with that unit. So in this case the pressure attainable as stated by Scheel and Heuse by the use of charcoal cooled by liquid air is 7/1000 of a micron.

The next article to which I will refer is one by Bessel Hagen.

Q. 15. Pardon the interruption, but I think that Scheel and Heuse article was taken out of chronological order and you failed to state the date.

A. I beg your pardon.

Q. 16. Will you please state the date?

Mr. Edmonds: 1909, he said. I made a note of it.

Q. 17. Then never mind the interruption. You may continue.

A. The article of Bessel Hagen is entitled "On a New Form of the Toepler Mercury Pump and Some Experiments Performed with It," in the *Annalen Der Physik*, Volume 12, pages 435 and 440 of 1881. This article is a description of an improved mercury pump and is of interest in showing or pointing out the degree of vacuum which was obtainable at this date, 1881, by the use of a mercury pump.

The author of the article explains or states the vacuum obtainable by the other methods of mercury pumps and then states that his own improved Toepler pump was capable of producing a vacuum 8/1000 of a micron.

It is important, too, to notice that Bessel Hagen appreciates the importance of thoroughly heating the walls of the vessel to be evacuated and in fact all glass work, including the portions of the pump, to a high temperature in order to remove the air film which adheres to the inside of the glass and also to bake out the water vapor.

For example, he speaks of heating to 300 degrees Centigrade for twenty-four hours. He also speaks of the use of an electric discharge in order to help remove the gases from the walls. I consider this important because here we have a reference to the necessity of removing water vapor and occluded gases.

The author refers to the fact that mercury vapor is of course present if no means is used to eliminate the mercury vapor, because mercury vapor has a considerable vapor pressure at foom temperature; but in a foot-note, he calls attention to the suggestion of Crookes that mercury vapor may be partially eliminated by some absorbing substance.

The next reference is to a patent by Edison, No. 411,019. The date of application of this patent is July 29, 1886, and concerns the manufacture of incandescent electric lamps. I quote from the patent:

> "The object of my invention is to produce high vacuums in the inclosing-globes of incandescing electric lamps, and especially to rid such globes of the watery vapor which adheres to the inner surface of the glass."

The scheme used by Edison is to impose in a small chamber connected to the incandescent lamp, a quantity of phosphorus pentoxide or iron.

This is heated, the purpose being to remove the water vapor and the oxygen, and then the incandescent lamp is pumped, while the walls are being heated to a temperature of from 600 to 800° F. which translated into Centigrade is from 315 to 426° C.

This patent shows that Edison appreciated the necessity of removing water vapor from the inside of the glass walls which he accomplished by heating, and of the necessity of removing oxygen.

The next reference is to a patent by Malignani, applied for August 15, 1894:

> "The process of evacuating incandescent lamps."

I quote from the patent:

> "The present invention consists of a process for evacuating incandescent lamps and bulbs."

Malignani introduces small quantities of arsenic or iodine into the small tube used for evacuating the lamp, and after pumping by the usual evacuating pumps, the small tube is heated to vaporize the substance, that is, put into the tube, and also the filament is heated. The idea is to effect a chemical combination between the vapors of the reagent that is put in and the oxidizing constituents of the air, in order to more effectually improve the vacuum. The vapors form solid precipitates which are deposited on the inside of the glass. This is one of the first references which refers to the chemical method of obtaining high vacua, and he specifically states that by this means a high vacua can be obtained in a very short time.

The next patent to which I will refer is one to E. F. Dwyer, filed October 26, 1897. The title of the patent is: "Process of Producing High Vacuums," Patent No. 596,654.

The fundamental idea or the basis of this patent is, as I understand it, to introduce a vaporizing reagent or vaporizable reagent into the bulb instead of putting it into the pumping tube. The vaporizable reagent, as for example, phosphorus, is mixed up with the hydrocarbon paste which is used to join the filament to the lead-in wires. A certain small definite quantity is introduced in this way. The process of evacuation consists in first pumping, then heating the filament to drive the gases which occur in the filament. Then further pumping, and finally heating the filament to a high temperature which vaporizes the reagent, phosphorus, for instance, and causes a high vacuum because of the combination of the vaporizable reagent and the gases in the tube.

Q. 18. Before you pass on to the next patent, Doctor, will you explain what is meant by the statement beginning at line 67, page 1, of the Dwyer patent?

Mr. Davis: And if I may interrupt, I suppose it is understood that these various citations which are not pleaded in the answer, are introduced merely to show the state of the art?

Mr. Darby: I think that is correct. I think that the answer supplemented by the bill of particulars, however, incorporates everything that this witness is referring to.

Mr. Davis: I want to make sure about the status of the bill of particulars. That is all. Have you it in the answer?

Mr. Darby: In our bill of particulars we set forth these references, either as showing complete anticipation or as showing the state of the art, and they can be used as such at the trial. That is my understanding.

Mr. Davis: My understanding is that all the alleged references mentioned in either the answer or the bill of particulars may be taken as pleaded references, and that others are introduced only to show the state of the art, and we need not call attention to them as they come up one at a time.

Mr. Darby: Yes, sir, that is the purpose.

By Mr. Darby:

Q. 18a. Did you find the place, Doctor?

A. Yes, did you say line 67?

Q. 19. Line 67, page 1.

A. Quoting from the patent:

"For example, ammonia-gas has been introduced and absorbed by phosphoric anhydrid, or solids—such as mercury-vapor, the vapor of sodium, potassium, iodin, etc., have been introduced, the pumping continued, and the residue allowed to condense in a cooled auxiliary vessel connected to the lamp during exhaustion."

Q. 20. My primary inquiry is what function does the mercury vapor, the vapor of sodium, potassium and iodine, and so forth, play?

A. This part of the specification to which you have called my attention refers to the prior art, and shows what has been done, and as I understand it, the introduction of these various substances such as vapors of sodium, potassium and iodine; which are vaporizable reagents, to use the term that has been used, are introduced for the purpose of absorbing or combining with oxygen and water vapor that exists in the gases. We have in the patents of Malignani and Dwyer, examples of the chemical method of obtaining a vacuum——

THE COURT: Are you passing to another reference, Doctor?

THE WITNESS: Yes.

THE COURT: Recess for five minutes.

(After a short recess):

THE WITNESS: The next article to which I will refer is one by Duncan. The title is: "Crookes Tubes and Experiments with Roetgen Rays," in the *American Electrician*, Volume 8, of May, 1896. This article describes methods of evacuating Crookes tubes. I find in that article reference to several necessary precautions in order to obtain high vacuum. For instance, he speaks of its being necessary to dry the apparatus completely. He speaks of the necessity of heating the walls to rid the walls of occluded gas. I believe I may quote in that connection:

"If an incandescent lamp be exhausted until no air can be seen escaping through the valves of the pump, and the filament then incandesced, considerable quantities of air will be expelled at each operation of the pump, thereby showing that this air has been occluded in the pores of the carbon filament, and could not have been gotten rid of without heating the filament and driving the air out into the vacuous space surrounding it."

This has to do with denuding the filament of its occluded gases by heating the filament. I will quote further down:

> "If the electrodes are made from aluminium or other porous metal, the secondary terminals from a spark coil can be applied to them, and set in operation in a similar manner to that in which the tube is to be used afterwards. This can not help but be a ready and satisfactory means of eliminating the air occluded within the electrodes."

This shows very clearly that Duncan appreciated the fact that large quantities of gas were occluded in the metal electrodes and that it was necessary to remove this gas from the electrodes in order to obtain a high vacuum. He also speaks of the presence of mercury vapor and refers to Crookes suggestion that mercury vapor can be removed by the use of chemical absorbing substances.

In short, this article very clearly describes the necessary precautions which must be taken to obtain a high vacuum, as for instance, heating the filament, if there be a filament, bombarding the electrodes, heating the walls of the tube, and absorbing mercury vapor. There is one additional point that I forgot to speak about. He describes the use of the phosphorus pentoxide tube connected between the pump and the vessel being exhausted. This phosphorus pentoxide tube is for the purpose of absorbing water vapor, because phosphorus pentoxide has a great affinity for water.

Passing on to the next reference——

THE COURT: What was the last reference?

A. Duncan in 1896. Passing on to the next reference which is to an article by Dewar, the title of the article is: "Application of Liquid Hydrogen to the Production of High Vacua, together with their Spectroscopic Examination," in the proceedings of the

Royal Society A, Volume 64, 1898. This is of interest in showing the enormous absorbing power of charcoal cooled with liquid hydrogen in this case. Dewar started in his experiments with tubes containing gas at atmospheric pressure and on plunging a portion of the vessel to be evacuated into liquid hydrogen, he was able to reduce the pressure from practically atmospheric pressure, down to a pressure of approximately six-thousandths of a micron. He tested the degree of vacuum which he attained by the spark method, and stated that he had to heat the tubes in order to cause a spark discharge to pass through the evacuated chamber. That would indicate certainly a high vacuum.

The next reference is to Lenard and an article called: "The Production of Cathode Rays by Ultra-Violet Light," which was published in the *Annalen Der Physik*, Volume 2, 1900.

Lenard performed some experiments with photo-electrons. I do not know whether your Honor understands that term. If a metal plate is illuminated by light there are ejected from that plate electrons which are exactly the same as those coming from a heated filament, but they are produced by light rather than being produced by heat. May I quote from Lenard's article as follows:

> "When many phenomena are superposed on one another, one must endeavor to isolate a particular one. I endeavored, therefore to study the phenomena when the air was excluded, whereby it was above all to be decided whether with the passage to the most extreme vacuum a reversal did not occur with the final cessation of the action, as is really the case with other discharge phenomena."

The importance of that passage is that in his study of photo-electricity he was desirous of entirely excluding the disturbing action of gases and therefore his aim was to obtain the highest degree of vacuum possible.

He goes on to describe his method of obtaining this high degree of vacuum and he says:

> "By prolonged heating and the discharge of a large inductorium we bring the tube into the steady condition in which it no longer passes the discharge through, the discharge passing outside around the tube."

Again we have here the spark method of indicating the degree of vacuum and again we have a reference to the necessity of thoroughly heating the tube in order to drive off the occluded air from the inside of the walls of the tube.

Another quotation:

> "It may also be remarked here that cooling with solid carbon dioxide and ether of the vessel containing phosphorous-pentoxide located between tube and pump did not affect the quantities of escaping electricity to be measured."

In order to exclude the mercury vapor and also to absorb water vapor, Lenard has used the expedient of phosphorus-pentoxide tube located between the tube being exhausted and the pump and cooling the tube by solid carbon dioxide and ether. Solid carbon dioxide has a very low temperature, not so low as liquid air. The ether is for the purpose of obtaining a close contact between the solid carbon dioxide and the tube, so that it may be readily cooled. There is no question but that this would eliminate any effects due to mercury vapor. His conclusion was that he obtained photoelectrons in the most extreme vacuum.

To summarize this article then we have described clearly the necessary precautions to obtain a high degree of vacuum, including baking the walls and removing the water vapor and removing the mercury vapor, and also of bombarding the electrodes in order to remove the occluded gases in the electrodes.

The next article to which I will refer is by Doane. This article is entitled: "A Résumé of Incandescent Electric Lamp Exhausting," published in the *Electrical World and Engineer*, Volume 3, May 21, 1904.

This article summarizes the various methods that have been used for exhausting incandescent lamps, and I would like to quote a passage from this article:

> "The completed lamp must not only be free from gases and vapors, but must also have had those parts capable of giving off gases and vapors, thoroughly freed from them. The only way we knew to accomplish this was to highly heat everything we wished to free from gas. We had three things to heat; the glass, the filaments and the joints between filaments and leading-in wires."

This indicates the appreciation of the necessity of thoroughly denuding the walls of the tube and removing the occluded gases in all portions of the apparatus or the lamp in this case which is being exhausted.

He then goes on to describe the blue glow which is utilized in exhausting incandescent lamps in order to improve the vacuum. At a certain stage in the pumping process, the filament is heated to a high temperature and because of the difference of potential between the two legs of the filament, a discharge is caused to pass through the gas in the space.

This discharge is evidenced by blue glow and helps materially to improve the vacuum and also helps to heat the little joints that exist between the filament and the leading-in wires.

Q. 21. Can you tell us in just a few words how the blue glow, which I understand from your last answer extends between the two legs of the filament, helps in increasing the vacuum?

A. In heating the filament a voltage is impressed across the terminals of the filament in the neighborhood of 100 or 200 volts, if it be a 200-volt lamp. There exists then between the two lead-in wires this potential difference of one or two hundred volts. Of course, the filament connects those two points inside the lamp, but that does not alter the fact that there is a difference of potential between those two points and we might consider then those two points as two terminals in a discharge tube, one of which is heated—of course, both are heated in this case.

The negative terminal is heated and will and does give off electrons the same as any heated filament emits electrons in a thermionic device. The other leg of the filament, which in this case is the positive terminal, attracts the electrons from the negative end of the filament over to the positive end. Of course, this attraction will also spread down the filament or will exist between portions of the filament remote perhaps from these lead-in terminals, but the difference of potential will of course gradually decrease as you progress up the filament.

If there is sufficient gas in the space these electrons will ionize the gas because the voltage is well above the ionizing voltage. It has long been known that the existence of this blue glow improves the vacuum, probably by bombarding the walls with gas ions and consequently causing them to stick to the glass walls. It is known and will be referred to in some subsequent articles. Does that answer your question?

I believe I have not finished with the reference to Doane's article. Doane also describes the chemical method of obtaining a vacuum and refers to the methods which we have already described of the use of vaporizable reagents such as phosphorus and the like.

I would like to add a few words concerning this blue glow. The manufacturers of incandescent lamps utilize the disappearance of the blue glow as an indication that the vacuum is high.

The next article or rather reference is to the patent to Von Recklinghausen, No. 946,068, date of application July 30, 1904. The patent relates to the evacuation of tubes and the title of the patent "Means for Exhausting Inclosed Receivers."

He says:

> "My invention contemplates the use of magnesium or other metal for absorbing air or other purposes and the safeguarding of the same from the chances of doing injury, either by so mounting the magnesium or other metal in a glass container as to prevent its coming in contact when in a heated state with the material of the container," and so forth.

This is an interesting case because it suggests the use of magnesium as a material for improving the vacuum or as he states for absorbing the air. I will read the first claim:

> "The combination with a closed container, of a holder within the container, magnesium within the holder, and a source of electric current connected with the opposite ends of the magnesium whereby the same may be rendered active for absorbing injurious gases in the container."

Although this patent is directed mostly to the absorbing of injurious gases in mercury devices, it is not necessarily restricted to that use as I understand it.

Magnesium, I believe, has been classed as an alkaline earth metal. It has a high vaporizing temperature, and so it was necessary to devise some scheme of igniting or vaporizing the magnesium by passing in this case an electric current through the piece of magnesium. It was supposed that there would be some deleterious reaction between the magnesium and the glass containing envelope, and so he states that

> "When it is desired to employ magnesium in order to secure a very high degree of exhaustion and without any danger of injury to the container, the latter may be made entirely of some metal or association of metals such as will not be attacked by magnesium in its active state."

Q. 22. Before you pass on to the next patent, Doctor, is your understanding of this Von Recklinghausen patent that the magnesium was used as an alternative to pumping or in addition to pumping to secure exhaustion. I call your attention to line 9, page 1, of the patent.

A. My understanding is that the use of magnesium was in addition to the pumping process. I may quote those lines:

> "It has been found advantageous in exhausting containers of mercury vapor apparatus, . . . to make use of magnesium for absorbing some of the gases which remain after a certain degree of exhaustion by pumping has been attained."

The next reference is to a patent to Merritt, 909,811, date for application, January 27, 1905, "A Process of Exhausting Lamps." To quote from the specifications:

> "My invention relates to the manufacture of incandescent lamps, and consists more particularly in a new process of employing a chemical assistant in the exhaustion of the bulb."

Merritt's scheme as described in this patent is to introduce into the bulb, as shown right here, on the inside surface of the glass a small bit of phosphorus or some other reagent to assist in the evacuating process. During the exhausting process the bulb is heated as usual to drive off the occluded gases and the filament is lighted to drive off the gases occluded in the filament and later in the process the bulb is sufficiently heated to vaporize the reagent which has been placed on the inside surface of the bulb and the chemical action takes place. During that action the blue glow appears and the lamp is exhausted when the blue glow disappears. It is the same process that is used by others.

The next reference is to an article by Fleming. The title is "On the Conversion of Electric Oscillation into Continuous Currents by Means of a Vacuum Valve," published in the proceedings of the Royal Society, Volume 74, January 24, 1905.

There was an earlier article by Fleming in which he described the unilateral conductivity of two carbon filaments sealed within an exhaust chamber one of which was heated. In this article he describes the use of those devices for detecting high-frequency signals or for use in radio telegraphy. It was not a perfectly clear step to assume that the rectifying property that he recognized in his device in the earlier article, which rectified low-frequency currents, would necessarily rectify high-frequency currents such as used in radio telegraphy. This article is an announcement of the discovery that the device worked to rectify high-frequency oscillations as well as low-frequency oscillations.

He draws the conclusion stated in these words:

> "An ideal and perfect rectifier for electric oscillations may, therefore, be found by enclosing a hot carbon filament and a perfectly cold metal anode in a very perfect vacuum."

It seems to me this indicates that Fleming understood the process of rectification and thoroughly appreciated the desirability of removing all of the disturbing effects of gas in the tube.

He speaks in the article of the necessity of freeing the plate, if a plate be used in the device, from occluded gases. Perhaps I have not made perfectly clear the device that Fleming used. His device consisted either of two carbon filaments enclosed in an evacuated chamber, one of which may be lighted, or of a filament and a cold plate. So as I stated, if a plate is used he described the necessity of removing the occluded gases from the plate.

I refer now to Fleming's United States Patent No. 803,684, called "An Instrument for Converting Alternating Electric Currents into Continuous Currents." The date of the application is April 19, 1905. This patent describes the same device that was described in the previous reference and he states:

> "As a very high vacuum should be obtained in the bulb (a) and as a considerable quantity of air is occluded in the conductors, these should be heated when the bulb is being exhausted."

He goes on to explain that the filament can be heated, and if a plate is used, it can be heated by surrounding the bulb with a heating coil to increase its temperature.

There is another article by Fleming, "On the Electric Conductivity of a Vacuum," published in the *Scientific American*, Supplement, No. 1568 of January 20, 1906. In this article he again describes his two-electrode device, consisting of two carbon filaments sealed in an evacuated chamber.

In a previous article referred to by Fleming, he stated that a very perfect vacuum should be attained. In order to show that Fleming understood what is meant by high vacuum, he refers in this article to the work of Sir James Dewar to which we have referred. Then he says:

> "Let us assume that we make a high vacuum of one hundred-millionth of an atmosphere"—(This is a pressure of about seven-thousandths of a micron) and then he supposes that a voltage of one-hundred thousand volts be placed across the terminals of his tube, and states in that case:
>
> "Not the slightest measureable current would pass."

But then if one terminal be heated and connected to a source of potential making that heated terminal negative that a current would pass, showing that the evacuated space is a good conductor of electricity in one direction, and not in the other, he then goes on to say:

> "Imagine a bulb of glass, made as in Fig. 1, containing two loops of platinum wire, or better still, two carbon filaments. Let this bulb be exhausted as completely as possible, so that in it the highest attainable vacuum is made. To achieve this, the filaments must be heated to bright incandescence while the exhaustion is going on. Having done this, if the secondary terminals of an induction coil are connected to the two separate filaments when cold, no discharge will take place across the vacuum between them; thus apparently showing that the space is a very perfect non-conductor."

I read these excerpts in order to show that Fleming appreciated the degree of vacuum necessary in a device of this type, and he goes on to say:

> "Let us define these conditions more closely. The vacuum is said to be low when the original normal air pressure in it is reduced to one-thousandths of an atmosphere, or it may be only to one three-hundredths. It is said to be high when it is reduced to one hundred-millionth of an atmosphere."

Again, he specifies a pressure of about seven-thousandths of a micron.

I believe it is perfectly clear from this reference to Fleming that he knew what he was talking about when he was talking about vacua and that he knew that in order to get unilateral conductivity to the highest degree, that it was necessary to entirely exclude gas. I should modify this statement, because it is impossible to entirely exclude gas, but to reduce the effect of gas to a minimum.

The next reference is to——

By **Mr. Darby**:

Q. 23. Before you go to the next reference, Doctor, what could you say as to Fleming's knowledge as to how to get that vacuum from the articles?

Mr. Davis: Just a minute, please. Read that question. (Question repeated as recorded.)

I suppose my brother means merely what directions there are in the article as showing how to produce vacuum?

Mr. Darby: That is all.

Mr. Davis: If that is all the question——

A. Fleming refers to Dewar's work, showing that he had a knowledge of Dewar's methods of obtaining high vacuum. He also speaks of the necessity of heating the filaments and driving off the occluded gases from the elements and from the walls of the tube. I should say that Fleming knew how to produce high vacuum.

Mr. Davis: There I object, if your Honor please, and move to strike it out.

The Court: Objection sustained. That last statement is stricken out. It is in that reference?

The Witness: Yes.

The Court: Unless there is some special desire to go on, I think we will adjourn now until tomorrow, 10 o'clock tomorrow.

(Whereupon, at 4.50 P. M. adjournment was taken until Tuesday, October 19th, 1926, 10 o'clock A. M.)

U. S. District Court,
Wilmington, Delaware,
Tuesday, 19th October, 1926,
at 10 o'clock A. M.

FOURTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Howson: Will your Honor permit me to offer a word of explanation about that finding you named on the face of the copy of the stipulation which Mr. Davis read to your Honor?

The Court: That does not need any explanation.

Mr. Howson: I would like to explain just this much, if your Honor will permit me, that some time after the stipulation had been signed by counsel, a month or so after, we sent down to our associate, Mr. W. G. Mahaffy, to have it entered and presented to your Honor and we got word that it had been so entered. Your Honor will have noticed, perhaps, that in the New York fashion, we have so marked it, and our associate told us it had been entered. I thereupon wrote in pencil on the copy in my file, with the endorsement, and when I came down to the trial I asked my clerk to supply me with the copies of the stipulation, and she took what was in the file.

The Court: The explanation is fairly obvious, and that is one of the reasons I said it needed no explanation, because I realize full well how it happened.

Mr. Howson: I am very sorry for the mistake.

E. LEON CHAFFEE, resumes the stand as a witness on behalf of the defendant.

DIRECT EXAMINATION (Continued).

By MR. DARBY:

Q. 24. I think that you had gotten as far in your consideration of the prior art publications as the Fleming *Scientific American* article of 1906. Had you finished with the Fleming article?

A. I had.

Q. 25. Will you proceed from that point?

A. We will refer now to a patent to Soddy. Patent No. 859,021: "On Means and Apparatus for Producing High Vacuums." The date of the application is July 13, 1906. Now, quoting from the patent:

> "The object of this invention is to obtain a high vacuum in a rapid and economical manner without the use of the mercury pump, but of a degree of rarefaction fully equal to that which can be produced by the mercury pump under the most favorable conditions."

That states his object, but for our purpose the omission of the mercury pump is of no consequence. I quote again:

> "In the production of high vacua not only has the air to be removed, but also the gases occluded or condensed on the walls of the vessel being exhausted and on the contained electrodes or filaments or other contents of the said vessel, which condensed gases are given up slowly after exhaustion and if not removed during the exhaustion cause the vacuum to deteriorate."

Again here is a clear statement of the necessity of getting rid of all of the gases occluded on the walls, and also in the electrodes or metal parts contained in the tubes to be exhausted. Then he states that he has discovered that certain reagents are capable of enormously improving the vacuum by absorbing the residual gases.

And he states:

> "One of the reagents I may employ is the metal calcium. I have discovered that the metal calcium under suitable conditions absorbs rapidly and completely nearly all gases, including not only oxygen and nitrogen, the two chief constituents of atmospheric air, but also hydrogen, carbondioxid, carbonmonoxid, water vapor, acetylene, ammonia, sulphurdioxid, and even such a complex mixture as coal gas."

Further down I will quote these words:

> "The metal calcium instead of being used alone may if desired be used in the form of alloys with other metal or metals, for example with magnesium."

Then he goes on to state that the metal strontium may be used as well.

Another quotation:

> "The heating and expelling of the condensed and occluded gases may be effected in any usual, or suitable, manner of expelling condensed and occluded gases from the walls and contents of vessels being exhausted. The usual manner of effecting such an operation is to heat the vessel while it and its contents are subjected to the same treatment as they are subjected to in after use. In incandescent electric lamps for example an electric current is passed through the filament, and in X-ray bulbs an electric discharge is passed between the electrodes during the continuation of the exhaustion."

He appreciates the fact that calcium does not remove the inert gases such as argon, a constituent of the atmosphere, and points out that this difficulty may be overcome by either washing out the apparatus with some gas that is absorbed by calcium or he states that if evacuation be continued by the ordinary pumps and then the metal parts of the tube and the walls of the tube be heated, the gases that are evolved from these metal parts and from the walls of the tube are those gases which are readily absorbed by calcium.

Then one other quotation:

> "The upper and large part"—speaking of the chamber in which he places the calcium which is to be heated—"is employed when a reagent such as metal calcium is used which gives off a vapor which it is desirable to condense this enlarged part constituting a surface upon which the vaporized reagent will deposit."

I would like to read the first claim:

> "A process of producing high vacuum which consists in bringing a heated alkaline earth metal capable of absorbing gas into the presence of a rarefied atmosphere whereby the remaining gases are absorbed."

Soddy in this patent outlines one of the chemical methods of obtaining high vacuum pointing out the necessity of heating the vessel and the electrodes and then saying that the vaporized calcium or magnesium is capable of absorbing the residual gases.

The next reference is to an article also by Soddy entitled, "The Wehnelt Kathode in High Vacuum," published in *Nature,* Volume 77, November 21, 1907. This paper was also published in the *Physikalische Zeitschrift.* This article describes an experiment which Soddy performed in which he used a Wehnelt cathode enclosed in a bulb and observed the current passing through the bulb as a result of impressing a voltage upon the tube and heating the Wehnelt cathode and comments upon the fact that the currents dropped to a very, very small, or immeasurable value, at least, when he employed metallic calcium to clean up the vacuum. In fact, he states that it is his conclusion that the current actually stops.

However that may be the article is of interest I think in the application of the use of calcium to obtain the high vacuum, and I quote from the article these words:

> "In a tube provided with a Wehnelt kathode of about a sq. cn. area was mounted an anode of the metal calcium. I have recently shown (pro. of Royal Soc., 1907, 78A, 429) that calcium at its volatilizing temperature (700° C. to 800° C.) absorbs practically instantaneously and very perfectly all known gases and vapors except the chemically inert gases of the argon family, and have described a form of vacuum furnace suitable for this operation."

Then describing the experiment that he performed, he says: "Quite suddenly and completely the current through the tube stopped, and at the same moment a copious mirror of calcium was volatilized from the anode." The calcium which was vaporized deposited on the inside of the tube in the form of a film.

Several investigators answered Soddy's experiment, explaining the reason that the current dropped or apparently stopped and I want to refer to one of those replies, a reply by Lilienfeld which was published in the *Physikalische Zeitschrift*, Volume 9, 1908. The title of the reply is: "A remark to the article of Fred. Soddy."

The particular thing I would like to point out here is the explanation given by Dr. Lilienfeld for the change in current observed by Soddy. Dr. Lilienfeld says:

> "I pointed out more specifically in my second paper"—referring back to an article of Lilienfeld—"this view, that in consequence of the absence of the last traces of gas the number (volume density) of the negative electrons supplying the current becomes great in comparison with the number of gas molecules per unit volume, so that therefore the tendency exists for the formation of the greatest possible negative space charge in the path of the current which opposes the current transport by the negative electrons."

This is an extremely clear statement, in fact it is as clear as we might give today, of the space charge phenomena.

I would like to refer very briefly to an article by Hogg, published in the *Proceedings of the American Academy of Arts and Sciences*, Volume 45, August, 1909. The title is "Friction in Gases at Low Pressures."

This particular experiment was performed at the physical laboratory at Harvard College, so that I remember the arrangement of the apparatus.

The point of interest is the degree of vacuum which he was able to obtain at that time. He heated the apparatus to get rid of the water vapor and he goes through elaborate precaution to eliminate mercury vapor, washes out his apparatus with dry gas and measures his vacuum by a McLeod gauge and states:

> "It may be of interest to state that, at the stage of exhaustion when mew equals. 000022 was obtained, the McLeod gauge indicated a pressure certainly less than 0.000001 m.m."

which is one-thousandth of a micron.

We need not concern ourselves with the purpose of the research, but I will state that he was investigating the frictional retarding force exerted on a swinging disc or a disc which was supported by a fiber and was made to oscillate in the evacuated chamber and by determining the number of oscillations it made in dying down, he was able to deduce the friction produced by the gases. I refer now to an article by Hupka entitled "A Contribution to the Knowledge of the Inertia of Moving Electrons,"[4] published in the *Annalen Der Physik*, Volume 31, 1909. Hupka's experiment concerned photo-electrons, which I believe I explained to your Honor yesterday. The points of interest to us I can explain by quoting as follows:

> "I have also made experiments with the process of calcium vaporization suggested by Soddy. In one case the calcium rod connected in the circuit by a loose contact was vaporized by direct short-circuiting and formation of an arc."

Another time he says of calcium:

> "The size of peas, were put into a porcelain tube cemented to the vessel to be evacuated and closed at the end. This was carefully heated to a red heat by the flame of a blower."

The degree of vacua obtained in this manner were not inconsiderable, and so forth; merely a reference to the power of calcium to improve the vacuum; but he does not use that method in his final experiment, but resorts to the charcoal and liquid air method of obtaining high vacuum.

I quote another passage:

> "Vacua made in this way stood up under about 90,000 volts without a discharge taking place of itself. Under these conditions effects are observed which are very remarkable. In spite of a discharge potential which in air at atmospheric pressure corresponds to a gap of 8 cm. between 5 cm. balls, the eye does not perceive the slightest light inside the tube."

This again refers to the spark method of determining roughly the degree of vacuum. He impressed a voltage of 90,000 volts on his discharge tube, and saw no traces of the discharge through the tube. Again, later on in his article, he makes this statement:

> "but a few sparks produced in a high vacuum by very high voltages remove sufficient of the gas from the electrodes."

This is not a particularly important excerpt but states that by bombarding the electrodes, I presume he was able to get rid of some of the gas from the electrodes.

I will now refer to an article by Von Baeyer concerning slow cathode rays, *Phys. Zeit.*, Vol. 10 of 1909. The title indicates that Von Baeyer was interested in slow cathode rays, cathode rays being another name for the electrons from a hot filament, although not necessarily from a hot filament but the beam of electrons which one observes in high vacuum discharge tubes. He used as a source of electrons, a heated filament. He is really continuing the work of Lenard, to which I referred yesterday, except that Lenard utilized photo-electrons instead of electrons from a heated wire, and Von Baeyer states in his article:

> "These experiments were of course carried out in the highest possible vacuum to avoid the influence of ionization. For the evacuation a Kaufman pump was employed and, furthermore, to remove mercury and fat vapors a U-shaped part of the connection to the discharge tube was cooled with liquid air."

Von Baeyer was interested to see or to determine how much gaseous ionization he obtained. Of course, he was desirous of getting rid of gaseous ionization and he utilized what has been termed the third electrode method. I believe Mr. Hogan referred to this method, and Mr. Davis spoke of it as "counting the ions." It is one method of determining how much gaseous ionization exists. I will quote further:

> "When the vacuum was raised as high as possible by the application of charcoal cooled with liquid air a condition was easily obtained where the ionization with not too high velocities became no longer measurable by the methods here given."

Indicating that by the application of the third electrode method, he was not able to detect ionization. Further down he states:

> "That ionization in the space between reflector and wire screen did not here occur could be easily established by the fact that with a negative charge of 40 volts on the reflector with respect to the wire screen, no current flowing from the reflector could be detected."

That is, there was no appreciable ionization with a voltage of forty, forty being well above the ionization voltage in most gases.

We now come to a patent to Thatcher No. 1,028,636, filed March 30, 1910. The title of the patent is: "Method of Exhausting Vessels," and I will quote one of his early paragraphs:

> "The process which constitutes this invention relates to the exhaustion of any vessels whatsoever in which it is desirable to rapidly and economically attain high vacua. It may be used either for exhausting electrical apparatus which are permanently provided with electrical conductors or terminals, such as incandescent lamps, vacuum tubes, and etc., or for exhausting non-electrical apparatus provided with suitable conductors or terminals only for the purpose of exhaustion."

Continuing, he says:

> "The object of this invention is therefore to attain high vacua in any vessel requiring complete exhaustion, and the invention consists in effecting this in a rapid and economical manner without introducing into the vessel, or otherwise employing, any gas absorbing substance."

And here is a departure from the methods that have been used in incandescent lamp exhaust, a departure, at least, apparently.

Now, Thatcher does not introduce a vaporizable reagent such as phosphorus, he utilized the cleaning-up property of a heated filament. I will quote further:

> "I institute the intensive incandescence of the filament proper, that is I bring the current voltage up to a sufficient intensity to produce the blue haze phenomenon, and maintain the same until the blue haze disappears and the desired almost perfect vacuum is attained."

This last quotation begins line 130, page 2. It extends to line 6 of page 3.

Now, quoting again, from line 23, page 3:

> "The current must be sufficiently intense to overcome the resistance of the vacuous space, and to suitably ionize it and produce a pronounced luminous discharge in the vessel practically until the desired final gaseous pressure is obtained."

That is to say, the process consists in first evacuating by pumps, and then raising the filament to a high degree of incandescence in which case you obtain the blue glow of which I spoke yesterday, between the legs of the filament. That blue glow, or better simultaneously with that appearance of blue glow and thereafter, the residual gases disappear. I believe I pointed out in the manner in which this took place yesterday.

I would like to refer back to a reference that I cited yesterday by Doane. I neglected to point out in connection with that reference that this discharge or blue glow which takes place between the legs of the filament, is, of course, an electron discharge between two terminals at a difference of potential. The effect of that discharge is to heat by bombardment the positive terminal. That is, the positive leg, and by heating, drive off the occluded gases. This, in effect is exactly the process of denuding an electrode of gases by bombardment. It was specifically explained in the reference to Doane which I cited yesterday.

By Mr. Darby:

Q. 26. Was that the reason then that the blue glow when it appears in between the legs of an incandescent filament was stated by you yesterday to increase the vacuum? I think I asked you that question yesterday, and does this explanation that you have given now, relate to that same subject matter of why the blue glow increases the vacuum?

A. It relates to that subject matter, but I would like to explain further, in order that there may be no misunderstanding, I understand there are two effects which may take place when the blue glow exists. The heating to which I have just referred which drives off the occluded gases from the elements heated, and in addition a cleaning-up possibly due to the bombarding of the walls by gas molecules, and their occlusion on the walls, at least there is a definite clean-up effect which takes place as the result of the presence of the blue glow in the space. I think I stated that yesterday.

One more quotation from Thatcher's patent, following on page 4, line 50. Pardon me, I will have to make a slight explanation.

Previous to this quotation, he points out that phosphorus which has hitherto been used as a chemical getter in incandescent lamps has an appreciable vapor pressure if the lamp becomes hot while operating, so that there is a definite or a certain pressure of vapor in the tube. Now, he says:

> "This effect can not occur when my process is used, for the gases are precipitated and premanently held in combination with practically nonvaporizing particles such as carbon, tungsten or the like."

The particles to which he refers here are the vaporized particles from the carbon or tungsten filament which combine with the gases or occlude the gases, so that they are precipitated with these solid particles.

The next reference is to a patent by Friedrich, No. 1,083,677. The title is: "Method of Producing High Vacuums in X-ray Tubes and the Like."

The date of the application, October 11, 1910. I am quoting from this patent:

> "This invention has reference to a novel method of producing high vacuums in X-ray tubes and the like and pertains also to improved tubes of that type."

That quotation is line 10 to 14, page 1.

Another quotation starting line 43, page 1:

> "In order to produce a lastingly high vacuum in an X-ray tube under present conditions when enormously strong currents are sent through the tube during use both the anode and the cathode should be heated to red heat during the evacuation so that all gases contained in the metal are driven out and removed by the air pump."

Now, in the use of an ordinary X-ray tube, the anode or positive terminal is bombarded and heated by the discharge, but the cathode may not be sufficiently heated to rid it of its gases. Friedrich proposed then to heat both electrodes by surrounding the electrodes with a resistance coil, through which he can pass a current and bring the electrodes up to a high temperature.

We now come to an article by Lilienfeld, entitled: "Conduction of Electricity in Extreme Vacuum," published in the *Annalen Der Physik,* Volume 32, 1910. This is also published in the *Leipsiger Berichte,* Volume 63, 1911. The articles describe some experiments made by Dr. Lilienfeld in investigating the nature of the discharge through a vacuous space. He employs a tube containing a Wehnelt cathode for emitting electrons and an anode and some other sounding electrodes, as he calls them, for determining the potential drop in the tube.

From results of some early experiments which need not concern us here he draws the conclusion that he wishes to obtain the highest permissible or highest possible vacuum and he describes in his article elaborate means for obtaining the extreme vacuum including heating the walls, washing out the apparatus with gas which does not contain argon or any of the inert gases, the use of liquid air and charcoal to condense residual gases, passing a heavy discharge through the apparatus which heats the anode and in fact practically all of the methods which may now be used, which are now used for obtaining extreme vacuum.

He even goes so far as to pump out one charcoal liquid air tube by means of another one in order to reduce the gases in the first charcoal tube to as low an amount as possible before putting it into action to still further reduce the vacuum, a sort of a two-stage evacuating process.

I think there can be no question about the degree of vacuum which he obtained.

He makes a reference here to the space charge similar to the statement he made in his answer to Soddy's paper in these words:

> "One can formulate more generally the conditions for high vacuum and large current density as follows: the production of a state in which the volume density of the electrons carrying the current is as large as possible compared with the density of gas molecules, in which there exists, therefore, a tendency for the formation of the maximum possible volume charge in the path of the current."

During the course of the experiment he thought desirable to see whether the material of the anode made any difference in his conclusions. He had previously used a platinum anode and he seals into his device anodes of various materials, one of which is gold and he uses English platinum, and aluminum, nickel and so forth, but the important point is that during the evacuation and operation of the tube the gold anode, because of its imperfect heat contact with the outside was heated to a glowing temperature. This then is another example of the bombardment and heating of an anode or a terminal to get rid of the occluded gases.

He refers in his article to the fact that it took some time to attain a constant condition on account of the gas which was evolved from these anodes while the discharge took place, but that eventually a steady condition was obtained.

During the course of his investigations he drew some very important conclusions. I will quote here an italicised passage in his article which your Honor may recognize as earmark No. 3 as I stated yesterday.

> "From a definite maximum density of the gas downwards the discharge phenomena are independent of the gas density in the region investigated."

Another quotation which your Honor may recognize as another earmark, I think it was No. 1,

> "Now, as a matter of experience it not only makes no difference at all whether the cathode is very strongly or feebly heated during the discharge, provided of course that its temperature is high enough to insure its proper functioning."

This states that he was operating his discharge tube on the space charge portion or space charge region where the current was limited by space charge and not by the temperature of the filament. We have spoken of that as the flat-top temperature curve.

Lilienfeld observes the current passing through his device and the potential across the sounding terminal and he plots his result and deduces certain laws concerning the discharge. In fact, he plots them logarithmically and he finds that the plot which he obtains can be divided into two parts, both parts being straight lines when plotted logarithmically. The lower part of the discharge curve or plot follows the law which is stated in these words, quoting from his article:

> "More exactly formulated; the characteristic consists of two parts. In the first part the potential drop [gradient] increases as J 2/3 in the second as J 1/2. In both parts the connection between J and V is represented simply by a power."

I think it has already been called to your Honor's attention that expressing the voltage as proportional to J (which is current) to the 2/3 power is identical mathematically to expressing the current as varying with voltage to the 3/2 power, so that we have here the earmark No. 2, the 3/2 power law.

In the course of Lilienfeld's experiments he uses a current of the order of about 11 milliamperes.

The next reference is an article by Denber——

Q. 27. Before you take up the Denber article, have you covered the subject matter as to whether or not Lilienfeld shows in this article any reference to whether or not the gas pressure has any appreciable effect on the characteristic of the device?

A. Yes. I quoted from the article pointed out that it corresponded to earmark No. 3. I believe I quoted this excerpt from the article which I will quote again. But "from a definite maximum density of the gas downwards the discharge phenomena are independent of the gas density in the region investigated," which is, earmark No. 3.

Turning now to the reference to Denber entitled, "A Method of Exciting Very Soft Roentgen Rays In An Extreme Vacuum," Volume 13, 1911, of the *Verh. d. Deutsch Phys. Ges.* The object of Denber's work was to produce very soft X-rays using photo-electrons. The only comment which I would like to make in connection with this article is to call your Honor's attention to the vacuum which he obtained and quoting:

For evacuation a Gaede pump was used first and then charcoal cooled in liquid air. In the final experiments the pressure was less than 10^{-5} mm. of Hg.

That transcribed into microns is 1/100 of a micron.

Reference to Gehrts "Reflection and Secondary Radiation of Photo-Electrically Produced Electrons," in the *Annalen der Physik,* Volume 36, 1911. Here too Gehrts uses photo-electrons in the experiment and I believe we can pass this reference with this quotation:

> "Up to the highest velocities used, there was no trace of ionization."

He used voltages up to 480 volts.

I will refer now to a patent by Marshall No. 1,205,002, entitled, "Process of Exhausting Lamps," filed October 23, 1911. This patent concerns the getter method of evacuating incandescent lamps.

Mr. Davis: Your Honor, I do not see the pertinency of a patent issued November 14, 192[illegible]

The Court: I will hear you, Mr. Darby.

Mr. Darby: Your Honor is familiar with the recent case of the Supreme Court which makes the filing date of the patent the effective date as an anticipation where the invention claimed in the patent in suit is in issue and disclosed in that case.

The Court: What was the effective date of this patent?

Mr. Darby: The effective date of the patent that the witness is referring to is 1911.

The Court: I am probably not clear in my recollection of that decision as I remember, but the effective date of the patent in suit is before that.

Mr. Darby: No, sir; 1913 is the filing date and the earliest date claimed for the invention is the latter part of 1912.

The Court: That is right. Is your understanding of the principle of law involved the same as that of Mr. Darby?

Mr. Davis: No, but I do not feel that my recollection of the decision is sufficient to enable me to contradict him. I would like to reserve the point and look at the opinion if I may.

The Court: Very well.

Mr. Davis: I hope the Court will understand that on a thing of this sort, where the claims for the invention are substantially the same, of course the claims in this case are details in the process of making incandescent lamps, in this Marshall patent.

The Court: They are limited to the process.

Mr. Davis: Yes, they are all process claims, steps in the manufacture.

The Court: Would that make any difference?

Mr. Ballard: I think I can clear it up.

Mr. Darby: I think I can end the discussion.

I raised the point as to that case as a proposition of law without any particular reference to the subject matter of the patent. On the examination of the patent, I see it has to do with vaporizable reagents and Patent No. 4 in this case was not applied for until 1921.

THE COURT: Then you are using it now or are you restricting your evidence or this reference to the fourth patent in suit?

MR. DARBY: No, sir; not necessarily. It certainly is admissible for that patent at least.

MR. DAVIS: May we let it in for that and discuss later what, if any, other application it will have?

THE COURT: Yes.

. . . .

A. (Continued.) I believe I have referred to the patent to Marshall. Quoting from his specifications:

> "This invention relates to the production of evacuated vessels in which a high degree of vacuum is desired, and more particularly to exhausting incandescent lamps."

The method adopted here by Marshall is to place the vaporizable reagent on the end of the filament mounting in an incandescent lamp, so that when the filament is lighted the heat will vaporize the reagent and cause the vacuum to be improved by the chemical method. It is significant that the cleaning-up process in this patent takes place after the tube has been sealed from the pump.

I refer now to an article by Child, entitled "Discharge from Hot Calcium Oxide," published in the *Physical Review,* Volume 32, 1911. Child in this article sets forth very clearly the idea of space charge. I will quote from the article:

> "There are two ways in which ionization in the gas can increase the current. It can increase the number of positive ions moving toward the cathode, or it can change the field near the cathode, so that all the electrons shall be drawn from it, instead of being driven back by the electrostatic repulsion of those which had previously been emitted."

This passage describes the manner in which positive ionization can neutralize the space charge near the cathode of the electron discharge device.

Then Child enters into a mathematical discussion, the net result of which is a mathematical expression of the 3/2 power law, which your Honor will recognize as earmark No. 2. The final formula to which he arrives is as follows:

$$\text{I equals} \quad \frac{I}{9_1\pi}\sqrt{\frac{2\varepsilon}{m}}\,\frac{V_1{}^{\frac{3}{2}}}{x_1{}^2}$$

We need not concern ourselves with most of the terms in that formula, but we have there a statement that the current varies as the voltage to the 3/2 power which is a precise statement of the 3/2 power law.

Directly below the formula he states:

> "In other words, this is the largest current which it is possible to have carried by positive ions with the given distance and the given potential difference between the plates."

It should be pointed out that Child deduced his formula assuming positive ions instead of negative electrons, but the mathematics would be identical and the final expression would be the same for electrons.

I would like to quote a little further on in the article:

> "When there is no ionization of the gas, the electrons coming from the cathode may be so nu-

merous as to reverse the direction of the field in part of the space and hold back other electrons which may be leaving the CaO."

This again is the statement of the fact that a space charge may exist around the cathode.

I will refer briefly to an article by Majorana on "Electromagnetic Wave Indicators Based on the Principle of Electronic Emission from Incandescent Wires." It is published in a Roman publication which I hesitate to pronounce. Atti Della Reale Accademia dei Lincei, serio quinta rendiconti, published in Roma, Volume ~~21,~~ 1912.

This article deals with a thermionic wave indicator similar to the device of Fleming. I would like to point out in this article that he states that extremely rarefied gas should be used. And he gives curves and diagrams, Figure 1, showing milliamperes or current through the device plotted vertically against voltage impressed across the device plotted horizontally; a current through the device is not the filament current, but what we term the space current, or the current through the vacuous space. He gives there three curves which do not indicate as far as we can judge, any ionization, although he utilizes voltages as high as 50.

I refer to an article by Dr. J. E. Lilienfeld and Dr. Rosenthal, and along with this another article forming part of this paper, by Dr. Rosenthal, which was published in the *Fortschritte auf dem Gebiete der Rontgenstrahlen,* Volume 18, 1912.

Mr. Davis: Is that both articles in 1912?

The Witness: I believe so. I shall have to check that up to be absolutely positive. The article by Lilienfeld-Rosenthal describes an X-ray tube of novel character, which consists of the ordinary cold cathode and anode similar to those used by X-ray tubes, of the gas type, but in addition, there is incorporated in this tube a heated filament such as a Wehnelt filament, and a second or a fourth terminal which serves as the anode operating in conjunction with the filament. The tube is evacuated to a high vacuum; and he refers in this article, which describes the tube, back to his former work in these words:

> "The construction here described owes its being to the considerable studies I have carried on in connection with discharges in extreme vacua."

And then gives reference to his latest report.

Your Honor will recall I outlined in connection with the former reference to Lilienfeld, that he used the greatest precautions to attain a high degree of vacuum.

The two additional electrodes including the Wehnelt cathode and its anode, were used to help the discharge to pass or to cause the discharge to pass through the main portion of the tube.

If the filament was not lighted, no discharge would pass through the X-ray tube even although a very high potential was impressed but on heating the filament and causing the electron current to pass between the filament and its anode, then and only then, did a discharge take place between the main electrodes of the X-ray tube; and he claims certain advantages for this type of X-ray tube, which includes a long life terminated only by a burning out of the filament.

I would like to quote a passage from this paper:

> "I found that the required voltage for the production of a certain current strength from an incandescent cathode, which, at first, diminishes when the tube is evacuated, then again begins to increase, as the gas attenuation is carried beyond a certain limit. This tension does not then increase with diminishing pressure, but remains sta-

> tionary at a certain limit that is, if it reaches this limit, and the tube is further freed of gas, the tension—meaning voltage—no longer changes with diminishing pressure."

This is a statement of the earmark No. 3, where the discharge between the hot filament and its anode is independent of the gas pressure, which indicates that he was operating in this case with a pure electron discharge.

I should call your Honor's attention too to the fact that in this discharge tube, he used currents of the order of 150 milliamperes between the filament and its anode, and voltages of several hundred volts. The fact to which I would like to call your Honor's attention is the fact that these tubes were evacuated and sealed from the pump and put into practical use, with a life terminated only by the burning out of the filament.

The second paper to which I referred by Dr. Rosenthal, outlines the practical application of the tube, because Dr. Rosenthal was a surgeon, not a scientist. He was interested in the application of the X-ray tube to taking X-ray photographs, and it is well known that the hardness of the X-rays, that is, their penetrating power, depends upon the voltage that exists across the X-ray tube.

This voltage was caused to vary by changing the amount of electron current passing between the hot filament and its anode. So he described a tube in which the degree of hardness or the penetrating power of the X-rays could be varied at will, and he sums up the advantages of the tube:

> "The tube receives the degree of hardness independent of its vacuum."

and

> "The durability of the tube seems to be especially good, even under longer exposure and higher load. Its duration will be as far as we can foresee, the same as that of a metal filament lamp."

(Here a short recess was taken.)

Q. 28. As part of that article of Lilienfeld and Rosenthal, were there any pictures of the X-rays that were taken with the equipment?

A. There are. These pictures were taken in order to show the different penetrating power which can be obtained using the same tube. These pictures show a variation of penetrating power of the X-rays. The first picture of the right, on the middle line indicates very low penetrating power showing the shadow of the whole hand. The middle picture indicates higher penetrating power and the last picture still higher penetrating power where the flesh around the fingers is hardly discernible. This variation in penetrating power as I have stated was accomplished by varying the current from the thermionic filament to the auxiliary anode associated with it.

Q. 29. Before we leave the subject matter of the Lilienfeld work, will you please refer to the conclusions or summary as it is headed of the Lilienfeld 1910 paper and point out any stated conclusions which are pertinent to the issues in this case.

A. In this summary I find these conclusions, quoting from the paper:

> "From a certain maximum value of the gas density downwards the characteristic of the discharge is entirely independent of the gas density, and therefore we have more especially for the factor mentioned under B"

and then follows a mathematical formula which does not concern us.

The important point there is that he definitely states that the discharge is independent of the gas pressure below a certain value of gas pressure which is a definite statement of earmark No. 3.

Then again:

> "If the gas density is sufficiently small, we find for current densities between O and the regions of B and C the law that the potential gradient varies as J 2/3."

To this I have already referred in the main part of the article. This with a very simple mathematical inversion is the statement of the 3/2 power law which is earmark No. 2.

Now, referring to the article by Kunz & Kemp, "About the distribution of light during the stratified discharge in vapors of alkali metals," published in the *Physikalische Zeitschrift*, Volume 13, in the year 1912. This paper deals with the study of the light emitted when a discharge passes through vapors of some of the alkaline earths, but I will call your Honor's attention to this passage:

> "Potassium and sodium was placed and vaporized in the lateral extending portion of the tube. A complete vacuum was produced so that Roentgen rays were created, without heating the Wehnelt cathode. As soon, however, as the calcium oxide electrode had been sufficiently heated, then there appeared the blue rays of electrons which spread from the cathode to the anode, however, without producing any other light."

In this experiment a discharge tube was utilized, employing a heated filament and a cold plate. Attached to the tube was an auxiliary chamber in which was placed the sodium and potassium which was vaporized by heating that chamber. The excerpt which I read states that on vaporizing the sodium or potassium a very high vacuum was produced as indicated by the fact that Roentgen rays were created without heating the Wehnelt cathode.

When the Wehnelt cathode was heated since the potassium and sodium had appreciable vapor pressure, then the luminous effects were obtained due to the discharge through those vapors.

I refer now to the article by Whitney on "Vacua," published——

Q. 30. Is that Willis R. Whitney?

A. W. R. Whitney, published in the *American Institute of Electrical Engineers*, proceedings of 1912, June 25th. Dr. Whitney is discussing here the various methods of obtaining high vacua with particular reference to incandescent lamps and he outlines or describes the methods that have been previously used and I would like to quote from his article:

> "In case of incandescent lamps where the voltage is above 50 for a fair brilliancy of filament, a blue discharge passes through the bulb and this blue quickly disappears when such vapors are introduced. The blue discharge seemed to be necessary for any considerable improvement of the vacuum due to such vapors as phosphorous, and this led to the assumption that the gases still left in the lamp by the pump were removed quickly during the blue glow and probably by the vapors which were at the same time being deposited on the glass."

This is merely a rehearsal of the methods which have been used indicating the necessity of the blue glow discharge in clearing up the vacuum in incandescent lamps.

A little further down:

> "That this improvement of vacuum is quite commonly produced when vapors of any kind are caused to condense in the space is not new. It

even takes place markedly when the filament is first heated to very high temperature without added vapor, and a *blue glow* also passes through the lamp at the time."

I call your Honor's attention with reference to this to the Thatcher patent which obtained a vacuum by heating the filament to a high temperature and causing a clean up of the gas as the result of that process.

Further on in the article I quote as follows:

> "If, however, the lamp were allowed to burn at a normal brilliancy for a longer time and the same vacuum test was made from time to time on the unlighted lamp in the dark room it was found that the duration of the impressed rotation rapidly increased."

I would like to explain that this is a kind of experiment in which the clean-up effect was investigated and the degree of vacuum was indicated by the rotation of a little vane inside of the vacuum chamber. It is to that to which he refers when he speaks of the duration of the impressed rotation.

Then he goes on:

> "In many cases a rotation lasting fifteen minutes would be produced by allowing the lamp to burn twenty-four hours. This phenomenon of automatic vacuum improvement received the name of the 'clean-up.' While the clean-up, as measured in this rough way, did not seem to take place in all lamps to the same degree, it was always present under ordinary conditions. Other types of vacuum lamps improved made their vacua on running. In fact, no lamp, unless we accept the mercury arc, fails to do so."

The last sentence or portion of the sentence in this article is as follows:

> "It seems as though the clean-up effect proceeds to as nearly perfect vacuum as we can measure even qualitatively."

I will refer now to a patent by Clark, No. 1,121,802: "Method of Coating Projector-lamps with Reflecting-surfaces." Date of application is January 11, 1913. I will refer to this only briefly, calling attention to the fact that Clark outlines a method of depositing film of sodium or potassium inside the bulb for the purpose of acting as a reflector.

I will refer very briefly to an article by Angerer, "Concerning the Pressure of Cathode Rays," in the *Annalen der Physik,* Volume 41, 1913. Angerer was interested in the mechanical pressure that would be exerted by this stream of electrons which we call cathode rays. He uses a thermonic device, a hot filament, and outlines his method by obtaining the vacuum by Dewar's method of obtaining the vacuum of using charcoal cooled by liquid air. He states that pressures were obtained as low as 8 times 10 to the minus seventh power millimeters. That transcribed into microns is 8/10,000 of a micron.

He also observes in the experiments that the discharge current does not vary with the pressure of the gas up to pressures of 4 times 10 to the minus fifth millimeters which is 4/100 of a micron.

Here again is a statement of the independence of the discharge with varying gas pressure which is earmark No. 3.

I turn to a patent by Clough, No. 1,246,054, the date of the application is October 30, 1915. This patent has to do with an enclosed arc between a hot filament and a cold terminal. The cold terminal consists of either calcium or magnesium or other metal and the purpose of utilizing such a metal as an anode is to clean up certain deleterious gases which may exist by the clean-up effect of vaporized calcium or magnesium.

I will quote from the specification:

> "The anode 3 comprises metallic calcium, magnesium, titanium, or other metal, highly reactive chemically to gases other than the inert so-called rare or monatomic gases."

Finally I will refer to a patent to Mackay, No. 1,208,597, filed October 30, 1915. This patent also has to do with discharge devices consisting of a hot filament and a cold anode, the space containing inert gases.

I will quote from the specification, beginning line 14, page 1:

> "I have discovered that a markedly lowered voltage drop or loss in the arc is secured in a device of this type containing gases protecting the electrodes from chemical deterioration and electrical disintegration when there is provided within the device a material, as for example, calcium and related alkaline-earth metals, magnesium or non-metallic absorbents such as phosphorous tentoxid,"—

and so forth, and he states that water vapor, hydrogen, nitrogen, and so forth are absorbed by the vapor of these metals.

Further on I will quote as follows, and this is line 88, page 1:

> "Metallic calcium or magnesium may, for example, be introduced as a small strip of foil or wire 9 placed upon or wrapped about one of the cathode conductors and in proximity to the cathode so as to be vaporized by the heat of the arc or by the incandescent cathode."

The little piece of vaporizable reagent is placed on one wire leading to the hot filament near the filament and when the filament is heated the metal is vaporized. That I believe completes the list of references.

Q. 31. As a matter of convenience for quick reference, Dr. Chaffee, can you enumerate the list of references that you have referred to which refer to baking the walls of the containers of the discharge devices to free them of occluded gases?

A. Yes, I will refer to these by name and in the case of any ambiguity I will indicate that. The references which refer to baking the walls are as follows: Bessel Hagen, Edison, Duncan, Dwyer, Lenard, Doane, Merritt, Soddy patent, Hogg, Geherts and Lilienfeld 1910.

Q. 32. Will you similarly enumerate a list of the references which refer to heating the electrodes in the discharge devices for the purpose of freeing them of occluded gases?

A. The references are as follows: Malignani, Duncan, Dwyer, Doane, Merritt, Soddy U. S. Patent, Friederich and Lilienfeld.

Q. 33. Will you likewise enumerate the reference that you have referred to which described the bombarding of the electrodes to free them of occluded gases?

A. The references which refer to bombardment of the electrodes are Duncan, Lenard, Doane, Soddy U. S. Patent, and Lilienfeld 1910 article.

Q. 34. Will you please enumerate the references that refer to the employment of a vaporizable reagent?

A. The references which refer to a vaporizable reagent are Malignani, Dwyer, Doane, Von Recklinghausen, Merritt, Soddy U. S. Patent, Soddy reference 1907, Hupka, Marshall, Kunz & Kemp, Whitney, Clark, Clough, Mackay.

Q. 35. Now, will you give us some illustrative references that make reference to the space charge.

A. References on space charge are Lilienfeld's reply to Soddy, the Lilienfeld article in 1910, and Child's article. Also I may add the article by Lilienfeld and Rosenthal.

Q. 36. Will you give me some illustrative references referring to the 3/2 power law?

A. References relating to the 3/2 power law are Lilienfeld 1910 article and Child.

Q. 37. And can you give me illustrative references referring to the logarithmic plot?

A. Lilienfeld 1910.

Q. 38. Can you give me one or two illustrative references that refer to the flat top temperature curve or as you have otherwise stated it independent of cathode temperature?

A. Lilienfeld 1910 article.

Q. 39. Will you similarly give several illustrations of the references referring to the use of alkali earth metals as vaporizable reagents?

A. These references are Von Recklinghausen, Soddy U. S. Patent, Soddy 1907 article, Hupka, Clough and Mackay.

Q. 40. Will you likewise give one or two illustrative references referring to the current in the discharge device being independent of the gas pressure below a certain limiting value?

A. Such references are Lilienfeld 1910 article, Lilienfeld and Rosenthal, and Angerer.

Mr. Darby: Your Honor, may I say in explanation that I have not attempted by Dr. Chaffee to cover all of the references which are already in the case in the Arnold-Langmuir Interference. We have merely picked out illustrative ones and a good deal of the art that this witness has discussed is in addition to that, but for the sake of economy of time we are not going to traverse step by step the same ground that was covered.

Q. 41. In connection with the Dewar article of 1875, the transcript of your testimony of yesterday makes it appear that you described in connection with this work of Dewar, that he employed charcoal and liquid air. What have you to say with respect to that?

A. In rereading the article I find no reference to liquid air as the cooling agent in causing charcoal to absorb gases and I will have to correct my testimony to the extent of omitting reference to liquid air in connection with Dewar's article of 1875.

Mr. Darby: I would like to offer in evidence the patents and publications referred to by this witness in the order in which they were referred to by him and they are thirty-six in number. May I at a later time collect unmarked copies of them and submit them?

The Court: And give them one exhibit number?

Mr. Darby: Each will get a separate number.

(Article of Dewar dated 1875, received in evidence and marked "Defendant's Exhibit No. 2." *See Volume V, Defendant's Exhibits, page 3.*)

(Article of Sheele & Hause, dated 1909, received in evidence and marked "Defendant's Exhibit No. 3." *See Volume V, Defendant's Exhibits, page 8.*)

(Article of Bessel Hagen, dated 1881, received in evidence and marked "Defendant's Exhibit No. 4." *See Volume V, Defendant's Exhibits, page 15.*)

(U. S. Patent No. 411,019 to Edison, received in evidence and marked "Defendant's Exhibit No. 5." *See Volume V, Defendant's Exhibits, page 37.*)

(U. S. Patent No. 537,693 to Malignani, dated 1894, received in evidence and marked "Defendant's Exhibit No. 6." *See Volume V, Defendant's Exhibits, page 40.*)

(U. S. Patent No. 596,654, to Dwyer, dated 1897, received in evidence and marked "Defend ant's Exhibit No. 7." *See Volume V, Defendant's Exhibits, page 42.*)

(Article of Duncan, dated 1896, received in evidence and marked "Defendant's Exhibit No. 8." *See Volume V, Defendant's Exhibits, page 47.*)

(Article of Dewar, dated 1898, received in evidence and marked "Defendant's Exhibit No. 9." *See Volume V, Defendant's Exhibits, page 53.*)

(Articles of Lenard, dated 1900, received in evidence and marked "Defendant's Exhibits, Nos. 10 and 10-A." *See Volume V, Defendant's Exhibits, pages 62 and 79.*)

(Article of Doane, dated 1904, received in evidence and marked "Defendant's Exhibit No. 11." *See Volume V, Defendant's Exhibits, page 122.*)

(U. S. Patent No. 946,068 to Von Recklinghausen, dated 1904, received in evidence and marked "Defendant's Exhibit No. 12." *See Volume V, Defendant's Exhibits, page 135.*)

(U. S. Patent No. 909,811 to Merritt, dated 1905, received in evidence and marked "Defendant's Exhibit No. 13." *See Volume V, Defendant's Exhibits, page 138.*)

(Article of Fleming, dated 1905, received in evidence and marked "Defendant's Exhibit No. 14." *See Volume V, Defendant's Exhibits, page 142.*)

(U. S. Patent No. 803,684 to Fleming, dated 1905, received in evidence and marked "Defendant's Exhibit No. 15." *See Volume V, Defendant's Exhibits, page 157.*)

(Article of Fleming, dated 1906, received in evidence and marked "Defendant's Exhibit No. 16." *See Volume V, Defendant's Exhibits, page 165.*)

(U. S. Patent No. 859,021 to Soddy, dated 1906, received in evidence and marked "Defendant's Exhibit No. 17." *See Volume V, Defendant's Exhibits, page 181.*)

(Articles of Soddy, dated 1907, received in evidence and marked "Defendant's Exhibits Nos. 18 and 18-A." *See Volume V, Defendant's Exhibits, pages 190 and 192.*)

(Reply to Soddy by Lilienfeld, dated 1908, received in evidence and marked "Defendant's Exhibit No. 19." *See Volume V, Defendant's Exhibits, page 222.*)

(Reprint by Hogg, dated 1909, received in evidence and marked "Defendant's Exhibit No. 20." *See Volume V, Defendant's Exhibits, page 225.*)

(Article of Hupka, dated 1909, received in evidence and marked "Defendant's Exhibit No. 21." *See Volume V, Defendant's Exhibits, page 241.*)

(Article by Von Bayer, dated 1909, received in evidence and marked "Defendant's Exhibit No. 22." *See Volume V, Defendant's Exhibits, page 281.*)

(U. S. Patent No. 1,028,636 to Thatcher, dated 1910, received in evidence and marked "Defendant's Exhibit No. 23." *See Volume V, Defendant's Exhibits, page 305.*)

(U. S. Patent No. 1,083,677 to Friedrich, dated 1910, received in evidence and marked "Defendant's Exhibit No. 24." *See Volume V, Defendant's Exhibits, page 309.*)

(Articles of Lilienfeld, dated 1910, received in evidence and marked "Defendant's Exhibits Nos. 25 and 25-A." *See Volume V, Defendant's Exhibits, pages 315 and 388.*)

(Article of Dember, dated 1911, received in evidence and marked "Defendant's Exhibit No.

26." *See Volume V, Defendant's Exhibits, page 397.*)

(Article of Gehrts, dated 1911, received in evidence and marked "Defendant's Exhibit No. 27." *See Volume V, Defendant's Exhibits, page 403.*)

(U. S. Patent No. 1,205,002 to Marshall, dated 1911, received in evidence and marked "Defendant's Exhibit No. 28." *See Volume V, Defendant's Exhibits, page 433.*)

(Article of Child, dated 1911, received in evidence and marked "Defendant's Exhibit No. 29." *See Volume V, Defendant's Exhibits, page 437.*)

(Articles of Magorana, dated 1912, received in evidence and marked "Defendant's Exhibits Nos. 30 and 30-A." *See Volume V, Defendant's Exhibits, pages 457 and 465.*)

(Reprint by Lilienfeld & Rosenthal, dated 1912, received in evidence and marked "Defendant's Exhibit No. 31." *See Volume V, Defendant's Exhibits, page 472.*)

(Reprint by Kunz & Kemp, dated 1912, received in evidence and marked "Defendant's Exhibit No. 32." *See Volume V, Defendant's Exhibits, page 488.*)

(Reprint by Whitney, dated 1912, received in evidence and marked "Defendant's Exhibit No. 33." *See Volume V, Defendant's Exhibits, page 491.*)

(U. S. Patent No. 1,121,802 to Clark, dated 1913, received in evidence and marked "Defendant's Exhibit No. 34." *See Volume V, Defendant's Exhibits, page 502.*)

(Article of Angerer, dated 1913, received in evidence and marked "Defendant's Exhibit No. 35." *See Volume V, Defendant's Exhibits, page 507.*)

(U. S. Patent No. 1,246,054, to Clough, dated 1915, received in evidence and marked "Defendant's Exhibit No. 36." *See Volume V, Defendant's Exhibits, page 539.*)

(U. S. Patent No. 1,208,597 to Mackay, dated 1915, received in evidence and marked "Defendant's Exhibit No. 37." *See Volume V, Defendant's Exhibits, page 542.*)

Mr. Darby: Mr. Davis may cross-examine.

Mr. Haight: With the consent of the other side, if it meets with your Honor's approval, we would like to have the cross-examination of Dr. Chaffee postponed until Dr. Jewitt is finished, so that he can testify today and leave for Europe.

The Court: That is satisfactory. Dr. Chaffee is excused for the present.

E. Leon Chaffee resumes the stand.

Cross-Examination.

By Mr. Davis:

XQ. 42. The word vacuum, what idea does that convey to your mind? What is a vacuum?

A. I cannot answer that in definite language.

XQ. 43. When you see the expression in a technical periodical saying there was a vacuum in a certain tube, what does it mean, does it mean that all the air is exhausted out of it?

A. Not at all.

XQ. 44. What does it mean?

A. Vacuum when used in connection with experiments on the discharge of electricity through gases or having to do with discharge devices may mean anything from say a pressure of a few millimeters down to as low or as high as is possible to obtain.

XQ. 45-6. What does the expression high vacuum mean to you?

A. Again that is a relative term and cannot of course be defined specifically unless you have reference to some particular art or some particular application.

XQ. 47. It would depend on who used the term?

A. It would depend on whether a physicist or an experimenter in this line of work which we have been discussing used it or whether the term was used in connection with an entirely different art.

XQ. 48. It would depend on who used the term and what he was talking about when he used it, wouldn't it?

A. I believe that is correct, yes.

XQ. 49. And there is no such thing as a perfect vacuum?

A. There is no such thing.

XQ. 50. There is always some pressure?

A. Always.

XQ. 51. And every substance has its own vapor pressure?

A. True.

XQ. 52. At any temperature?

A. True.

XQ. 53. For instance, mercury has a vapor pressure?

A. True.

XQ. 54. Do you know what the vapor pressure of mercury is at room temperature?

A. Something of the order of a micron or a micron and a half.

XQ. 55. Your position as you stated in your direct is that to your mind this alleged invention comprises an electron discharge tube with a little better vacuum than existed in the three-electrode devices, for instance, such as the DeForest detector tube at the time of about

1913, and that this is done, that evacuation was accomplished by means which were fully described in the art previous to the year 1913 and which were well known at that time. Is that a clear statement of your position?

A. Yes.

XQ. 56. You referred us to an article in *Nature* of October, 1875, Defendant's Exhibit 2. Is it your view that this article by itself would teach you to do this thing that you said could be done with the knowledge of the art?

A. I corrected my deposition regarding that article in my direct examination. I was under a misapprehension when I forgot for the moment. That article, which was written by a correspondent who reported on Dewar's lecture, spoke of the use of charcoal which was cooled, but as I remember he does not give the temperature to which the charcoal was cooled, and not knowing that one cannot form a definite idea of the pressure in the chamber evacuated.

XQ. 57. What do you mean by charcoal was cooled?

A. Charcoal was contained in the chamber being exhausted and it was cooled in some way from the exterior.

XQ. 58. You think that is what it means, do you? Does it say that in the article?

A. I will refer to the article, if you please.

XQ. 59. Just read the fourth paragraph of the article and see if you think it means that.

A. I do not think you mean the fourth paragraph, do you?

XQ. 60. I beg your pardon. It is the fifth paragraph.

A. In that paragraph it states that the charcoal was heated to drive off the gases that are contained in the charcoal and then the charcoal was allowed to cool.

XQ. 61. Just what does it say? It says, "And as the charcoal cools." Is there any indication that it is cooled in any artificial sense?

A. No.

XQ. 62. It is simply putting a piece of charcoal inside of the tube and heating the thing so that the charcoal will give off some gas and then taking the lamp away and letting the charcoal cool?

A. That is the purport of that paragraph.

XQ. 63. Do you find anything else in the article which justifies your suggestion that charcoal was cooled or anything was cooled?

A. I find no reference to cooling.

XQ. 64. Then you were wrong the second time. As a matter of fact, liquid air was not known in those days, was it?

A. I do not remember the date when liquid air was first available.

XQ. 65. I thought it was many years after that when liquid air first became available. This is 1875.

A. It may have been a few years.

XQ. 66. What vacuum do you think would be produced by the procedure which Dewar is described as using in this article of *Nature* as you now understand it?

A. The article states that the test was made by impressing upon a tube exhausted in this way the potential from a powerful coil, meaning an induction coil, and that no discharge took place.

XQ. 67. What does that mean to you?

A. That of course is a rough test of a degree of vacuum.

XQ. 68. Is it millimeters?

A. I think it is very much better than a millimeter.

XQ. 69. How much better?

A. I was going to estimate, but of course I do not know the dimensions of the tube, but I would guess about somewhere in the neighborhood of a micron or a tenth of a micron or possibly even better.

XQ. 70. Better than a tenth of a micron?

A. I think so.

XQ. 71. Of course, we know it could not be better than a micron because it had mercury vapor in it?

A. This being not a complete account of the experiment, I do not know whether Dewar took precautions to exclude mercury vapor.

XQ. 72. There is nothing in the article about taking precautions?

A. No.

XQ. 73. And it is a mercury pump?

A. Yes.

XQ. 74. So that, unless there is something which was not mentioned in the article, the pressure could not have been lower than a micron or a micron and a half, is that it?

A. That is true.

XQ. 75. And from the other test, the spark test, you judge it might be as low as one-tenth of a micron. The article states on the second page, if I can read this print correctly, that it is one-four-millionth of atmospheric pressure, is that right?

A. I believe that is correct.

XQ. 76. What would that be in microns?

A. Atmospheric pressure is about 760 millimeters. One-millionth of that would be 7/10 of a micron.

XQ. 77. One-millionth of atmospheric pressure I thought was a micron, is that right, roughly, or 7/10 of a micron?

A. Yes.

XQ. 78. And this is four-millionths?

A. Yes.

XQ. 79. This is a quarter of 7/10 of a micron or about 2/10 of a micron?

A. Yes.

XQ. 80. So that that is another estimate of the vacuum of this device?

A. Yes.

XQ. 81. Was any current passed through this device so far as the article discloses?

A. Yes.

XQ. 82. Just read what it says about it.

A. It says "As the densities diminish, the spark passes more easily."

XQ. 83. Then it says when it gets to final vacuum there is no spark at all?

A. Yes.

XQ. 84. I am interested in that final vacuum. I am not interested in what he is doing but in the final vacuum, did any current pass through the device?

A. The statement is that it did not allow a spark to pass.

XQ. 85. So that there were no problems of evolution of gases or anodes or cathodes or of heating, of the glass by the discharge which presented themselves to this gentleman, is that right?

A. I would not draw that conclusion from this article.

XQ. 86. Is there anything in this article which leads to any different conclusion?

A. No, there is not.

XQ. 87. I understand you withdrew your answer to Q. 13 to the effect that this disclosure gives you a degree of vacuum which you believe is as great as modern methods obtained today. That was based on a misapprehension?

A. In answering that question I do not remember that I referred specifically to this reference. I was referring to the method of the use of liquid air and charcoal.

XQ. 88-89. In any event this statement does not apply to this reference?

A. No.

XQ. 90. Are you familiar with what is called a Geissler tube?

A. I am.

XQ. 91. What is the vacuum in that?

A. It may be anything from a few microns up to a few millimeters. It is a tube which is used in electric demonstration to show the discharge of electricity through gases.

XQ. 92. It was a low vacuum tube?

A. It was a low vacuum tube.

XQ. 93. And when you passed a high potential discharge through it it glowed and gave various colors, and so on?

A. Yes.

By Mr. Davis:

XQ. 94-95. Now, Crookes tube differs from the Geissler tube in what respect?

A. The Crookes tube is ordinarily considered to have a better or higher vacuum than the ordinary Geissler tube.

XQ. 96. It was regarded, was it not, when Crookes first produced it, as an extreme vacuum?

A. I do not know that I would say that.

XQ. 97. I know what the vacuum was of a Crookes tube. I am not interested in the Crookes tube at the moment. I am trying to talk of the Crookes tube of the art prior to Dr. Langmuir. I imagine they were the same, but please keep that in mind.

A. May I ask——

Mr. Darby: What is that, Mr. Davis?

Mr. Davis: I have already stated that we will show that Dr. Langmuir made this invention during the second half of the year 1912.

Mr. Darby: But if you are predicating your question on a specific date, I think I am entitled to know what that specific date is.

Mr. Davis: If your Honor please, it is all in the record in detail and testimony and sketches, and all about it, and if the Geissler tube changed substantially between the first of July, 1913, and some other date in 1923, we will take that form up.

Mr. Darby: I object to the form of the question unless the date is specifically given.

The Court: Read that Mr. Smart. (Previous record repeated as recorded.) I think the objection is well taken on this ground, Mr. Davis, that you are asking the witness to assume a certain date for Dr. Langmuir, rather than give him a date.

Mr. Davis: I will give him the date of August 1st, 1912. That is the date to which my questions refer. When I say "was," I mean that, with reference to these prior art articles.

XQ. 98. What were the Crookes tube vacuum prior to that date?

A. I cannot give any numerical value or define the numerical value because the vacuum in a Crookes tube as of that date or prior to that date, was different in different cases. I would, I believe, assert that it was certainly less than a micron.

XQ. 98a. The X-ray tube was a type of Crookes tube, was it not?

A. Yes, I think so. It was ordinarily so considered.

XQ. 99. Let us think of the X-ray tubes that were well-known articles of commerce for many years, were they not?

A. Yes.

XQ. 100. Prior to this date which I have mentioned?

A. Yes.

XQ. 101. Now, what would happen to an X-ray tube if you ran it too long?

A. Do you mean in regard to the vacuum?

XQ. 101a. Yes.

A. The vacuum ordinarily increased?

XQ. 102. And ultimately the tube would stop?

A. That is true.

XQ. 103. Now, just think of that time, or condition when the tube just stopped, what is the vacuum then, roughly?

A. My answer will necessarily be an estimate, as I have made no measurements of the pressure in the Crookes tube at that stage or under those conditions. My impression is that the vacuum would be better than a tenth of a micron.

XQ. 104. It is merely your impression, of course; you have no knowledge of it?

A. I said I have not measured the pressure in a Crookes tube.

XQ. 105. Would you be surprised if I say it were ten microns?

Mr. Darby: I object, if your Honor please.

The Court: Do you press it, Mr. Davis?

Mr. Davis: No, if your Honor please.

XQ. 106. How were these vacua measured; that is, what was the standard gauge, the best gauge that was known in the art, up to the time I have mentioned, August 1st, 1912?

A. The best known?

XQ. 107. Yes.

A. The best known was the McLeod gauge.

XQ. 108. Does the McLeod gauge show the mercury pressure?

A. No.

XQ. 109. Water vapor?

A. No.

XQ. 109a. So that a reading of the McLeod gauge of say one micron would not be inconsistent with the presence in the tube of two microns of mercury vapor or three microns of water vapor; is that right?

A. Quite right.

XQ. 110. Now, there was a paper by Sheele & Hause published in August, 1909, to which I think you referred, which I think is Defendant's Exhibit No. 3. In your opinion does that paper teach how to perform this result which you stated could be reached by the use of the prior art, that is the conversion of the DeForest audions into the tube of the patent in suit?

A. Yes, I believe it does.

XQ. 111. All by itself?

A. Do you mean the paper all by itself?

XQ. 112. What did you say?

A. Do you mean the paper all by itself would teach?

XQ. 113. Yes.

A. Yes. May I ask you to read the question once more. I may want to modify my answer. (XQ. 110 repeated by the stenographer as recorded.) I would like to modify my statement to this extent: That paper outlines methods of obtaining high vacua, showing the degree of vacua which it is possible to obtain by the use of the various pumping methods or exhausting methods that were then known. The paper states that a Toepler pump will exhaust to a certain pressure which is two-hundredths of a micron and that charcoal and liquid air will reduce the residual gas pressure to seven-thousandths of a micron. Of course the paper does not discuss other precautions that are necessary in any specific device, such as baking the walls and denuding the electrons, and so forth.

XQ. 114. Then the paper does not by itself accomplish this result?

A. Not by itself.

XQ. 115. Is there anything more in the statement than that certain pumps will pump certain vacuums?

A. My impression is that is a correct statement, that it deals particularly with the operation of pumps.

XQ. 116. Is there anything in the paper about the speed of the pump?

A. Yes. There is a table given which gives the time and minutes required to attain certain degrees of vacuum by the use of cocoanut charcoal and liquid air "backed up," as we term it, by the Gaede pump.

XQ. 117. Now, attain such a vacuum in what Professor Chaffee?

A. I do not see that it specifies any——

XQ. 118. It makes quite a difference, does it not?

A. In the time required to attain a vacuum?

XQ. 119. Yes.

A. Yes.

XQ. 120. And in the possibility of getting a vacuum?

A. Certainly. The larger the vessel exhausted, the longer time it would take.

XQ. 121. That is, if the vessel were too large, you never would get a vacuum, would you, with a given pump, with a good vacuum, whatever that may mean?

A. I am not ready to adopt that at this time.

XQ. 122. There is always some gas to come off from the walls, is there not?

A. Yes.

XQ. 123. And in a given sized vessel, and the given capacity of pump, there may be a balance in which the gas given off from the walls, would be equal to the gas drawn away by the pump, may there not?

A. I should think that is correct.

XQ. 124. So it does make a difference how big the vessel is; is there anything in this article about there being any electrodes in the vessel?

A. No reference, I believe, to that.

XQ. 125. Or about the vessel being exposed to any changes in use or anything of that sort?

A. No.

XQ. 126. You recognize there is quite a difference, don't you, between pumping a vacuum, expressed by a decimal point, and a number of zeros, and then a figure, in a perfectly plain glass receptacle, say three inches long, and an inch in diameter on the one hand, and on the other hand, pumping and maintaining a vacuum in a vacuum tube, that has got to run and do something in the world?

A. I recognize the difference, yes.

XQ. 127. Do you know how the vacuum was measured in this Sheele & Hause paper?

A. It mentions McLeod gauge.

XQ. 128. Now, cocoanut charcoal does not absorb mercury vapor, does it?

A. I am not absolutely positive on that point, but my feeling is that at ordinary temperatures, cocoanut charcoal would not absorb mercury vapor to any great extent.

XQ. 129. Do you know as a matter of fact that it will absorb at all, I mean, as a matter of your own knowledge?

A. I stated my own knowledge.

Mr. Davis: I beg your pardon. Will you read that answer? (Answer repeated as recorded.)

XQ. 130. You do not know whether this tube or whatever the vessel was, in which this vacuum was said to have been produced, was sealed off from the pump or not, do you?

A. I do not know.

XQ. 131. You do not know whether the walls were baked?

A. No.

XQ. 132. Do you not?

A. I have seen no reference to that, no.

XQ. 133. You have not seen a paper in the *Physical Review*, Volume 13, page 434, published in 1919, by J. E. Shrader?

A. I do not remember the paper.

XQ. 134. On the possibility of reducing pressure in a bulb which has not been baked out?

A. As I said, I am not familiar with the paper. I have not seen it.

XQ. 135. Now, there was a reference also to a paper of Bessel-Hagen, which I think was Defendant's Exhibit No. 4. Does this paper tell how to make a DeForest tube into a tube of the Langmuir patent?

A. The paper of Bessel-Hagen of course, has no reference to any specific object or vessel being exhausted, but it does describe the operation of an improved pump. In the description it does outline the degree of vacuum which was attainable by the pump which was eight-thousandths of a micron. It does speak of the necessity of thoroughly baking the walls, or baking the walls of a tube to a temperature of 300 degrees. He states the necessity of removing the film of air from inside the walls, which can be more completely done in addition to the baking process, by passing a discharge through the vessel.

Mr. Davis: I move to strike out the answer as not responsive.

Mr. Darby: I object to that. I think it is responsive.

The Court: It is argumentative, is it not? It is not a direct answer. Mr. Davis is entitled to a yes or no answer, is he not?

Mr. Darby: What does the——

The Court: Do you want the question read? (Record repeated as recorded.) I do not know whether from that answer it does or does not tell how to convert a DeForest tube of 1912, say, November 1st, 1912, into a tube having the degree of vacuum called for by the Langmuir patent.

Mr. Darby: That was not the question.

The Court: I think it was. Then I missed it, Mr. Darby.

Mr. Darby: No, sir. I understood the question to be whether by Bessel-Hagen he could make a DeForest audion tube to have the higher vacuum; is that it?

Mr. Davis: His Honor's statement is correct; yours, if you will pardon me, is wrong.

Mr. Haight: I do not think, if your Honor please, that is a question of a kind that a witness should be bound to answer with a categorical yes or no. That is what my trouble is, as Mr. Davis' question does not tell you to do so and so. In terms, it probably does not, but to a man of science as Dr. Chaffee is, it does, and he proceeds to outline to you the things which tell him how to do it.

Mr. Davis: I beg your Honor's pardon. He has not said that these things tell him how to do it.

The Court: If he said, Judge Haight—no, not in terms, but in substance because—then I know what the answer is, but I do not know what the answer is now. I think the motion should be granted.

Mr. Haight: May I ask the witness this question to find out what he meant by his answer? Did you mean to convey——

The Court: Do your want the question reput before we take our adjournment, Mr. Davis? The motion is granted. Let the question be read to the witness by Mr. Smart. (XQ. 135 repeated as recorded.)

Mr. Haight: You can answer that practically, Doctor.

The Witness: May I remark that I did not consider that I had finished my answer to the previous question.

The Court: Will you begin again, Doctor, please.

The Witness: The question cannot obviously be answered yes or no, but as I attempted to point out, this paper by Bessel-Hagen outlines some of the necessary precautions to be used in making an alleged Langmuir device from a DeForest audion.

XQ. 136. Some but not all?

A. He does not speak specifically of heating the electrodes.

XQ. 137. Some but not all?

A. Some but not all.

The Court: Do you find, by following the instructions and applying that instruction to a DeForest audion, that you would get a Langmuir audion, just those instructions without them being supplemented by any other explanation at all, would you be able to convert the DeForest audion into a Langmuir audion?

The Witness: I believe you would able to convert the DeForest audion into a Langmuir audion, provided you worked below certain limits.

The Court: Touching this, let us finish that out.

Mr. Darby: Touching that, I would like to have him explain what the limits are, but I think that is a matter for re-direct examination.

The Court: Yes. Ten o'clock tomorrow morning.

(Whereupon, at 5 P. M. adjournment was taken until Wednesday, 20th of October, 1926, at 10 o'clock A. M.)

E. LEON CHAFFEE, resumes the stand.

CROSS-EXAMINATION (Continued).

By MR. DAVIS:

XQ. 137a. Going back for a moment to the Scheel & Hause article, have you read that article through, Professor Chaffee?

A. Yes, I have read the article through.

XQ. 138. What does he say in the article about the use of McLeod gauges and the limitations of the use?

A. The paper deals to a considerable extent, as I remember it, upon the reliability of the McLeod gauge when used for measuring the pressure.

XQ. 138a. Well, what conclusion did he reach; just read what he says about it?

A. I have not the complete article here.

XQ. 139. You have not the complete article. You have read the complete article, though?

A. Yes.

XQ. 140. Have you read it in German or in English?

A. I read the English translation.

XQ. 141. Do you read German, Professor?

A. Well, I do, yes, with some more difficulty than reading English.

XQ. 142. Which is excusable. You have not the translation here?

A. I have not, no.

XQ. 143. Or the German?

A. No.

MR. DAVIS: Unfortunately, I have not either, but we will have it a little later.

XQ. 144. Now, yesterday, we were speaking during the last of the day, beginning at page 668 of the record, of the Bessel-Hagen, which was Defendant's Exhibit No. 4, and in answer to cross-examination question 137 and the preceding questions, you said that this Bessel-Hagen article outlined some but not all of the necessary precautions to be used in making the alleged Langmuir devices from the DeForest audion—those were your words, "some but not all." Then, his Honor Judge Morris, asked you whether, by following the instruction, just those instructions without they being supplemented by any other explanation at all, you would be able to convert the DeForest audion into the Langmuir audion, and you said, I believe, you would be able to convert the DeForest audion into a Langmuir audion, provided you worked below certain limits; and I am not able to reconcile the two statements which you made, the one which you made in your answer to the Court, and the other in your answer to me.

A. May I explain my answer?

XQ. 145. I wish you would, please.

A. The methods outlined in the article by Bessel-Hagen would unquestionably be sufficient to convert a DeForest audion into one of the Langmuir type. I had in my mind when I made those reservations, certain rather unnecessary limitations at the time, so that I think I would like to withdraw those limitations.

XQ. 146. Then your answer is now that the Bessel-Hagen article, taken by itself and not supplemented by any other explanation at all, gives the information to convert the DeForest audion into the Langmuir audion; is that right?

A. Yes, sir; that is right.

XQ. 147. Have you a translation of the Bessel-Hagen article complete, I mean?

A. Not, complete.

Mr. Darby: I will get that for you, Mr. Davis. Unfortunately it is not here, but I will have it very shortly now.

XQ. 148. Then may we pass for a moment to the Edison Patent No. 411,019, which is Defendant's Exhibit No. 5. Does this in your opinion give such instructions as to convert the DeForest audion into the Langmuir audion——

A. Yes, I believe it does. The patent describes the necessary precautions to be taken in heating the walls to exclude the occluded gases and heating the electrodes and I am convinced that it does give the necessary data.

XQ. 149. And you would also say the same thing, speaking from the point of view of the last three patents in suit, and the kind of vacuum required for those patents?

A. Read that question. (Question repeated.) I cannot answer that question yes or no. The patent contains some of the essential processes for obtaining the high vacuum, as for the last three patents, as to whether Edison, as shown in this patent, pushes these processes to the limit necessary for the last three patents. I have no way of determining. This is merely an account of the process.

XQ. 150. Do you know what effect phosphoric anhydride would be on the atomic film of thorium of the last three patents?

A. I hesitate to answer that question, because my training is not especial in chemistry, but——

XQ. 151. If you do not know, do not say, Professor.

A. Just cross out that part.

Mr. Davis: Please understand that I am not asking you to surmise anything in this cross-examination. If you do not know a thing, do not hesitate to say so. Nobody knows everything.

Mr. Darby: I hope that does not carry an implication, Mr. Davis, that the witness is testifying about things that he does not know.

Mr. Davis: I did not mean to convey any such implication. I simply want to show the witness that it is not a disgrace not to know a particular thing. I do not want guesses.

THE COURT: I missed that.

MR. DAVIS: I do not want guesses.

THE COURT: Yes, I did not understand at first.

XQ. 152. Do you happen to know what the vacuum was in carbon lamps about 1889?

A. The vacuum as I understand it, in carbon lamps of that period, would be pretty nearly anything from a micron to higher vacuum. I say a micron. I am not placing that as any perfectly definite limit. It is merely an estimate.

XQ. 153. Then, I judge a micron is good enough for carbon lamps?

A. No, I did not imply that.

XQ. 154. What was good enough?

A. That again is an indefinite question, because the better the vacuum, the better the lamp, the longer the life.

XQ. 155. They were making in those days, and let us make it 1886, as the application was filed in 1886, and our attention has been called to the Davis-Bournonville case, 1886—there was a substantial business being done in this manufacture and sale of carbon filament incandescent lamps in those days, was there not?

A. Yes, that is correct, of course.

XQ. 156. And there was really only one type that amounted to anything, was not there?

A. The carbon lamp.

XQ. 157. Only one size and voltage that amounted to anything commercially, the sixteen-candle power, 110 to 120-volt lamp; that was the only lamp that anybody cared about, was it not?

A. Were there not 220-volt lamps at that time? It is my impression there were.

XQ. 158. You are testifying, Doctor, and I am not; but I was under the impression that the 220-volt lamp was a very little-used thing. Do you know any circuits in this country on 220 volts today?

A. Yes, I do.

XQ. 159. Where are they?

A. There is one in Concord, New Hampshire.

XQ. 160. There was one in Providence, was not there?

A. I do not know about that.

XQ. 161. But they are concrete instances, are not they?

A. The 110-volt circuits are certainly more common.

XQ. 162. Infinitely more common, is it not, a thousand to one in the use of lamps?

A. That I can not say.

XQ. 163. Something like that, so that the commercial lamp in 1886 was the 110-volt to 120-volt, sixteen-candle power carbon lamp, was it not?

A. The most common lamp at that time, yes.

XQ. 164. Have you any reason to doubt that that is what Edison was thinking of when he took out this patent?

A. There is nothing in the patent restricted to 110-volt lamp, but if that was the most common one, why, it applies to that as well as to the 220-volt.

XQ. 165. What type of vacuum was commercial in lamps of that kind, as they were sold?

A. I do not know, because I never measured any of those vacua.

XQ. 166. How does the electron emissivity of carbon compare with that of tungsten?

A. At the same temperature?

XQ. 167. Yes, at the same temperature first?

A. I do not carry figures, of course, in my head, but the emissivity of carbon is probably less at the same temperatrue.

XQ. 168. Considerably less, is it not?

A. Well, I stated it was less. I would not want to say considerably until I refreshed my memory on figures.

XQ. 169. And the temperature of the operation of the carbon lamp was considerably lower than that of the tungsten lamp?

A. That is correct, yes.

XQ. 170. So that any disintegration of the filament by Edison current would be considerably less, other things being equal, in the carbon lamp than in the tungsten lamp?

A. Are you speaking of normal operation?

XQ. 171. Yes.

A. May I have the question read once more?

(XQ. 170 was repeated by the stenographer.)

A. Offhand I am not prepared to say that it would.

XQ. 172. What is the vapor pressure of vaseline at room temperature?

A. Well, Mr. Davis, I do not carry all those figures in my head.

XQ. 173. Order of magnitude only. It is a micron, isn't it?

A. It is of that order of magnitude.

XQ. 174. The patent says (quoting line 34, first page of the patent). Under those circumstances would you expect to get a high vacuum?

A. I must have heard the reference incorrectly.

XQ. 175. It is line 34.

A. Yes, I found the place where it speaks of using vaseline. If no precautions were used to condense the vapor of vaseline, of course the vapor of vaseline would be present in the bulb. Of course, the method as outlined here is specifically for pumping incandescent lamps and any physicist who is endeavoring to obtain a high vacuum, not specifically that in incandescent lamps, would certainly realize that the vapor pressure of vaseline is sufficient to impair the vacuum and he would take precautions to get rid of that. That is a mere detail in the method of pumping here. It is a mechanical convenience.

XQ. 176. Edison was trying to get a vacuum which is of a different order of magnitude from the vacuum which we are discussing in this case, isn't that so?

A. Edison was certainly endeavoring to get a good vacuum in his lamp. I do not know that Edison appreciated at that time to what extent he would have to go.

XQ. 177. May we leave the patent with the statement that what it really shows is that in exhausting a lamp it is or may be desirable to heat the bulb and the filament?

A. I am sorry, I have to ask you to read that again.

(XQ. 177. Repeated by the stenographer.)

A. That is correct.

XQ. 178. Now look at the Malignani Patent, 537,693, which is Defendant's Exhibit 6. I will first ask you if you ever heard any one using the process of the Edison patent we have been talking about?

A. Personally I have not.

XQ. 179. You have heard of the Malignani process being used?

A. Yes, sir.

XQ. 180. This was a patent on the chemical exhaust, was it not?

A. The exhaust as an adjunct, yes.

XQ. 181. What the lamp people call the chemical exhaust?

A. Do you refer to the term Getter?

XQ. 182. The term you find in the art, you will find the expression chemical exhaust, that is in a paper you produced.

A. Quite right, and I referred to that under the same name.

XQ. 183. And the Malignani patent was the patent on what you call a chemical exhaust. It is refreshing at last to get something that did amount to anything in the world. This process was used on a large scale?

A. Yes, that is my understanding.

Mr. Darby: May I move to strike out the statement of Mr. Davis?

The Court: Motion is granted.

XQ. 184. The patent specifies what materials as the materials to be vaporized, line 20, page 1?

A. Yes. The materials used are as stated in the patent, arsenic, sulphuric or iodine.

XQ. 185. It says to generate gases or vapors such as arsenic, sulphuric or iodine. Do you suppose he means to put sulphur in there?

A. In reading over this patent I was uncertain as to just what he meant by the term sulphuric.

XQ. 186. Do you know what was actually used in the Malignani chemical process, what material?

A. So far as I know, not being intimately connected with the incandescent lamp art, except what I have read, of course, phosphorus was one of the common materials.

XQ. 187. Phosphorus was the ordinary chemical used for that purpose?

A. It was one of them.

XQ. 188. Do you know of any other?

A. I cannot speak from any knowledge of what was used, having no acquaintance with the industry.

XQ. 189. Do you know what the vapor pressure of arsenic is at room temperature?

A. I do not. I do not carry those figures.

XQ. 190. It is rather considerable?

A. Even on that point I do not know because arsenic is not a common element around the laboratory.

XQ. 191. How about iodine?

A. Iodine would have considerable vapor pressure at room temperature.

XQ. 192. Does this patent contemplate a deposit on the globe?

A. The deposit on the inside of the globe can hardly be avoided by the process.

XQ. 193. As a practical matter, of course, it was not very desirable in a lamp, was it?

A. Of course, any deposit on an incandescent lamp would obstruct the light passing through the globe.

XQ. 194. That was one of the objects of the lamp, to generate light?

A. Quite right.

XQ. 195. So that they would naturally reduce that to the very utmost minimum that was possible?

A. That is quite right.

XQ. 196. Now, the process of Malignani was this, that he pumped some kind of a vacuum in the ordinary way perhaps with a mechanical pump and then he sealed off the bulb and he provided somewhere in the lamp a little quantity of these materials, whatever they are, such as arsenic. Having sealed off the lamp he heats the place where this material is and vaporizes a certain amount of it in the lamp, is that right?

A. I believe that is essentially correct.

XQ. 197. The preliminary exhaust in this case he mentioned as being two millimeters of mercury, at line 36?

A. I should imply by that statement that the exhaust should be carried to at least two millimeters.

XQ. 198. It says about two millimeters, does it not?

A. Yes, those are the correct words.

XQ. 199. How many microns is two millimeters?

A. Two millimeters is equivalent to two thousand.

XQ. 200. So that that is two thousand microns at that stage. Then what does he do, he heats the filament by passing a current through it, does he not?

A. Yes, sir.

XQ. 201. And something happens that gives him a better vacuum, is that right, Professor?

A. Yes, that is quite right.

XQ. 202. You refer to that as a chemical exhaust. It is actually an electro-chemical exhaust, is it not?

A. I do not think in my reference that I made any distinction, or I have not placed them in any limiting category. The chemical exhaust includes those processes which make use of chemicals to increase the degree of vacuum.

XQ. 203. I was not criticising you, Professor; I think the term is generally used, chemical exhaust. I am trying to simply bring out that there are two kinds of chemical exhaust, one in which the action is purely chemical and the other in which the action is electro-chemical?

A. I understand your point.

XQ. 204. In this case the action is electro-chemical?

A. It is both, I should say.

XQ. 205. When this filament is glowed by passing a current through it, a blue glow fills the bulb and then disappears; is that right?

A. That is right.

XQ. 206. You do not know what vacuum is produced in that way, in figures?

A. Are you asking what vacuum is possible?

XQ. 207. What vacuum was actually produced in the commercial manufacture of lamps by this process?

A. No, I am not familiar with the——

XQ. 208. The action is merely a clean-up action?

A. Yes, it is a clean-up action.

XQ. 209. Will it clean up mercury?

A. My recollection is that mercury will be cleaned up by some of the chemicals.

XQ. 210. I am talking about this patent. This patent mentions arsenic, sulphuric, whatever that is, and iodine.

A. I am not positive on that point.

XQ. 211. Will it clean up argon?

A. My impression is that argon would be cleaned up to a small extent.

XQ. 212. Here again there was no reason for producing a vacuum of any such order of magnitude as one one-hundredth of a micron, was there?

A. There was no limit placed in the patent, but here again, if I may remark, this patent outlines methods which can be utilized for the production of high vacuum.

XQ. 213. But it does not by itself tell you how to make the DeForest audion such as Hewitt dealt with in 1912, into the audion of the patent in suit. For instance, if you had iodine in there you would have vapor pressure very much higher than you could tolerate in the tube?

A. That is correct.

XQ. 214. So that it does not tell you how to do it; isn't that right?

A. This single patent taken alone does not give you the necessary instructions for doing that.

XQ. 215. Defendant's Exhibit 7, Dwyer patent, application filed in 1897, No. 596,654, you have read this patent?

A. I have.

XQ. 216. Are the statements in the specifications true?

Mr. Darby: I think I object to the form of the question.

(Discussion.)

The Court: You have asked him if he had read it and he said he had. Now, you have asked him whether the statements of fact therein contained are true and correct.

Mr. Davis: Yes.

The Court: I do not see that the answer will do any harm.

A. To answer that question I would have to have time to read it through critically. If you want to refer me to some special place, the specification is two whole pages long, and I do not want to make any premature statement one way or the other without critically examining it.

By **The Court:**

X. 217. From your former examination of the patent, do you now recall any statements therein made that are not true and correct so far as your knowledge goes?

A. No, I do not recall any questions or points at the moment.

By **Mr. Davis:**

XQ. 218. Will you look at the sentence beginning on line 26 on the first page:

> "With partial or incomplete vacuum, but one not carried sufficiently high to serve the purpose of the best grade of incandescent lamps, is readily obtained by a good mechanical or mercurial pump, but it is in the removal of the residual gases remaining after such exhaustion that the greatest difficulty is encountered. Since that part removed by each stroke of the pump or by the successively falling drops of mercury in the case of a Sprengel pump becomes continually smaller and smaller, being simply a certain fraction of the expanding remaining gases; and soon a limit is reached which

is still, however, below the desired vacuum beyond which no further exhaustion by this means is possible."

Is that a correct statement of scientific fact?

A. If I understand your question, there is given here a statement about the use of mercurial pump and especially referring to the Sprengel pump. It is my impression that the Sprengel pump will produce, excluding the mercury vapor or water vapor, will produce a very good vacuum.

XQ. 219. Then you do not think this statement is correct?

A. I fail to see anything incorrect in it.

XQ. 220. The statement says there is a limit "Soon a limit is reached which is however still below the desired vacuum," which I take to mean the vacuum desired in a carbon incandescent lamp?

A. I should attribute that same statement from a practical man. I thoroughly believe that the Sprengel pump is capable of going to a high vacuum but perhaps in the pump in which the mercury is dirty, or the pump has not been cleaned recently there may be practically a limit in that particular pump.

XQ. 221. So that whatever the situation may have been in 1897, when this application was filed, in the Cavendish Laboratory at Cambridge, or other great laboratories in the world, the practical man working in the incandescent lamp art found according to this patent that he could not pump the relatively poor vacuum required in a carbon lamp with this kind of mercury pump?

Mr. Darby: I object to the question, because it calls upon the witness to make an assumption as to this laboratory in Cambridge and some other things for which there is no foundation.

The Court: The question is put from a

slightly different point of view than they are usually put, but it is asking the witness as I understand it, what the disclosure of this patent really is on that point.

Mr. Darby: I have no objection to a question worded that way.

The Court: Mr. Davis has interpolated in his question, "according to this patent," and I understand his question to call for an interpretation of this specification by this witness.

Mr. Darby: The form of the question, however, I still submit, if your Honor will permit me, is entirely objectionable because it is argumentative.

The Court: I think it possibly is open to some objection on that score, but the real substance of the question is an interpretation of the specification by the witness.

Mr. Darby: I have no objection to the substance.

The Court: It is so interpreted and I will overrule the objection.

A. I will answer the question in this way, that to my mind when I read over the specifications, there was no question but that the mercury pump, the Sprengel pump, if you please, is capable of producing what we might term a high vacuum. Of course, that is excluding the vapor pressure of mercury or any other condensable vapors.

XQ. 222. And now, Professor, please answer my question.

A. Your question was whether, as I understand it, this statement is correct or incorrect.

(The stenographer repeated XQ. 221.)

XQ. 223. Either yes or no. That is a question that can be answered yes or no. It is either so or it is not so, according to this patent.

A. It seems to me that that question cannot be answered yes or no.

By The Court:

Q. 224. Do you find from your examination of that specification, that it discloses that the pump in question was not adequate to create a sufficient vacuum?

A. Yes, your Honor. As referred to——

Q. 225. Mr. Davis limits his question to the disclosure as embodied in the specification.

A. Yes.

By Mr. Davis:

XQ. 226. Then the answer to my question is yes?

A. Yes.

XQ. 227. You stated at page 505 of the record:

> "Then further pumping, and finally heating the filament to a high temperature which vaporizes the reagent, phospherous, for instance, and causes a high vacuum because of the combination of the vaporizable reagent and the gases in the tube."

Is that the process disclosed in this patent? You may look at page 505, beginning the third line of the typewritten record.

A. I have read my answer which I gave in my former testimony and it is correct.

XQ. 228. Please point out in the patent where it speaks about the combination of the vaporizable reagent and the gases in the tube?

A. From a very hurried glance over the specification, I do not find any specific reference to the chemical combination, but I think that is implied and certainly meant to mean that very thing, because of the prior art. Malignani for instance.

XQ. 229. The theory which is stated in the patent of the actions is an entirely different theory from that which you stated in your definition, is it not?

A. I certainly do not so consider it.

XQ. 230. The theory stated in the patent—now see if I am right—the theory stated in the patent is that in order to get these gases out which remain after the pumping has been carried as far as possible to carry it, with whatever means he has, he vaporizes some phosphorus, and the phosphorus vapor displaces the other vapor which passes out into the pump and then seals off and the phosphorus condenses and thereby he gets a better vacuum. Is that the theory stated in the patent?

A. He outlined in the specifications the process that you have outlined, yes.

XQ. 231. And that is the theory on which his invention purports to be based, is it not?

A. In answer to that question I would like to make this statement; To me, in putting in this reference, and it seemed clear to me——

XQ. 232. Excuse me. I wonder if you could not answer my question first, and then make your statement after?

A. Put the question once more. (XQ. 231 repeated as recorded.) That is the theory advanced by the applicant.

XQ. 233. As the basis for the invention?

A. Yes.

XQ. 234. Now, any statement you care to make, we would be glad to hear it.

A. This patent follows the patent to Malignani. Malignani uses the chemical method of obtaining a high vacuum. It appeared to me it was merely another method of using the chemical getter, and without question in my mind, would act as the chemical getter of the Malignani patent.

XQ. 235. You think something would happen then which is not disclosed in the specification?

A. I think that which I have stated would happen, yes.

XQ. 236. Of course, you realize as well as I do, probably better, that the theory which he suggests is an erroneous one?

A. Yes.

XQ. 237. That the action which he suggests would not take place. That is, the vapor pressure of the phosphorus would be independent of the gas pressure of whatever gases were in there?

A. Yes, sir.

XQ. 238. They would diffuse separately, independently of each other?

A. Yes.

XQ. 239. So that his idea of the phosphorus displacing the other gases is fundamentally wrong, unscientific?

A. I think there is some truth in his theory; that is, that whether or not the end result is—or rather, put it this way—whether or not the deposit on the film will have an appreciable vapor pressure, it is really perfectly possible to displace a permanent gas or gases by means of some substance which will later condense and therefore produce a higher vacuum.

XQ. 240. You will notice, referring to line 14 on page 2, that he is going to have the least possible, or the least permissible amount of foreign substances, because it has a film on the inner surface of the lamp bulb, because otherwise he would tint the lamp; you notice that?

A. Yes.

XQ. 241. Do you think the amount of phosphorus which he could get into the lamp that way, would displace the gases and enable a pump that was not good enough to make a lamp vacuum—make such a vacuum without chemical action?

A. Oh, I think it would help, yes.

XQ. 242. I think we can agree then that this patent does not tell us how to make the Langmuir tube; is not that right?

A. Yes, that is right, taking this patent alone—

XQ. 243. I beg your pardon; did you finish your answer, Professor?

A. But there ~~is~~ implied in this patent the chemical method of obtaining high vacuum, which is a possible method to adopt.

XQ. 244. And you never knew of any one using the particular process of this Dwyer patent?

A. No, personally not.

XQ. 245. And you notice that he uses iodine also?

A. Yes, I know.

XQ. 245a. Which has a high vapor pressure?

A. That is quite right, but iodine is not the only substance used.

XQ. 246. It would, however, convey to your mind, the mind of an expert, the idea that whatever the vapor pressure of iodine was, that was a pressure [illegible] he could tolerate in the vacuum he tried to get, would it not?

A. Yes, that is quite right.

XQ. 247. Of course you could not think of tolerating it in the modern vacuum tube?

A. No, you could not, that is correct.

XQ. 248. Now, I have here a paper which I understand to be a photostat of the Scheel & Hause article. Perhaps you would be good enough to look at it and tell me if it is (handing paper).

Mr. Davis: It may be there were two Sheele & Hause articles. I wish you would check and see if there were two, and that this is the right one. I am not sure.

The Witness: I believe this is not the one to which I referred.

XQ. 249. And you think that is the article, the earlier article referred to in the one to which you did refer; in that case, perhaps we need not trouble you about it?

A. Yes, sir.

XQ. 250. Now, there is an article by Duncan, which is Defendant's Exhibit No. 8; have you the complete article?

A. Not here, no, I have not.

MR. DAVIS: Will we have the complete article available, Mr. Darby?

MR. DABRY: Yes, sir. I have it right here.

XQ. 251. On page 510 of the typewritten record, you said: "This article very clearly describes the necessary precautions which must be taken to obtain a high vacuum," and when you said "high vacuum," did you mean the high vacuum of the first patent in suit?

A. I did.

XQ. 252. And does it describe means for maintaining that vacuum during the practical operation of the tube?

A. I do not believe I referred to that.

XQ. 254. I beg your pardon.

A. May I have the question read. I am sorry. (Question repeated as recorded.) Although I find no specific words to that effect, the presumption is that since he outlines in this article methods of pumping Crookes tubes, the presumption is that he—no, on second thought, I do not think that this necessarily deals with the maintenance of the vacua.

XQ. 255. Now, to come back to the production of the vacuum, the object set forth in this article is the evacuation of the Crookes tube, is it not?

A. That is quite right, it is.

XQ. 256. And the vacuum of the Crookes tube is of a different order of magnitude from the vacuum of such a tube as defendant's tube D-5, is it not?

A. That is correct, yes.

XQ. 257. So that whatever Mr. Duncan may have succeeded in disclosing what he was trying to do was to make a Crookes tube vacuum?

A. That is correct.

XQ. 258. With that cold cathode——

A. The cathode was cold in the sense that it was not heated by any filament or heating coil, but of course, during the operation of the tube or during the pumping process, the cathode would be somewhat heated.

XQ. 259. What would heat the cathode during the operation of the tube?

A. Positive ion bombardment.

XQ. 260. Positive ion bombardment?

A. And also, of course, general conduction of heat from the tube as a whole, when it is operated.

XQ. 261. The latter being relatively a very small effect?

A. Yes.

XQ. 262. Practically speaking, it is the positive ion bombardment that heats the cathode?

A. In this type of tube, yes.

XQ. 263. That does not exist in the tubes of the patent in suit, does it?

A. It does not to any extent.

XQ. 264. Then perhaps your statement amounts to this, that you believe that the precautions which were ordinarily used in the manufacture of a Crookes tube might be developed, extended and carried on to such an extent as to produce the vacuum tubes in issue?

A. That is exactly what I mean, that there are disclosed in there all the necessary precautions which are necessary to produce a sufficiently high vacuum.

XQ. 265. But disclosed in such a way as to produce a very different vacuum?

A. Of course, the practical object there was to arrive at a somewhat lower vacuum than exists in the ionic devices.

XQ. 266. Because if Mr. Duncan or anybody reading his article had produced in a Crookes tube the vacuum which we have been talking about in this suit, and had handed the tube to a doctor, the doctor would have given it back to him as being useless, would he not?

A. I am not so sure about that. I think it is perfectly possible that the vacuum which was attained in some of the Crookes tubes might be high enough to make a DeForest audion work as a so-called Langmuir device. Now, bear in mind that Crookes tubes are very different in their structure. They have the terminals far apart, and they are sometimes used for producing very penetrating rays, which necessitates a higher vacuum, so off-hand I do not want to say that the vacuum here is not high enough for the Langmuir device. I will go so far as to say that many of the Crookes tubes do work at pressures which are higher, certainly.

XQ. 267. Now, let us look at a Crookes tube and see what it does. Take an X-ray tube. We all agree, don't we, that it is what they call a self-sustaining discharge in the old literature?

A. Yes, that is the common term.

XQ. 268. And that, I think Professor Millikan spoke of it this morning, that the mechanism of current conduction is based on ionization of the gases?

A. Yes, that is quite right, in the case of the Crookes tube.

XQ. 269. I am talking of X-ray tubes of the art, at or around the time at which this paper was published, the ions produced by the ionization, dropped back to the cathode, to strike a blow, and knock out electrons, is not that what happened?

A. That is the accepted theory.

XQ. 270. And these electrons go across the tube and on the way across the tube, they may produce more ionization, and then produce more ions, and so on; is that right?

A. That is essentially correct.

XQ. 271. When you operate an X-ray tube, as you told me, I think, yesterday, there is a tendency for the vacuum to get higher and higher, due to what is called the "clean-up" effect. Finally the time comes that the tube will no longer carry current. Why will it no longer carry current?

A. Of course, the reason that it no longer carries current is because there is not sufficient gas in there to support the conduction.

XQ. 272. There is no longer enough gas in there, so that there can be a current which is caused and conditioned by ionization?

A. That is right.

XQ. 273. Is there not quite a margin between that vacuum and the vacuum of the tube of this issue?

A. But of course one has to take into account a lot of other factors, that is the distance between the terminals in an X-ray tube is of a very different order from the distance between the terminals of these thermionic devices.

XQ. 274. Well, of course, you are also taking into consideration the fact that the X-ray voltage was pretty high, was it?

A. Oh, in the thousands of volts.

XQ. 275. Thirty thousand, say?

A. That would certainly be within the range. It may be less, or it may be more.

XQ. 275a. And the voltage across one of these tubes such as the D-5, is what? What is the voltage?

A. I am not very familiar with the D-5 spoken of as type D-5. I would want to know—if I could see the tube, I could probably say.

The Court: He is not being cross-examined any way on the question of infringement, I take it, Mr. Davis?

Mr. Davis: Oh, no.

The Court: And really what you want to know is the modern vacuum tube, is it not?

Mr. Davis: I take it the modern vacuum receiving tube; that is what I am speaking of, your Honor. Of course, your Honor knows the tubes run to thousands of volts.

The Court: I was wondering whether the confusion had not arisen by restricting the witness to a specific device made by the defendant.

Mr. Davis: I beg your Honor's pardon.

XQ. 276. The ordinary receiving tube which ordinarily runs about 100 volts on the plate, does it not?

A. Yes, from 20 to 150.

XQ. 277. You have taken that into consideration when you were speaking of this question of distance apart, and so forth?

A. Yes, I meant to include the difference in voltage and the difference in distance, and the difference in shape of the terminals.

XQ. 278. That is to say, when you gradually increased the vacuum in the X-ray tube by clean-up, and get to the point where the current ceases to flow, now let us think of that tube, and not go off into some other tube—that tube is not in the condition of this issue, is it, of this invention?

A. Why, the chances are that the pressure in that tube would be perhaps too high, but as I said before, I am not at all sure but that you could get the three-electrode tube working on low voltages to come within the specifications of the patent in issue.

XQ. 279. Perhaps I am not making my questions clear, Professor. I am not talking about absolute magnitude of vacuum. I am talking about operation of the tubes. Now, let us suppose we had a tube which had a hot cathode in it, but which was otherwise built like an ordinary X-ray tube of the prior art, such a tube as are being dealt with in this Duncan article, and that we do not light the cathode, so that it becomes, to all intents and purposes, an ordinary X-ray tube, and we run it as an ordinary X-ray tube, we will have to have some method to prevent that cathode from being destroyed by the bombardment, but if you will make that assumption, we will go on. We run that tube until it cleans up, and you cannot get any more current through it. Now, light the cathode; is it the tube of this issue or not?

Mr. Darby: Will you state the voltage to make the question complete, Mr. Davis?

XQ. 280. The voltage must state itself. Let us assume we are talking about—I cannot state the voltage; I am not sufficiently technical; I do not know what voltage the tube would back up.

Mr. Darby: I object.

The Court: Unless some length of the voltage is given, it seems to me the question is incomplete, and all you ask is the range.

Mr. Darby: The range. Your Honor will appreciate the claims of the patent are below 40 volts.

Mr. Davis: I will ask the question about any voltage above the ionization range, say 40 or 50 volts, along that, and of course I assume the tube is not being saturated.

A. I hesitate to answer the question positively, because again, it depends upon the distance between electrodes; but I will say this, that the pressures in an ordinary Crookes tube are usually considered to be, and I consider them to be, on the average, higher than the pressures existing in these thermionic devices; but again, it is not clear—or rather, I am under the impression that it may be possible, with a suitably arranged condition to obtain a thermionic device, working with the voltages above ionization and pressure, which exists in some Crookes tubes, when they cease to operate, which would operate according to the specifications of the patent.

XQ. 281. Have you read this Duncan article through, Professor? I do not mean just a little extract from it that is in that book that you happen to have in your hand, but I mean the whole article.

A. I believe I have.

XQ. 282. There is a paragraph here which may help us if we are to know what Duncan is talking about—do you believe that, by the way?

A. That he knows what he is talking about?

XQ. 283. Yes.

A. I believe I do.

XQ. 284. This can help us on another matter, that is, what the vacuum was in an incandescent lamp. You have already stated that the vacuum in the Crookes tube in general was substantially lower than the vacuum of the tube in this issue, although you thought there may be exceptions. What does this teach us as to the vacuum in an incandescent lamp?

> "I have tried eight Crookes tubes made by four different incandescent lamp companies, but with only one tube could I obtain any good results, the vacuum in the other seven being so low and poor that it was useless to experiment with them. They did not seem to have any better vacuum than that shown by an ordinary incandescent lamp. The one tube which bore all the characteristics of a genuine Crookes tube was made by a St. Louis company, and if all their lamps are exhausted in as thorough a manner as exhibited by

> this tube, they must undoubtedly receive credit for it.
>
> "There seems to be one thing certain, and that is, if any one undertakes to make Crookes tubes for skiagraphing through opaque matter, they will have to improve upon the ordinary practice and methods employed in exhausting lamps."

You gather from that that the lamp vacuum is inferior to the Crookes tube vacuum?

A. Of course, the points at issue are quite different in the two cases. The lamp manufacturers are interested in getting a long life, and he does not care about the numerical value of the vacuum or whether he has positive ionization to any extent; of course, he does not want the appearance of the blue glow whereas the Crookes tube manufacturer is after a certain definite result, to impress a certain voltage on the tube and the penetrating power of the rays depends on that and so the aim of the manufacturer is quite different.

XQ. 285. I do not know that that is quite the point. I was wondering whether this statement here did not shed light on what the ordinary lamp vacuum was at that time regardless of what reason there was for it?

A. Duncan in that case was interested in pumping X-ray tubes and I would not vouch for his familiarity with the pressure in an incandescent lamp. I have no way of determining that.

XQ. 286. But you think he knows what he is talking about?

A. In connection with that, yes.

XQ. 287. I asked you if he knows what he is talking about in the article. There is an article by Dewar in 1898. This was supposed to produce a high vacuum, was it?

A. Not necessarily. I think in my testimony I remarked that this article was interesting because it showed the enormous absorbing power of charcoal cooled by liquid hydrogen. I did not state that the end result was a high vacuum in that case, because he started from an extremely high pressure.

XQ. 288. Then really the only point that you make of this article is as showing that liquid air, that charcoal and liquid air expedient is a good one, a helpful one?

A. It is to indicate the enormous absorbing power of charcoal and liquid air.

XQ. 289. And that is the only reason for which this article is produced?

A. That is it.

XQ. 290. Then the article by itself does not do any more than give us one tool, a sort of a pump, is that it?

A. Yes.

Mr. Davis: I want to be sure that the Court understands what this liquid air expedient is.

The Court: I think I understand, but will you not tell me so that I may be certain?

XQ. 291. I will ask the witness if it is anything more than this, having a tube connected to the vacuum system somehow, which tube contains charcoal. The tube is or has been highly heated to purify it and clean it and get the gases out of it. If you surround this tube with a cooling medium which in this case is liquid air, you get a considerable power in this charcoal of absorbing any gases which may enter the receptacle. Is that right, Professor?

A. That is right.

The Court: That is the way I understood it. We will recess until 2.20 today.

E. Leon Chaffee, resumed the stand.

Cross-Examination (Continued).

By Mr. Davis:

XQ. 292. You spoke of a publication of Lenard in 1900, Defendant's Exhibit 10. To what does that relate in general?

A. The article by Lenard in 1900, relates to the study of photo-electrons.

Mr. Davis: We have just had photo-electrons explained and there is no need of going into that again.

The Court: As I recall it, you dealt with that in your opening and the explanation corresponded to your statement.

Mr. Davis: I am very much complimented.

XQ. 293. The currents that were used by Lenard in these experiments as described in his paper were very minute, were they not, Professor?

A. Yes, the currents, speaking in terms of currents used in thermionic tubes were quite small.

XQ. 294. For example, how many watts of energy would be expended on the anode in one of these tubes of Lenard?

A. A very small amount, of course.

XQ. 295. I mean in numerical value? The current was what?

A. The current was of the order of 10 to the minus 7th or 8th amperes.

XQ. 296. Now, look at table 2 in the article. The quantity of escaping electricity is given in the table as coulomb. What is a coulomb?

A. That is the quantity of electricity.

XQ. 297. What is a coulomb second?

A. That is one ampere.

XQ. 298. The quantity given in the table is 10 to the minus 10th power coulomb seconds, is it not?

A. That is correct.

XQ. 299. And the largest current which is given in that table in the alleged high vacuum part of the table is 20.2, is that right?

A. That is right, but that would of course mean of the order of 10 to the minus 8th or 9th amphere.

XQ. 300. It is actually two times ten to the minus 9th?

A. Yes, sir.

XQ. 301. And at 10,000 volts. So, how many watts is that?

A. If I have done my arithmetic correctly, that is about two times 10 to the minus 5th watts.

XQ. 302. Which in the language which some of us understand more readily is 2/100,000 of a watt?

A. Of course, that is right.

XQ. 303. That was the energy of bombardment in that particular tube, is that right?

A. That is right. May I refer to table 1, in which he utilizes the potential of 45,000 volts? The current in that case is slightly larger.

XQ. 304. About twice that. That is it is about five one-hundred thousandths of a watt in the maximum case there?

A. It would be more than twice. It is 45,000 volts instead of ten thousand.

XQ. 305. Suppose you calculate it. There you have 24½ of these units and 45,000 volts.

A. That would be about one times ten to the minus fourth, I believe, if I have not made a mistake.

XQ. 306. That would be one ten-thousandth part of a watt?

A. That is correct.

XQ. 307. So that the problem of heating the anode by the discharges did not present itself to Lenard?

A. Certainly not.

XQ. 308. You notice he says in the paper:

> "As the immediate source of the quanta or our rays the illuminated electrode is indicated,"——

quanta what does he mean by quanta?

A. Will you give me a more definite reference to that?

XQ. 309. I am on page 8 of the typewritten translation.

A. He uses quanta there as we would use electron, if I remember or understand the reference.

XQ. 310. If you look at page 14 of the book that you have, the first unfinished paragraph at the top of the page, I think you will find the sentence to which I was referring——

> "While in the usual discharge tube the source of quanta appears to be the gas which is there indispensable."

Is that the way it reads in your book?

A. Yes.

XQ. 311. My translation reads:

> "While in the usual discharge tube it appears to be the indispensable gas."

I suppose in either case the meaning is the same. That is, Lenard is stating that he is contrasting his tube in which the emission is produced by the impact of light on the cathode with the usual tube in which he says the presence of gase is indispensable to the emission of the electrons; is that right?

A. I think that is essentially correct, yes.

XQ. 312. How did Lenard observe his rays, how did they issue from tubes?

A. I cannot seem to find any direct reference to his measuring instrument, but I have reason to believe that it was an electrometer.

XQ. 313. Did he not observe what was going on in the tube by a window which was in the tube? Perhaps I can put it a little differently and help the doctor. This light which passed into the tube had to pass through a window?

A. Of course, that is true, but that is not the way I understood your question.

XQ. 314-15. Perhaps my question is quite wrong. I was thinking of a window through which the light passed into the tube. That was a quartz window, was it not?

THE COURT: Suppose we take our afternoon recess.

(Here a short recess was taken.)

By MR. DAVIS:

XQ. 316. Have you found the window, Prof. Chaffee?

A. Yes, I did.

XQ. 317. What was it?

A. It was described as a quartz window through which the light which caused the emission of photoelectrons passed into the tube.

XQ. 318. You say—this was a quartz plate, a plate of quartz?

A. Yes.

XQ. 319. You say that fastened to the glass?

A. That was probably cemented on by some cement.

XQ. 320. What would the vapor pressure of that cement be?

A. I can not say. There are cements which have quite low vapor pressures.

XQ. 321. Now, you gave this as an illustration, as one of the references, did you not, to bombarding electrodes?

A. I believe I did, yes.

XQ. 322. Now, just exactly how do you justify that statement?

A. In the article and the quotation which I gave in my former testimony:

> "By prolonged heating and the discharge of a large inductorium we bring the tube into the steady condition in which it no longer passes the discharge through, the discharge passing outside around the tube."

XQ. 323. That is, this prolonged heating and discharge brought the tube to a vacuum which was as good as the vacuum in an X-ray tube, when it refuses to pass current; is that what that means?

A. No, I do not think you can say that, because in this case, the distances between the electrodes are not the same as the distances between the electrodes in X-ray tubes, and I might have pointed out, when we were discussing the X-ray tubes, that if the distance is large between the terminals, there is a larger chance for the electrons passing between the terminals to meet ions, and thereby ionize them, and on the other hand, if the distance is small, even for the same voltage, there is less chance offered for ionizing the gas; so, of course, the distance between the electrodes makes a very great difference. I do not think you can compare this directly with an X-ray tube.

XQ. 324. What was the distance between the electrodes in the ordinary X-ray tube?

A. Of the order of magnitude of three inches probably.

XQ. 325. And what was the distance here, roughly?

A. I do not see any reference to the distance, but I say judging from the diameter of the electrode U, which he states as being one and one-half centimeters, that the distance is about that order of magnitude, about a centimeter or so.

XQ. 326. And therefore this vacuum might have been higher than the X-ray tube, non-sparking X-ray tube vacuum, the distance in this case being a centimeter and a half?

A. Yes.

XQ. 327. That is your view, is it?

A. It might have been higher, or it might have been of the same order of magnitude—I do not know.

XQ. 328. I thought it took more voltage to break down a long gap than it did to break down a short gap?

A. That is a very complicated phenomenon that cannot be explained in a few words.

XQ. 329. Well, in this case, all you know about this vacuum is that inductorium spark coil did not put the current through it, and the distance between the electrode was a centimeter and a half, which is about half an inch, about half an inch, is it not to a centimeter?

A. There are two and a half centimeters to an inch, a little over half an inch.

XQ. 330. So that we have this gap which is a little over half an inch and we know that a spark coil would not spark through it. In the case of the X-ray tube, we have two or three or four inches gap, and in that case, the spark coil won't spark through it, and my impression would be, and I am asking you why, if it is wrong, that it would take less voltage to spark through a short gap than through a large one at the same vacuum?

A. That is not necessarily so, I believe.

XQ. 331. I won't trouble you to explain if I am wrong, just say so. Is it your view that these facts which we have developed, indicate that the vacuum which Lenard secured was higher or lower than the vacuum which we were speaking of in the X-ray tube, where it just ceases to pass current?

A. I should say it is of the order of magnitude of the vacuum of an X-ray tube which has ceased to function.

XQ. 332. So that there is no indication here that he had vacua substantially higher than an X-ray tube vacua, when that tube gets hard and won't function?

A. No, but there is an indication that he has described methods which anybody could follow and attain, a very high vacua. He has described practically all of the necessary precautions, all of the necessary methods; heating the walls, the bombarding, and so forth, all the necessary methods.

XQ. 333. He had mercury in there, did he not?

A. Not to any extent, no.

XQ. 334. Why not?

A. Because he had a tube in which he had phosphorus pentoxide and that tube was cooled by solid carbon dioxide in ether, and that tube containing the phosphorus pentoxide was located between the tube being exhausted and the pump, and that would be sufficient to exclude mercury vapor, or at least to reduce the amount of mercury vapor in there to a negligible amount or to an amount which would have no harmful effects.

XQ. 335. He used that tube once, did he not?

A. I do not know as I draw the conclusion that he used it once. He says that the use of that tube did not make any difference in the observations.

XQ. 336. So here again, the importance of the citation seems to be not in a particular vacuum which he attained, or any particular action in his tube, but the statement that it is desirable to take certain precautions when you want to get a vacuum; is that right, Professor?

A. My point is—read that, please. (XQ. 336 repeated as recorded.) Yes, that is quite right. Of course that is just the point of citing the article that he described methods by which anybody, any physicist could attain high vacua.

XQ. 337. And there was a vessel containing phosphorus pentoxide which normally was not cooled, located between the tube and the pump, was there not?

A. It may have normally not been cooled, but it was cooled for certain experiments, as I have indicated.

XQ. 338. Now, in certain cases I think you said that was cooled with solid carbon dioxide and ether. Was that a satisfactory and sufficient precaution for keeping the mercury out?

A. Now, satisfactory and sufficient for most work, yes, of course. The vapor pressure of mercury at the temperature of solid carbon dioxide is very, very small. That would be quite sufficient in exhausting tubes which would come under the patent specifications of the patent in suit.

XQ. 339. Well, for example, if we take the DeForest audion, such as Dr. Jewett saw in November, 1912, would that precaution have been sufficient for exhausting that to make it into a tube of the patent?

A. Certainly.

XQ. 340. How do you practically get solid carbon dioxide; how is it procured?

A. Solid carbon dioxide is usually procured by allowing the liquid carbon dioxide which is contained under a tank in high pressure, to escape rapidly and through the cooling action of the escaping gas, some of it is frozen into the solid snow. I have used it many, many times.

XQ. 341. That is a well-known thing?

A. Very well.

XQ. 342. And has been for many years?

A. Yes.

XQ. 343. And where did you get the liquid carbon dioxide?

A. The liquid carbon dioxide is procured from companies who manufacture it, I think largely for the soda fountain industry.

XQ. 344. So that is also a common article of commerce, is it?

A. It is very common, yes. I am not sure how long it has been common. I have not any knowledge of it. I do not remember the date when liquid carbon dioxide was first produced. That is unimportant.

XQ. 345. It was common in Lenard's time, was it not?

A. Apparently, because he used it.

XQ. 346. There is an article by Doane in the *Electrical World and Engineer* of May 21, 1924, which is Defendant's Exhibit No. 11. This purports to be a description of methods of exhausting incandescent lamps, does it not?

A. Yes, that is correct.

XQ. 347. Carbon filament lamps?

A. It must apply principally to carbon filament lamps because I believe tungsten lamps did not come along until somewhere about that time. I have forgotten just about the date when tungsten filament lamps came.

XQ. 348. Would you take 1907 from me as the date of the first tungsten lamp in this country, commercially, I mean; is that about your recollection?

A. Well, I have no recollection on that point.

XQ. 349. Do you think this relates to carbon filament lamps?

A. Yes.

XQ. 350. Now, you said in discussing this article on page 515:

"He then goes on to describe the blue glow," giving the impression that that was part of the description which you have given before. Am I not right in saying that the article describes two different methods of exhaustion, one a mechanical exhaust, and one a chemical exhaust, and that they are quite different?

A. Yes. The article describes two methods of exhausting.

XQ. 351. And this quotation of yours about the completed lamp, and so forth, to be free of gases and vapors, occurs in the description of the mechanical exhaust, does it not?

A. Will you give me the page, please?

XQ. 352. Page 514 of the typewritten record. Perhaps I can save time by showing you the place, Doctor (indicating)?

A. I am afraid I will have to ask for the question in order to answer it.

XQ. 353. Read the question. (XQ. 351 repeated as recorded.)

A. That is correct.

XQ. 354. And the quotation, or the statement, rather, about the blue glow, on page 515 of the typewritten record, occurs in the description of the chemical exhaust, does it not?

A. That is right.

XQ. 355. So that the two would not be used together; that is, if you had one of these things, you would not have the other, so far as this article goes?

A. So far as this article goes, they are not necessarily directly connected.

XQ. 356. You do not intend to give the impression that you described both of the things in the same treatment, did you?

A. I believe that is incorrect. I believe that the appearance of the blue glow was used in connection with the pump method of exhausting.

XQ. 357. You mean so described in the article?

A. So described in the article, yes.

XQ. 358. Where was that?

A. Quoting from the article; this quotation follows the explanation that it is necessary to bake the cells, heat the filament and free the walls from the occluded gas. I read this:

> "The filaments were also heated sufficiently by the current, but the joints were not heated sufficiently unless the current was passed through the lamps at a time when the gases were of just the right pressure to allow current to pass across the vacuous space from joint to joint. The current would not pass across this space, if the gas pressure was either too low or too high, and we had very little latitude in this respect."

And so forth, and he goes on to describe the cleaning up of the gas, due to the appearance of the blue glow.

XQ. 359. The expression "blue glow" or "blue flame" occurs for the first time in the article in the description of the chemical exhaust, does it not?

A. However that may be, I have not read the article recently enough to make that statement, but the blue glow is most certainly implied when he says that

> "the current would not pass across this space, if the gas pressure was either too low or too high."

That is, that quotation which I read from the article, describes the passage of a current through the gaseous space between the legs of the filament.

XQ. 360. And you read that to mean "blue glow"?

A. I certainly do.

XQ. 361. Now, come to the chemical exhaust, it says, does it:

> "The chemical process of exhausting consists roughly of mechanically exhausting a heated lamp to a pressure represented by a column of mercury about .125 mm. high."

A. Yes, I have that here.

XQ. 362. Then he seals off from the pump, and vaporizes his phosphorus and puts current through the filament; is that right?

A. That is right.

XQ. 363. And he gets the blue flame and the blue flame dies down and the lamp is finished; is that right?

A. That is quite right.

XQ. 364. Now, in this process were the bulbs heated or not, and if so, when? That is, the chemical process.

A. In a hurried reading of this article I do not find any specific reference to heating the bulb; but of course, if he heats the filament, the bulb is heated to some extent, and he had already described the necessity of the fact that heating the bulb was well known.

XQ. 365. I read from the article:

> "The tubular lamp is difficult to exhaust because the phosphorus gases are heavy the residual gases in the lamp are light; the phosphorus is in the form of gas at a high temperature only, and the lamps cool quickly from the high temperature of the heater in which it was heated before being placed upon the pump."

The implication is therefore, is it not, that the lamps were heated in a heater and taken to the pump from the heater?

A. Yes, that is correct.

XQ. 366. And that implication is confirmed by the description of the operator watching the progress of the reaction in the lamp bulb as indicated by the changing color and form of the blue light which fills the bulb?

A. Yes.

XQ. 367. If it was in a furnace she could not do that, could she?

A. Ordinarily not, because the furnace is usually not constructed of transparent material.

XQ. 368. Now, suppose there were phosphorus present in a lamp, but you did not have the blue glow. Would you get the clean-up?

A. You would get some clean-up, yes.

XQ. 369. Would it amount to anything?

A. Phosphorus would combine with some of the gases and I should say produce considerable improvement in vacuum.

XQ. 370. You would not expect to get rid of the nitrogen in that way, would you?

THE COURT: Get rid of what?

XQ. 371. Get rid of the nitrogen that way, would you?

A. Probably not. I am not absolutely positive, and I do not recall that nitrogen combines chemically with phosphorus. I am not sure.

XQ. 372. Now, I think you said you got some clean-up without phosphorus in the case of the blue glow?

A. That is correct, yes.

XQ. 373. As a matter of fact, there can be two actions there, can not there?

A. Yes, there are two actions.

XQ. 374. One action of clean-up and one action of the opposite?

A. I do not understand your question. I thought you implied that there are two methods by which, or two reasons why the gas may disappear.

XQ. 375. That, of course, is true. I meant to ask at least this—if you have gas in a tube, take a vacuum tube, let us drop lamps for a moment, and take a tube with electrodes, pass a discharge or current between the electrodes, the vacuum is not very good, and you get a blue glow, you get a sort of bombardment; you produce ions in the tube, don't you?

A. Oh, yes, of course.

XQ. 376. That is, the blue glow is one sign of ionization, is it not?

A. Of course, that is well recognized.

XQ. 377. That may help to improve the vacuum, may it?

A. That blue glow may act, yes, to improve the vacuum.

XQ. 378. What is the mechanism?

A. There are two mechanisms at work. First, the positive ions which are acted upon by the electric field made by being bombarded against the glass walls, or the metals, and be occluded or stick to those glass walls or the electrodes, of course. The other mechanism which is at work, is a sort of absorption of the residual gases, due to very fine particles which may be disintegrated or sputtered off, as the term is, from the cathode, when the cathode is bombarded by the positive ions that exist in the tube when there is a blue glow.

XQ. 379. And these fine particles combined with the gases to form a non-gaseous residue, which practically speaking, disappears from the lamp; is that right?

A. That is quite true. It may not be a chemical combination, but it may be a physical combination.

XQ. 380. Now, take the first action you mention, and that is the fact that the ions strike the walls. Suppose there is already gas on those walls or near the surface; is there any possibility of that gas being knocked off by those ions?

A. Yes. If the gas has not been thoroughly removed from the wall, of course that action may result in knocking off some gas.

XQ. 381. So that the blue glow in case the tube is not properly prepared may actually injure the vacuum rather than help it?

A. Oh, yes, I think that is true.

XQ. 382. The exact shade of this blue glow depends on the nature of the gas?

A. Yes, to some extent.

XQ. 383. In the case of nitrogen there is the tendency for the glow to be pink?

A. The tendency at high pressure is to be pink.

XQ. 384. Violet or purple at lower pressures?

A. Yes, that is right.

XQ. 385. Turning to Von Recklinghausen, U. S. Patent No. 946,068, Defendant's Exhibit 12. Is it your impression that the intention here was to create a film of magnesium on the inside of the glass?

A. No, the intention was to prevent the film forming.

XQ. 386. Because it was a lamp?

A. Yes.

XQ. 387. And you do not want the inside of the lamp covered with a mirror coating, is that it?

A. That is correct.

XQ. 388. Then this is not the formation of a film?

A. You can hardly prevent some of the magnesium from vaporizing. The idea in the patent, of course, is to minimize the amount of magnesium which would deposit on the glass chamber, but of course, it is absolutely impossible to prevent some from condensing on the glass walls.

XQ. 389. What you said is this: "It has a high vaporizing temperature, and so it was necessary to devise some scheme of igniting or vaporizing the magnesium by passing in this case an electric current through the piece of magnesium." He was not really devising a scheme of vaporizing the magnesium, but rather of avoiding it?

A. I do not understand your comment. Clean-up action takes place when the magnesium is vaporized, but the patentee attempts to prevent this vapor from condensing on the walls of the chamber, because it is a lamp.

XQ. 390. The particular arrangement he shows consists of a block of magnesia. Magnesia is an oxid of magnesium?

A. That is quite correct.

XQ. 391. A block then of magnesia which is refractory insulating material, isn't that it?

A. Yes.

XQ. 392. Which has a form of a little bathtub and reposing in this bathtub is a strip of magnesium metal, is that right?

A. Yes, I believe that is correct.

XQ. 393. And electric current is brought by leads, 11-11, and connected to the two ends of this strip of magnesium. His idea expressed in the patent is that he will pass current through that strip of magnesium in order to melt it, so that it may absorb the gases or help absorb the gases in the tube, is that right?

A. Why, in essence that is correct, but of course, if the magnesium is raised to the temperature of melting, there will be considerable vapor pressure of magnesium, and so there will be the vapor of magnesium throughout the bulb.

XQ. 394. Do you think as an actual matter of fact, that you could possibly get current enough through those walls to melt a strip of magnesium in that way?

A. Why, certainly. No specification is given as to the size of the strip. You can melt a strip of magnesium in a chamber by leading the current through the walls.

XQ. 395. Are you familiar with the possibilities of getting current through glass walls and maintaining vacua in 1904?

A. The use of platinum wire was of course very common at that time for lead-in conductors through glass chambers.

XQ. 396. The exact language which the patent uses, line 75 of the first page, is:

> "Thereupon the strip 7 of magnesium will be heated or melted and in that state it will absorb the injurious nitrogen and oxygen remaining in the container, thus completing the exhaustion of the apparatus."

You take that to mean that there will be incidentally some vaporization?

A. I certainly do.

XQ. 397. Nothing that Mr. Von Recklinghausen contemplated?

A. Not specifically.

XQ. 398. And your idea is that this heating and the help by the incidental vaporization causes the magnesium to combine with certain things existing in the lamp bulb and thereby improve the vacuum?

A. That is my understanding.

XQ. 399. Would mercury be eliminated in that way?

A. I believe it would, but I am not positive whether magnesium combines readily with mercury or not.

XQ. 400. Merritt Patent, U. S. 909,811, Defendant's Exhibit 13. You have not read this thing through recently enough to say whether you regard the statements of fact in the specification as true?

A. I cannot answer that question without perusing it again.

XQ. 401. Do you agree with the paragraph beginning line 60, page 1?

A. This is a long paragraph and so it will take a few minutes. I do not, reading it over once, find anything that I would disagree with, except that I think he overdraws his picture of clouds of moisture or vapor in there which so to speak stop up the pumping tube.

XQ. 402. It is true, is it not, that as stated at line 103, for some reason it tends to seal and narrow the opening, and so forth?

A. I would not express it that way, no.

XQ. 403. How would you express it?

A. In this paragraph he speaks of the possibility of the development of a crack when the tube is being hastily sealed off and the consequent admission of water vapor, and then he speaks of that water vapor as hovering around this opening. My opinion is that the water vapor would diffuse through the tube rather rapidly. I cannot picture a cloud of water vapor there hanging over the opening there and stopping it up.

XQ. 404. Did you read that sentence beginning with, "after completion of mechanical exhaustion"——

A. I did. I may have misread the paragraph. That is one thing which is spoken of in the paragraph.

XQ. 405. The getter in this case was red phospherous, was it not?

A. That is correct.

XQ. 406. Now you said that he heated the bulb during the exhausting process—you said that at page 520—that the bulb is heated as usual to drive off occluded gases and the filament is lighted and so on. I see on page 2, line 15, the words, "Prior to the exhaustion process the bulb is customarily heated in an oven to drive off the absorbed moisture and gases." You were not referring to that particular quotation when you made that statement, were you?

A. I am a little mixed up, and I would like to have the question asked once more.

XQ. 407. You say on page 520, "During the exhausting process the bulb is heated as usual to drive off the occluded gases." I ask you if that statement of yours was based on page 2, line 15, which reads:

> "Prior to the exhaustion process the bulb is customarily heated in an oven to drive off the absorbed moisture and gases."

A. Yes, that is the statement to which I referred.

XQ. 408. You will notice that you said "during," and he says "prior." There is that difference that I wanted to call attention to.

A. That is an unimportant distinction, I think.

XQ. 409. I would like to consider together several references all having to do with the work of Fleming, being Exhibits 14, 15 and 16, Fleming's paper before the Royal Society in 1909, U. S. Patent 803,684 to Fleming of 1905, and an article by Fleming in the *Scientific American* in 1906. This *Scientific American* article was a sort of a resume of the Royal Society article?

A. Yes, I think so. It was framed in more popular language, because it was for popular reading.

XQ. 410. Its history was this. It was first published in an English magazine called *Technics*?

A. That is right.

XQ. 411. A few weeks or months after the Royal Society paper was read. And subsequently it was reprinted in the *Scientific American*, is that right?

A. Yes, that is correct.

XQ. 412. And that referred to the same set of experiments?

A. Presumably, yes.

XQ. 413. Were you familiar with the actual Fleming valve?

A. I was thoroughly familiar and have been familiar with the principle of the Fleming valve. Of course, I had never seen one of Fleming's own productions. Perhaps I have misunderstood your question.

XQ. 414. I did mean just that. I assumed you are familiar with the principles, but I was wondering whether you actually saw the valve as made by Fleming?

A. No, not as made by Fleming.

XQ. 415. Have you seen it made by any one?

A. If you will allow me to include the two-electrode tube as representative of the Fleming valve, most certainly I have seen many of them.

XQ. 416. I suppose from the patent standpoint, they might be called a Fleming valve, but I was inquiring as to the valves that Fleming made or made under his direction, whether you have seen any of those?

A. No, I have not seen them.

XQ. 417. Then you do not know what the vacuum was in them?

A. Only from reading the articles of Fleming.

XQ. 418. The valves were actually used at exceedingly low voltage, were they not?

A. They may have been used with voltages of 30, 40 or 50. I am not absolutely positive on that point, because I shall have to refresh my memory, but that is my general impression.

XQ. 419. The use that they were put to primarily and the use to which the patent was sustained was the use of detecting wireless signals, was it not?

A. That may be, but if my recollection is correct, he refers in one of his earliest articles to the use of a Fleming valve for rectifying alternating currents of low frequency in which case the potential might be almost anything.

XQ. 420. Depending on the valve, would it not?

A. Not necessarily. I do not know that there is any distinction there.

XQ. 421. Fleming speaks repeatedly and emphatically in his papers of the highest possible vacuum, does he not?

A. He does.

XQ. 422. And Fleming talks about a vacuum with one one-hundred-millionth of an atmosphere, I think you said the other day?

A. Yes.

XQ. 423. He does not quite say he has such a vacuum, but says "Let us imagine," or "Let us suppose," that he had a tube with such a vacuum?

A. That is correct.

XQ. 424. A good deal of the discussion in the *Scientific American* article is in that form, "Let us suppose," or "Let us imagine"?

A. Yes, I think I made that very clear in my direct examination.

XQ. 425. I think you did. Fleming was a skilled man?

A. I should so consider him.

XQ. 426. Pretty well known and a rather prominent English electrical engineer?

A. Yes, I would call him better than an electrical engineer. I believe he had a sound knowledge of physics.

XQ. 427. Author of some books on alternating current phenomena?

A. Yes.

XQ. 428. Professor at Finsbury Institute?

A. I do not remember.

XQ. 429. He was a highly competent man?

A. Very competent.

XQ. 430. Have you ever examined and studied the curves which are contained at page 483 of the Fleming article, the Royal Society article?

A. Yes, I have.

XQ. 431. What did those indicate to you as to the character of the vacuum?

A. They indicate certainly the presence of gas.

XQ. 432. They are bad curves from the standpoint that we are discussing now?

A. Yes, they certainly indicate presence of positive ionization.

XQ. 433. That is indicated, is it not, by the very steep way in which the curves rise at about the ionization voltage?

A. Yes, that is an indication.

XQ. 434. For instance, just below 20 volts the curves shoot up very rapidly?

A. Yes, that is correct.

XQ. 435. And also the saturation line does not seem to be straight, but as the voltage goes up the saturation drops down. How do you account for that?

A. That may be due to gas.

XQ. 436. And Fleming most repeatedly refers to this sharp rise of the current?

A. As to that I shall have to refresh my memory. I do not remember offhand that he refers specifically to that sharp rise.

XQ. 437. How did Fleming describe the preparation of these tubes for the exhaust? May I ask you before that, please, first, does Fleming describe his exhaust and tell what kind of a pump to use or anything of that sort?

A. Do you wish me to take the time to go through these articles? I do not offhand remember any specific references to a pump.

XQ. 438. I will make a statement that there is no description anywhere in the Fleming articles so far as I know them that says anything about the pump or the method of pumping or anything connected with the exhaust, except certain references to the preparation of the tube, and I will ask you to correct me tomorrow morning if I am wrong in that. Is that satisfactory?

A. Yes, sir.

XQ. 439. If we do not hear from you, I will assume that we are right. There is a description of the method of preparing the tube and he says in the case where the tube has a filamentary anode and cathode, as it does in some of the forms, that current should be passed through those to drive the gas out of them or something of that sort?

A. Yes, I believe he does.

XQ. 440. And in case where the anode is a solid body he says that the heating coil should be placed outside of the lamp and thereby you should heat the metal part. I can give you a reference to that in a moment.

A. I do not remember whether he had the heating coil inside or outside. I was under the impression that he had it inside.

XQ. 441. It would be rather difficult to get it out, wouldn't it? Would you mind looking at the first page of the patent?

A. I have not got the patent here.

XQ. 442. Let me give you this copy, the paragraph beginning at line 96.

A. I was mistaken about that. The heating coil here is outside.

XQ. 443. So the only heat the anode gets in that case is the heat that comes to it through the bulb, is that correct?

A. That is correct.

XQ. 444. Whereas in the other case the only heat the glass gets is whatever heat it may get from the fact that the filaments are glowed to drive the gases out?

A. From the specific words of his articles that may be true. I think we must realize that Fleming was probably acquainted, certainly must have been, as every physicist is, with the necessity of baking the walls and denuding the glass parts and the electrodes of gases. I suspect he may not describe that in great detail because he probably supposed that it was well known and it was the natural thing to do.

XQ. 445. That is, he took the trouble to specify that the current should pass through the filamentary electrodes, and he took the trouble to specify that the heating coil should be put outside of the lamp in case where the electrodes or one of them was a solid body, but he did not take the trouble to specify that the bulb should be heated during the exhaust?

A. That is probably correct.

XQ. 446. You think if he had heated the bulb during the exhaust that he would not have obtained the vacuum?

A. I think it is perfectly possible to obtain the vacuum.

XQ. 447. And you know as a matter of fact that he did not obtain it?

A. The evidence from these curves is that he did not.

XQ. 448. That is all the history there is with reference to curves, and the description which he gives is insufficient to obtain a vacuum, unless you supplement it by something which to you now seems perfectly obvious; is that correct?

A. That is correct, but I do not know whether Fleming constructed his tubes or had them constructed by some lamp manufacturer. The point I made especially in my direct examination was, and I think it is a very important point, that Fleming recognized the unilateral conductivity and probably because of the very fact that his vacuum, as shown by the curves or by his experiments, was not good enough, he said. "Let us suppose that the vacuum is made as good as possible."

In other words, he certainly appreciated, whether he obtained it himself or not, the necessity of obtaining a high vacuum.

XQ. 449. He wanted to get a high vacuum because he thought his rectification was incomplete, didn't he?

A. Yes, that is, I guess, correct.

XQ. 450. As I remember it, Mr. Van der Bijl, one of the experts on behalf of Arnold in the interference proceeding, testified that Fleming was getting perfectly good rectification with the vacuum that he had. Do you agree with that?

A. I have not got enough data to judge on that. That would all depend on how much voltage he impressed upon the bulb.

XQ. 451. And you do not know whether at that time it was lamp practice to bake the bulbs or not during the exhaust? You will find places where somebody says to do it, I do not doubt that, but what was the practice?

A. My impression was that the practice was to bake the bulb.

XQ. 452. This patent that we are just looking at, the Merritt patent says that his practice was to bake the bulbs before they went on the pump and not to bake them on the pump.

Mr. Darby: I think that is not strictly accurate, Mr. Davis.

Mr. Davis: Suppose you read the language.

Mr. Darby: I think the language is:

> "Prior to the exhaustion process the bulb is customarily heated in an oven to drive off the absorbed moisture and gases. Unless the exhaustion is effected rapidly however, the subsequent cooling of the bulb causes a material reabsorption of those gases."

XQ. 453. Exactly; according to that patent the bulb was customarily heated before it was put on the pump and taken from the heating oven and then put on the pump; is that your understanding, Professor?

A. I am not ready to admit that that was common practice.

XQ. 454. That is what Doane talked about and we went all through that a few moments ago in the Doane article.

A. I certainly would have said without referring to any specific article that it was well known among physicists at any rate, at that time, that it was necessary to thoroughly bake the wall while being exhausted, whether it was lamp practice or not, seems to me to be unimportant in this connection, because I would consider Fleming to be acquainted with methods used by physicists.

XQ. 455. The lamp people were doing pretty good work in those days, were they not?

A. Well, I cannot answer that. They were doing the best they knew how at that time, I suspect. In terms of modern practice, I do not know that you would call it good or bad.

XQ. 456. Fleming himself speaks of the vacuum he wants in his lamp, as being a lamp vacuum, the kind of a vacuum that is in an incandescent lamp, does he not?

A. My impression is he refers to that in the general terms, but he specifically states the vacuum he would like in numeric terms, which seems to carry more force than the general statement about incandescent lamps.

XQ. 457. I will ask you a question—don't you think Fleming had some rather peculiar ideas in the measurement of vacuum? For instance, in one case he speaks of the X-ray vacuum as one-hundredth-thousandth of a millimeter, I think—no, as a ten-millionth of an atmosphere; that is in the "technique" article.

A. That is one-tenth of a micron. That is, with a range of X-ray vacua, I should say.

XQ. 458. Do you think that is the range?

A. Well, yes, I think that is the range; it is within the possible range.

Mr. Davis: If your Honor please, would your Honor care to adjourn now? I may have a chance to look this up and save further time in the morning.

Mr. Darby: If your Honor please, may I raise one little question: I understand that you ordinarily will not sit on Saturday, and I wanted to verify it that you will not sit this Saturday, because I have a tentative hearing set in New York I wanted to attend.

The Court: I assume counsel away from home would not want to have sessions in this case on Saturday. I happen to have engagements to sit practically every Saturday, but I shall not sit in this case on Saturday unless counsel unanimously request it.

Adjourn court until tomorrow morning at ten o'clock.

(Whereupon, at 5 P. M. adjournment was taken until Thursday, October 21st, 1926, at 10 o'clock, A. M.)

Wilmington, Delaware, Thursday,
October 21st, 1926, 10 o'clock A. M.

SIXTH DAY.

Before:
Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

E. Leon Chaffee, resumes the stand.

Cross-Examination (Continued).

By **Mr. Davis:**

XQ. 459. Speaking of that Royal Society paper of Fleming, read February 9, 1905, have you the paper there?

A. I have some abstracts.

XQ. 460. Here is the actual photostat of the paper. Will you read the last sentence of the paragraph in the middle of page 477? Read it out loud, please.

A. "The bulb must be highly exhausted to about the pressure usual in the case of carbon filament incandescent lamps, and the metal cylinder or plate must be freed from occluded air."

XQ. 461. Thank you. As a matter of fact, the conduction in the Fleming valve described in this paper was the ordinary well-known phenomenon of gaseous conduction, was it not?

A. The conduction through the particular valve for which he gives curves, was undoubtedly accompanied by positive ionization.

XQ. 462. What was then a well known phenomenon of conduction through gases, was it not?

A. Yes, that is so.

XQ. 463. And he says so, does he not, from the paper? For instance, just before Table 1, he says, at the bottom of page 481, does he not:

> "The facts so exhibited are well known characteristics of gaseous conduction in rarefied gases."

A. I believe here he is referring to the curves, is he not, which I have discussed, which do show gaseous conduction.

XQ. 464. That is, you mean you think he is referring to the curves which he gives in the paper as the characteristic curves of his tube?

A. In the particular case.

XQ. 465. Is there any other case mentioned in the paper?

A. Not that I remember at the moment.

XQ. 466. And we were speaking yesterday, I think, of the sudden rise of current in the neighborhood of the ionization voltage. You know, do you not, on page 481, that he says just before the place we were looking a minute ago:

> "If we plot the current . . . we find that the current curve quickly rises to a maximum value and then falls again slightly as the potential difference increases steadily."

He says that, does he not?

A. He says that, but I would not necessarily interpret that as indicating that a rise occurs at any particular voltage, but merely that the current increases rapidly, as you increase the voltage.

XQ. 467. And on the curves themselves, on page 483, you find, do you not, that the rise does occur just about 20 volts?

A. The curves show an upward trend from zero up to the point where the curves have obtained their maximum value. As I stated before, unquestionably ionization is shown by these curves, and there is a rapid rise but the current has risen all the way, and it is typical of the curves obtained in any thermionic device, that the rapidity of rise very rapidly increases as you increase the voltage.

XQ. 468. Where a current is limited or governed by space charge, the rise is more gradual than shown in that drawing, is that not so?

A. Yes, I believe that is correct, because I have already stated that these curves do show the presence of gas in this particular case.

XQ. 469. You say on page 525 of the typewritten record:

> "I believe it is perfectly clear from this reference to Fleming that he knew what he was talking about when he was talking about vacua and that he knew that in order to get unilateral conductivity to the highest degree, that it was neces-

sary to entirely occlude gas. I should modify this statement, because it is impossible to entirely exclude gas, but to reduce the effect of gas to a minimum."

Is that the only modification which you wish to make in that statement?

A. No other modification occurs to me at the time.

XQ. 470. As a matter of fact, it is not necessary to have a gas-free tube in order to get perfect rectification, is it?

A. I am quite aware of that, provided you do not impress too high a voltage.

XQ. 471. Coming back to these curves, the 3/2 power curve is a curve of gradually and constantly increasing slope, is it not? I am talking now about the mathematical 3/2 power curve.

A. Yes, that is correct. In other words, there are no sudden jumps.

XQ. 472. And it continually tends more and more upward?

A. That is correct.

XQ. 473. Is it a parabola?

A. No, it is not.

XQ. 474. It is a hyperbola?

A. No, it is not.

XQ. 475. It is somewhere between a parabola and a straight line?

A. Yes.

XQ. 476. We were just talking about ordinates and abscissa. What do those terms mean?

A. The term ordinate always applies to the quantities plotted vertically on a graphical representation, and the term abscissa applies to those quantities which are plotted horizontally.

XQ. 477. And in a practical tube of the invention, the 3/2 power curve merges into the saturation curve through what is called the transition and then finally we come to a flat line which they call the saturation part of the curve, is that true?

A. That is quite correct.

XQ. 478. What is this 3/2 power law? That is, just state it for the information of the Court.

A. The 3/2 power law states that the space current, that is the electron current——

XQ. 479. That is the current across the tube?

A. The current across the tube, increases as the 3/2 power of the impressed voltage, of course remembering that certain assumptions have been made in the derivation of that law and that experimentally it may not come out absolutely strictly according to the equation.

XQ. 480. You say of the impressed voltage. The voltage impressed where?

A. The voltage impressed between the emitter and the cold electrode, commonly called the plate.

XQ. 481. If you will look at this sketch which I show you which happens to be on page 1052 of the transcript which is not yet in evidence, the black line continued as a dotted line is what, that is, considering the black line to where it comes to the dots and then carrying on with the dots, that is the 3/2 power law line?

A. That is what I would take to represent the 3/2 power law.

XQ. 482. And the black line continued beyond the dotted line is the transition followed by the saturation, is that correct?

A. That is correct.

XQ. 483-84. And that is a typical curve illustrating the performance of the tubes we are discussing, subject of course to various modifications which may happen, but I mean this is a type curve?

A. Yes, that is true.

XQ. 485. And this 3/2 power law is derived, with this simplifying assumption which we have discussed, from a mathematical consideration, from the fact that the electrons in the space between the anode and the cathode tend to repel each other, is it not?

A. That is correct. That is one of the assumptions.

XQ. 486. If you have a little gas in there and get ionization, what effect has that on the space charge?

A. One of the effects of gas ionization is to neutralize partially the space charge effect, because of the presence of positive ions which are oppositely charged or have a charge of opposite sign to the charge on the electrons.

XQ. 487. So that if we get positive ionization there is a tendency for the current curve to rise more rapidly than it would in that sketch which I showed you just now?

A. That is correct.

XQ. 488. And that rise would tend to manifest itself above the ionizing voltage?

A. Of course.

XQ. 489. Because below the ionizing voltage there is no ionization; that is correct, is it not?

A. That is correct.

XQ. 490. And that in a general way accounts for the difference between the curve that I showed you and the curve of these Fleming curves which we have been discussing, that is for the difference in that part of the curve?

A. Yes, that is another way of stating the reason for the difference in curves.

XQ. 491. And this rise of current above the ionizing voltage, this departure from the 3/2 power curve is not necessarily accompanied by blue glow, is it?

A. Yes, it is.

XQ. 492. It is necessarily accompanied by blue glow?

A. The blue glow may not be visible, but you cannot have ionization without blue glow.

XQ. 493. I will put it this way, is it necessarily accompanied by perceptible blue glow?

A. That depends upon so many factors. It depends upon the adaptation of the eye, and the intensity of the light from the filament, and how much light there is in the room.

XQ. 494-5. You would not think this a proper statement:

> "The plate voltage was so high that the gas was ionized although showing no perceptible blue glow."

A. May I have the question?

(XQ. 494-5 was repeated by the stenographer.)

A. I think that is a perfectly proper statement.

XQ. 496. It is a statement you made yourself, is it not, Professor?

A. I do not remember.

XQ. 497. Do you recognize the book which I have here?

A. Yes, I recognize that.

XQ. 498. And you said in this paper, which is published in the Institute of Radio Engineer Proceedings, 1922, at page 444:

> "Figure 6 gives the plate and grid current plotted against grid voltage for a tube containing a trace of gas, probably air. The plate voltage was so high that the gas was ionized, although showing no perceptible blue glow."

A. That is quite correct.

XQ. 499.

> "The positive ion grid current is evident between grid voltages of minus 1.5 and plus 0.5. Also

the excessively steep rise of plate current should be noted giving a large mutual conductance which is characteristic of gas tubes."

A. Quite correct.

XQ. 500. And that is the very thing we have been talking about this excessively steep rise of plate current?

A. Yes, that is correct.

XQ. 500a. And you said on page 446 of the same paper, did you not:

> "It is well known that a gas tube operated under certain critically adjusted plate and grid voltages and filament current often given phenomenal sensitivity as detectors. These sensitive spots on the characteristics are due to small kinks in the curves resulting from ionization of small traces of gas, too small in amount to make the tube break over into the familiar blue glow."

A. That is correct, meaning a perceptible blue glow, of course.

XQ. 501. Yes, the blue glow that you can see?

A. Yes.

XQ. 502. Have you a copy of Defendant's Exhibit 31 there, the Lilienfeld-Rosenthal paper or article?

A. I have.

XQ. 503. Now, you testified on your direct examination that the tube described in this article operated by a pure electron discharge?

A. I do not think I so testified.

XQ. 504. You said on page 181 of the record, did you not, near the top of the page:

> "This is a statement of the ear-mark No. 3, where the discharge between the hot filament and its anode is independent of the gas pressure, which indicates that he was operating in this case with a pure electron discharge."

A. That is a correct statement as to my testimony and it is perfectly true. There is shown definitely the earmark, as I remember, No. 3. Now, as to whether a discharge is pure electron or not, is a matter of degree. I would like to make that point clear. We have been speaking of pure electron discharge. Now, theoretically, there is no such a thing as a pure electron discharge; so in this particular place I was speaking of pure electron discharge in the sense that it has been used, for instance, in patent No. 1; some ionization always accompanies the passage of electrons through space, and from that point of view the discharge is never pure electron discharge.

XQ. 505. May we speak of this subject from the practical point of view?

A. From the practical point of view, that is discharge in the Lilienfeld and Rosenthal article which occurs between the heated filament and its anode, has the earmarks of a pure electron discharge.

XQ. 506. I do not want to ask you to define things too accurately, because I know the danger of any attempted definition, but would you say a pure electron discharge was one, which was, from a practical standpoint, so pure that the impurities were negligible from the point of view of operation?

A. Yes. I would agree, I guess with that statement, that is, that the amount of ionization or other effects, have no practical effect upon the discharge.

XQ. 507. Now, this tube, as you understand it, of this article, Exhibit No. 31, is, so far as vacuum is concerned, the precautions, the same as the tubes described in the earlier Lilienfeld article, Exhibit No. 25, which you mentioned?

A. I should assume that the vacuum is about the same order of magnitude.

XQ. 508. I want to be very clear. I am not talking of the earlier tests described in Exhibit No. 25, in which he was not satisfied with the vacuum; you will remember some of the earlier tests wherein the vacuum was not good; I am speaking in my last question of the later tests in which he was satisfied with the vacuum?

A. Yes, I understand.

XQ. 509. And you answered the question on that assumption?

A. That is quite correct.

XQ. 510. Have you a copy of the picture or diagram of that article available, because I have not?

A. I have.

XQ. 511. I find that I have also.

A. That is, you mean a picture of the X-ray tube?

XQ. 512. Yes, sir. That is on page 257 of the paper.

A. That is the one I have.

XQ. 513. Now, referring to that picture, will you please explain to the Court how the tube operates?

A. The terminal denoted by the figure 3 is a heated filament. The cylindrical terminal No. 4 is the anode, which goes with the filament. Beside those two electrodes are two other electrodes, No. 1, which is similar to the cathode in an ordinary X-ray tube and No. 2, which is analogous or similar to the target or anode in an ordinary X-ray tube. When the filament is not heated, no discharge takes place through this tube because of the high vacuum that exists. On heating the filament 3, a very heavy discharge takes place between the terminal 3 and either the anode 2 or the anode 4. 2 seems to be nearer than 4 to the filament, but both are connected as shown by exterior wire 2″ and 3″, while the electrons from the heated filament 3, pass to either 4 or 2, they encounter some gas molecules and produce a very small degree of ionization, as of course will be produced in practically any high vacuum thermionic devices. As I said before, you can not get entirely rid of all positive ionization, although it may not affect practically the operation of the device. These positive ions so produced are attracted toward the highly-charged terminal 1, which is charged negatively, and would therefore attract the positive ions. I am stating now the common theory for the operation of this device. These positive ions, on striking the terminal 1, knock out from its surface, some negative electrons, so that because of this bombardment with positive ions, the terminal 1 becomes a source of electrons, and then the discharge through the main tube takes place between cathode 1 and anode 2.

Now, I would like to point out here that this in effect is exactly the third electrode method of determining how much ionization is in the tube. Dr. Millikan testified yesterday to the effect that the third electrode method is a very, very sensitive method for determining the presence of gas or the degree of evacuation, in fact I think he said it is the most sensitive method. Now, this is an amplified third electrode method, because the discharge, the electron current discharge which Dr. Lilienfeld used here, amounting to something, if I remember correctly, about 150 millimeters, is an extremely large current. Therefore, there are a large number of electrons passing from the filament to the anode, and of couse there would be some ionization although relatively small in amount, still, because of the large current, some positive ionization would certainly be produced, no matter how high the vacuum is, in the highest attainable vacuum there would be positive ionization.

These positive ions are drawn then in the very powerful field which exists between the cathode 1 and the target and strike the target. Now, from experiments which have been recently performed, one positive ion can knock out a great many electrons, so that we may consider terminal one equivalent to the third terminal of Dr. Millikan's method of measuring vacuum, but in this case instead of using the current of positive ions, that go to this terminal, we are using an amplified current resulting from the multiplication of the number of electrons that are knocked out by these positive ions. That is, if you have one positive ion, you may have perhaps 20 electrons, and then if you measure that electron current, you have the method of determining or indicating the presence of gas in the tube, that is enormously more sensitive than even the third electrode test as ordinarily performed; that is, in my opinion, the method in which this test is operated.

XQ. 514. You say that experiments usually with one ion can knock out how many electrons; do you remember how many?

A. That depends on the voltage.

XQ. 515. But on the order of magnitude?

A. I believe that also depends upon the metal which is bombarded by the positive ions, but I believe perhaps in the neighborhood of from 400 to 1000 volts, you would get about one electron for one positive ion; but as you increase the voltage, the number of electrons knocked out increase very rapidly, so that I can not state the exact number. Here the voltage was very high, amounting to 30- or 40- or 50- or 100,000 volts.

XQ. 516. Let us see if we can put this very simply. If you have an ordinary X-ray tube of the old type, the tube got hard, as they put it, as you used it, and took more and more voltage to pass current through it. That is correct, is it not?

A. Yes, that is correct; quite correct.

XQ. 517. And finally a time would come when no more current could, as a practical matter, be passed through it with the apparatus which the Doctor had available?

A. That is correct.

XQ. 518. Now, in the Lilienfeld tube, you have the old anode and the old cathode which are unchanged, and something else; is that right?

A. Yes, I believe that is correct. Of course, the anode and the cathode take different forms in different design of tubes, but essentially that is correct.

XQ. 519. And you have in addition in the tube another pair of electrodes, one of which is a hot cathode?

A. That is correct.

XQ. 520. You have, so far as structure is concerned, a little Fleming valve there in the tube?

A. That is quite right, if you wish to speak of it in that way.

XQ. 521. The old X-ray tube with a little Fleming valve in the same tube. You pass current through that auxiliary pair of electrodes, which, for convenience, I am referring to as a little Fleming valve, that ionizes gas in the tube, and the ions thus produced, do just what the ions do which are produced at the lower vacuum before the tube gets too hard. That is, they go to the cathode and knock out some of the electrons; is that right?

A. That is correct, that is just as I stated.

XQ. 522. So that the Lilienfeld tube depends for its operation on the presence of gas?

A. Of course. May I point out here, however, that the pure electron discharge to which I referred in my testimony, was not the discharge passing between the main cathode and anode, but the discharge passing between the filament and its anode.

XQ. 523. And in the Lilienfeld tube, if there were no gas ionization, the current would go out?

A. The main current?

XQ. 524. Yes.

A. It would stop.

XQ. 525. Would stop?

A. Yes. By main current, I mean the current passing between the ordinary cathode and its anode producing X-rays.

THE COURT: You mean cathode 1 and cathode 2?

THE WITNESS: 2, quite correct.

XQ. 526. Can you give me an approximation of the distance between the main anode and the main cathode, that is, the high tension anode and high tension cathode in that tube?

A. Why, I do not believe I can do this very accurately, because this is merely a drawing with no figures as to scale, but I know that X-ray tubes are made having a diameter ranging from two inches up to seven or eight or even ten inches, the distance between the cathode and the anode would ordinarily be about half the diameter of the bulb.

XQ. 527. When you are thinking of two-inch X-ray tubes, you are speaking of very modern developments, are you not?

A. Yes, modern developments used by dentists.

XQ. 528. That is the Coolidge Dental Tube?

A. I do not think of any particular name attached to the tube. I have seen the tube, and also we have some at the laboratory, tubes of very old design, used for demonstration, having a bulb diameter not certainly exceeding three inches.

XQ. 529. These tubes according to these papers which you have produced, were practical tubes, which were used by a doctor at least from which photographs were made which you showed to the Court the other day, so perhaps we can exclude two inches from our consideration, can not we?

A. Possibly.

XQ. 530. What would you say the diameter would be?

A. My guess would be that the diameter might be of the order of five or six inches.

XQ. 531. And under those circumstances, the distance between the main anode and the main cathode would be what?

A. Of the order of two or three inches.

XQ. 532. And between the auxiliary cathode and anode, would be what?

A. Between the filament and anode No. 2, possibly one-eighth of an inch or a quarter of an inch. Between the filament and anode No. 4, slightly greater distance.

XQ. 533. You said that the distance between the three which is the auxiliary cathode and the anode, was ⅛ to ¼ of an inch?

A. I believe so.

XQ. 534. Which anode were you speaking of?

A. Anode 2.

XQ. 535. It is about 1/16 of an inch in the picture, is it not?

A. I think it is a little less than 1/16 in the picture.

XQ. 536. And the intensity of the X-rays or the frequency of the X-rays were controlled in this tube how?

A. Are you speaking of the wave length of the X-rays?

XQ. 537. Yes.

A. That is largely determined by the voltage between the cathode and anode and to some extent by the material of the anode.

XQ. 538. I thought the article said it was controlled by the value of the current in the auxiliary circuit?

A. The article states that that is the way they accomplished the variation of hardness of the ray, but I would like to explain that point.

XQ. 539. Please do.

A. The X-ray tube is operated by some sort of a high tension apparatus and that high tension apparatus is operated from the city mains, I presume. As the current from the filament 3 and anode 2 or anode 4 is varied by varying the voltage impressed upon that particular circuit, the amount of ionization is of course varied, the amount of ionization will then vary the current passing through the main part of the X-ray tube. The transformer or the device supplying the high tension current was of such a nature that when current was drawn its voltage fell so that here was an indirect way of varying the voltage on the tube instead of a direct one. And of course the hardness of the X-rays followed with the voltage as I have stated.

XQ. 540. It was really varying the voltage necessary to send current through the tube, was it not?

A. It was varying the voltage utilized in the production of X-rays.

XQ. 541. By varying——

A. The auxiliary current.

XQ. 542. And thereby varying the voltage required by the tube to pass current?

A. Not required but existing across the tube. There is no indication that a lower voltage would not produce a discharge.

XQ. 543. Suppose you had no current in the auxiliary circuit what voltage would be necessary to pass current through the tube?

A. A very high voltage. In fact, he states, I believe, that he was unable to get any discharge.

XQ. 544. Suppose you have a heavy current in the auxiliary circuit, you can pass current through the tube with a relatively low voltage?

A. Yes.

XQ. 545. Low from an X-ray standpoint?

A. Yes.

XQ. 546. So that by varying the current in the auxiliary circuit you vary the voltage?

A. It varies the voltage that exists there. That voltage is determined by the characteristics of the device supplying the voltage. It does not indicate that a lower voltage would produce no discharge through the device. There is no implication of that whatsoever. It merely depends on the characteristics of his high tension source.

XQ. 547. But it is a practically constant energy source?

A. I do not see why one should assume that. Undoubtedly the source drew more or less current or power from the main as he varies the auxiliary current.

XQ. 548. But it is a source with a very drooping characteristic?

A. Quite right. That is what I have already stated.

XQ. 549. I do not know that we are discussing anything more important than whether the hen or the egg was the first, but it is a fact, is it not, that if you spoke of the resistance of the tube—I realize it is a bad term, but it is a term that Fleming used in his article, but using it in a rough way, the resistance in the tube depends on the amount of current in the auxiliary circuit?

A. If you are speaking of resistance to a direct current——

XQ. 550. Yes.

A. The resistance in the tube is varied by varying the alternating current.

XQ. 551. And the voltage necessary to pass a given current through the tube therefore depends on the current in the auxiliary circuit?

A. Yes, in a broad sense.

XQ. 552. That is to say, you showed the Court the other day some photographs taken under various conditions of tube use, some in which the rays were very penetrating and the flesh only showed very lightly and others where the rays were deliberately made less penetrating, in one case I think the bones hardly showed at all; is that right?

A. That is correct.

XQ. 553. How is that difference accomplished?

A. The variation of hardness or penetrating power of the rays was accomplished by varying the voltage across the tube, which as I have already stated was varied by varying the voltage on the auxiliary portion of the tube.

XQ. 554. You do not agree with the statement in the paper which I read:

> "However, as the conductivity momentarily changes with the primary current, the resulting Roentgen rays consequently become softer with increasing primary current and harder with decreasing primary current between desired limits."

A. May I read that over again?

(XQ. 554 was repeated by the stenographer.)

A. I do not see that that is at all inconsistent with what I have already said.

XQ. 555. Then you do agree with it?

A. I do agree with it.

XQ. 556. And you agree with the following from the second part of the paper, the Rosenthal part:

> "The primary current sent through the tube which varies the hardness of the tube as desired during the photography is changed from 50 to 180 milliamperes."

Have you a translation of that?

A. Yes, I have.

XQ. 557. Will you please read then yours, if you will, because I am not sure that my translation is the same as yours. It is on the third page of the paper as

I have it. It is the paragraph beginning with, "The primary current sent through the tube"—

A. Certainly I agree with that.

XQ. 558. Will you read the paragraph, please, into the record?

A.

> "The primary current sent through the tube which varies the hardness of the tube as desired during the photography is changed from 50 to 180 milliamperes."

XQ. 559. What does that mean?

A. That means just as I have stated.

XQ. 560. I am worrying just about the English.

A. It means from 50 to 180 milliampéres.

XQ. 561. Please go on.

A.

> "If the current in the primary discharge circuit is raised above 180 milliamperes, the tube sends out such soft rays that they are of no use for photography. With soft arrangement, that is about 150 milliamperes, the outlines of the dark phalanges may at once be recognized on the X-ray hand."

XQ. 562. Now, how is this variation in the current in the auxiliary circuit accomplished?

A. I understand by variation of the voltage in the auxiliary circuit. He has definitely stated that the heating current is maintained constant.

XQ. 563. Where does he state that, for convenience?

A. I am not sure whether that is in this paper or the other part of the paper. Perhaps I can find it.

XQ. 564. Perhaps, Professor, you can find that later and call our attention to it. If you will call my attention to it I will appreciate it. I simply want the reference. May I see those pictures, those X-ray pictures?

A. Yes, sir.

XQ. 565. Take this picture No. 6, which is the picture of which I have spoken in which the bones show only faintly; roughly, what would be the voltage of the tube when that picture was taken? I merely want the order of magnitude.

A. Possibly twenty or thirty thousand—I have taken X-ray pictures myself, but I have not measured the voltage accurately.

XQ. 566. And what would be the value of a current in the auxiliary circuit; that is, that corresponds to the larger value?

A. Yes, that is correct.

XQ. 567. And that was 150 milliamperes?

A. Yes.

XQ. 568. And you would assume that that 150 milliamperes corresponded to this figure of 20,000 or 30,000 volts?

A. Yes, I believe so.

XQ. 569. And what was the voltage of the auxiliary circuit?

A. He states—well, I am not sure whether he states definitely. I believe he derives it from the city mains.

XQ. 570. He states that he derives it from the city mains?

A. I believe so, but I am not absolutely positive that he had no transforming device.

XQ. 571. He specifically states it is a direct current, and I think we can assume that he did not?

A. There again my memory fails me, because I know he used these devices on alternating current.

XQ. 572. But he says, does he not, that he uses direct current because he gets very peculiar phenomenon when he tries to use alternating?

A. I know he did use direct current in some of the experiments.

XQ. 573. He says on page 3:

> "It is to be noted with special emphasis that these accounts are given for the case when the primary discharge is produced by direct current."

I will go back a little: "An account in actual figures"—can you find that—that is in the main paper?

A. The beginning of the paragraph is what?

XQ. 574. "An account in actual figures"—at the bottom of the third page.

A. That does not correspond with my translation.

XQ. 575. Here it is.

A. Oh, yes.

XQ. 576. Will you read that paragraph beginning in your translation with "Numerical figures"——

A.

> "Numerical data as well as the description of the extremely simple manipulation of the tube are contained in the second part of the work before us. We should emphasize more especially that these data are applicable for the case where the primary discharge is produced by a direct current. If an alternating current is used for this purpose very divergent conditions arise, the details of which will be given below."

XQ. 577. Then he did use direct current?

A. Yes, apparently.

XQ. 578. And he got it from the city mains?

A. Yes, that is correct.

XQ. 579. And what would the voltage be, or assumed to be?

A. Possibly as high as 500 volts.

XQ. 580. From the city mains?

A. Not necessarily lighting mains. City mains may be used for power purposes and there are 500-volt circuits in many places.

XQ. 581. Where are there 500 power circuits? I do not mean trolley circuits.

A. In Cambridge up to the last two years, I guess.

XQ. 582. You think he would put 500 volts into a doctor's office?

A. If necessary, yes. I see no reason why not.

XQ. 583. Is there any reason to think that it is necessary?

A. If it was required to operate this tube.

XQ. 584. But is there any reason to think it was required?

A. I am not sure without going through the article again to see if he specifically states voltages as high as that.

XQ. 585. What is the ordinary lighting voltage?

A. 110 volts or 220 in special cases.

XQ. 586. Don't you think he would have mentioned it if he had had power voltages?

A. I do not know.

XQ. 587. I suppose every city has wires running through it with 10,000 volts perhaps of alternating current at least, but you do not bring them into doctors' offices?

A. No, you do not bring voltages of that size in.

XQ. 588. You spoke as though you had some information which I have not with reference to the number of electrons produced per impact of ions and gave the figures at 1000 volts, did you?

A. I did.

XQ. 589. Do you happen to remember the figure at say 20,000 to 30,000 volts?

A. I do not remember, except that I understand that the number increases very rapidly, not necessarily lineally with respect to voltage.

XQ. 590. Have you any reference to any paper in which this work is published?

A. I believe the work has not been published.

XQ. 591. The work has not been published?

A. That is my understanding.

XQ. 592. Would you fix even the order of magnitude at say 30,000 volts?

A. No, I cannot, because I have not read the paper. It has not been published.

XQ. 593. May we look at the other Lilienfeld paper, the 1910 paper for a moment, Defendant's Exhibit 25. Have you a copy of the figures and illustrations showing a picture of the tube?

A. Yes, I have.

XQ. 594. That is on page 685 of the article. Will you please point out to the Court what the various parts are in the structure?

A. The tube is arranged mainly in a vertical position. At the upper part is a bulb, a nearly spherical bulb, containing at its center a heated filament. I believe the filament is marked O. The spherical portion opens up into a cylindrical portion which is marked E^1. This cylindrical portion then narrows into a smaller tube, the smaller tube being E^2, which terminates in an enlargement which has a metal electrode sealed into the glass and is the main anode of the device. The filament to which I have previously referred is the cathode. In the narrow portion of the tube are two what are called sounding electrodes s^1 and s^2, which are very carefully insulated and are used to determine potential difference that exists between these terminals in the discharge tube, while the discharge is taking place.

There is another terminal sealed into the larger cylindrical portion of the tube and the terminal is marked Z. This is a starting electrode apparently necessary to initiate the discharge when it would not occur of its own accord. Also in the larger cylindrical portion of the tube there is something marked F, I believe, and that is, in the picture, shown as a small glass prism, to enable the observer to see what is going on throughout the length of the tube.

XQ. 595. The tube is shown as broken off there?

A. Yes, it is so shown in the diagram.

XQ. 596. And that indicates that there was more length to the narrow part of the tube than shown in the drawing?

A. Yes, that is true.

XQ. 597. How long was the narrow part of the tube?

A. I do not remember that he refers or gives any definite length. Perhaps you can point that out if he does.

XQ. 598. It is a very long article and it is very hard to find anything. It was of considerable length, that is what I mean, it was a matter of feet?

A. Not certainly many feet.

XQ. 599. My recollection is that it was two or three feet?

A. My recollection is that it was not as long as that, but it may have been over one foot.

XQ. 600. You spoke of this electrode Z as a starting electrode. What is the theory of it? How does it operate?

A. As far as I know probably a high potential discharge was put between the terminal Z and the cathode 0 in order to start the discharge. I do not remember in the article any reference to the method by which this starting terminal is used. Without a description of the method I am at a loss to give a very definite answer to the question.

XQ. 601. Now, this tube, was built by Dr. Lilienfeld to study certain physical theories which he had?

A. That is quite right.

XQ. 602. And during its operation it was always either on the pump or connected to a liquid air and charcoal tube or both?

A. He describes a valve by which he can disconnect the tube from the pump but not seal it off and he operates the tube for a considerable time with that valve closed.

XQ. 603. Will you refer to the sketch on page 682 of the article, showing the connections of the vacuum apparatus. Have you found it?

A. Figure 4?

XQ. 604. Yes. My understanding, am I right, is that one of these charcoal tubes, tube a^2, is always connected to the device to be evacuated?

A. In that diagram that is correct, because one of the tubes it states goes to the entladungrohr.

XQ. 605. And that at the left end of the figure the connection is to the pump?

A. To one of the pumps.

XQ. 606. And in the middle of the figure the downward connection is to another pump?

A. That is right.

XQ. 607. There is no mechanism for disconnecting the charcoal tube a^2 from the tube to be operated?

A. Not in this figure.

XQ. 608. That is the description of the experimental arrangement, is it not?

A. He gives later on——

XQ. 609. He says the vacuum tube is shown in Fig. 4?

A. Yes, but that may have been for only one arrangement.

XQ. 610. He is describing his experiments, is he not?

A. He has two sets of experiments.

XQ. 611. Is there anything in the article which indicates that he ever disconnected this charcoal liquid air tube?

A. Offhand, I do not remember any. But without refreshing my memory I am not sure whether the bulb of which he speaks later was connected between this charcoal tube and the discharge tube or placed at another point.

XQ. 612. You do not know where that reference to the valve is?

A. Fig. 1, page 164 of this reference book.

XQ. 613. Could you give me the page of the article?

A. Page 535.

Mr. Davis: There is no page 535 in the article.

Mr. Darby: That is the second Lilienfeld article, I believe.

XQ. 614. You are referring now then to the 1911 article?

A. Yes, that is correct.

Mr. Davis: This is the first I have heard of the 1911 article being put in and I have not read it and know nothing about it.

Mr. Darby: It was quoted from in the direct examination of the witness, Mr. Davis.

Mr. Davis: Doubtless. I am very much at fault, but it is a fact. It is not stated in the list of exhibits.

Mr. Darby: It is part of Exhibit 25.

Mr. Davis: Then Exhibit 25 consists of the Lilienfeld *Annalen der Physik* article, Volume 32, 1910, which is the article I have been talking about and also of *Leipsiger Berichte* of 1911.

Mr. Davis: If the Court please, the only reference to this Berichte article is on the record, page 546. Beginning at page 545 the article says:

> "We now come to an article by Lilienfeld entitled: 'Conduction of Electricity in Extreme Vacuum,' published in the *Annalen der Physik*, Volume 32, 1919."

Which is a misprint for 1910, I assume.

"This is also published in the *Leipziger Berichte*, Volume 63, 1911."

The offer was made of the 1910 article, as I understand it.

MR. DARBY: The second article was not specifically mentioned. It was entirely by oversight. I wanted to put in evidence everything the witness referred to.

(Discussion.)

THE COURT: When will they be ready, Mr. Darby?

MR. DARBY: We are working on them right along. We are getting some of them in. I think Mr. Richmond has a photostat marked or unmarked, of this complete article, which we will make available to Mr. Davis.

MR. DAVIS: I now have, if your Honor please, and I was not a moment ago aware of the fact, in fact I was distinctly under the opposite impression, that among the copies my brother has been kind enough to lend me, there is a copy of *Leipziger Berichte* article, so that I shall be glad to read it over during the noon recess.

THE COURT: Very well.

MR. DAVIS: I may not be able to read it over, but I will look at it at least.

XQ. 615. I would like to go back for a moment if I may, to the Lilienfeld-Rosenthal article and particularly to the picture on page 257, which gives a diagram of connections. Now, what is this thing that is marked 2 in the article; I think you said that was what——

THE COURT: I remember it very well.

A. Two, I stated was the anode, main anode, which co-operates with the main cathode 1.

XQ. 616. Is it not what is ordinarily called the anti-cathode?

A. That is correct in the terminology used with X-ray tubes.

XQ. 617. The old X-ray tubes had frequently two electrodes, which are both positive, and one of them is called the anti-cathode?

A. In some cases that is correct, some of them did, not all of them.

XQ. 618. But the anti-cathode was the positive electrode on which the stream of electrons from the cathode impinged, and from which the X-rays issued?

THE COURT: From what?

XQ. 619. From which the X-rays issued; is that right?

A. If you ask for a strict definition of "anti-cathode," I can not give it, but that was my understanding, but I am not sure whether the term "anti-cathode" applies to the target, or to this other side terminal which sometimes was incorporated in the tube.

XQ. 620. Let us not bother with terms then. That is the fact in this figure 2, is the electrode from which the X-rays issued?

A. That is correct.

XQ. 621. I would like to be very frank with you, Professor. I think there is a misprint in this article, and the description of the anti-cathode and cathode and anode, are a little bit mixed up. Perhaps you would like during the noon recess, to look it over, and satisfy yourself, particularly as to, for example, this point—we asked you for the distance between the auxiliary cathode and the anode with which it co-operated, and you gave us the distance between the little thing 3, and the little thing 2, in the picture as one-eighth of an inch, if you remember?

A. I did not specify one-eighth of an inch as a definite figure.

XQ. 622. I understand, but you gave your rough estimate as one-eighth of an inch?

A. Very rough estimate.

XQ. 623. But the point I am trying to make is that that estimate was based on the distance between 3 and 2 in the picture?

A. Yes, but may I point out that this is merely a diagrammatic drawing, and I have no reason to assume that is even to scale.

XQ. 624. I have not quite made my point, Professor. I will just call your attention to the fact in the drawing, 3 and 2 are connected together electrically?

A. That is correct.

XQ. 625. So that there cannot be 1, an anode, and the other a cathode on the same circuit?

A. I did not imply they were. There are two circuits in this device, the main circuit, which supplies the high tension current between cathode 1 and anode 2 for that circuit. One will be the cathode, and 2 will be the anode. Now, it is perfectly possible, and it is my understanding that this arrangement was described, the electrode 3 can be a cathode in a separate auxiliary circuit, operating with either 4 or 2, as the anode.

XQ. 626. Now, how can—and that is just where my difficulty is, perhaps you can help me—how can 3 be a cathode for an auxiliary circuit of which 2 is the anode when 3 and 2 are connected together by a wire, and therefore the same potential; that is where my difficulty is.

A. Three and 2 are apparently connected here. On that point I should have to look it over.

XQ. 627. That is the thing I would like to have you look over, that is what I want to call your attention to, I think you were misled by the misprint in one article and after luncheon we would like to straighten it out, and see what the facts are?

A. Very well.

XQ. 628. Now, still on that paper, where it is describing the several references to that article, it says:

> "The discharge 3 and 4 supplied by the city net-work or other suitable current of source, will hereinafter be called the primary discharge."

Just before that:

> "The consumption of current required for heating corresponds to approximately what is needed for a glow lamp of the average candle power."

That is the heating of the hot cathode, is it?

A. Yes, I should so interpret it.

XQ. 629. Now, on the page preceding, it says:

> "This voltage in the X-ray tube we describe is of an order of magnitude just sufficient to be supplied by city mains."

Would not that to your mind be a rather unusual expression of 500 volts or anything of that sort?

A. Not at all. It is perfectly possible to have 500 volts.

XQ. 630. You mean you, as an electrical engineer—you are not qualified as an electrical engineer—but that is what it would convey to your mind—500 volts?

A. I say that it is perfectly possible in this case——

XQ. 631. What would it naturally mean, Professor Chaffee?

A. The city main?

XQ. 632. It is the voltage supplied by the city mains; what does it convey to your mind as a practical man?

A. We have city mains entering our laboratory, and whenever that expression is used it does not mean

110 or 220 volts or 450 volts; it may mean any one of them.

XQ. 633. Coming back to the 1910 paper, in his final results, the anode was continually kept in liquid air during the experiment, was it not?

A. I remember that in some experiments, yes.

XQ. 634. Those were the experiments in which he thought he got results which were satisfactory to him, were they not?

A. I do remember that he made the experiment in which he first observed results without the tube immersed in liquid air, and then the results with the tube immersed in liquid air, and found there was no change in current or no change in voltage, and from those observations, he deduced that there was no change in results because of the change of gas pressure, which would, of course, result from that change of temperature from room temperature down to liquid air.

XQ. 635. He says, does he not:

> "After the tube with which diagrams 1 to 4 were taken, had shown that one could to a very great extent get rid of the gas on the walls of the vessel, I tried to still further improve as far as possible this method of denuding the walls of gas. Since in the lower part of the tube in which only the anode could not be kept at a definite temperature even when the rest of the tube was dipped into liquid air, I introduced a platinum cap anode, which is shown in Fig. 7 on page 687, and which can have its whole surface in contact with the cooling liquid."

He says that, does he not?

A. He says that.

XQ. 636. Now, what was the current he used in the tube? I think you stated it.

A. Do you mean the space current or the heating current?

XQ. 637. The current lengthwise through the tube, the current flowing through the tube?

A. As I remember it was of the order of ten or eleven milliamperes.

XQ. 638. And what is the voltage across the tube?

A. I do not remember that he states the voltage aross the tube. He describes or deals with the voltage between the sounding electrodes.

XQ. 639. And he does not state the voltage across the tube?

A. I do not remember that he does at the moment.

XQ. 640. He states then, you will remember, that he does state voltages observed between two wires which were stuck into this tube from the side?

A. Yes.

XQ. 641. Which he called sounding electrodes?

A. Yes, that is right.

XQ. 642. Is it your opinion that voltages measured in that way mean very much?

A. Under certain conditions, yes.

XQ. 643. Is it the general scientific opinion that they are reliable?

A. One must take certain precautions in order that the results may be reliable.

XQ. 644. Is it the general scientific opinion that if those precautions are taken, you do get reliable results?

A. I believe it is, if the necessary precautions are taken.

XQ. 645. Do you remember what Richardson said about sounding electrodes in his book—the reliability of the sounding electrodes?

A. I think I do remember that he mentions sounding electrodes.

XQ. 646. You do not remember what he said about them?

A. I do not remember.

XQ. 647. What are the precautions you have to take?

A. You have to be sure that the insulation is very high between the electrodes and from the electrodes to any other points. The sounding electrodes would have to be used in case where there is sufficient current passing and ions of both signs in order that the sounding electrodes may be charged up, so that they will assume the potential of the point of space, where they are situated. Of course, there may be danger of getting a steady potential known as a contact potential between the terminals, but that can perfectly well be.

XQ. 648. How did Lilienfeld take account of it, according to the article?

A. In his results, or in the calculation of his results, he has a factor eleven, which be subtracts from the voltage readings; and I have assumed that that was a constant error or a potential, which he subtracted, in order to correct, for various things, such as contact potential or other constant error.

XQ. 649. Do you know what the magnitde of that alleged correction is, when it is worked out with eleven; did you ever work it out to see what it amounted to?

A. I do not really understand your question.

XQ. 650. Let me ask you this question: What is the order of magnitude of contact potentials?

A. Oh, 2, 3, 4 volts of that order of magnitude.

XQ. 651. Well, we will come later to this eleven, and when we do, will you please bear in mind that this suggestion has to do with contact potentials?

A. I do not say the eleven was all contact potential.

XQ. 652. Well, then, what Dr. Lilienfeld mentioned, Professor Chaffee, was not the voltage across the tube, but was the voltage which existed from time to time between two wires which were struck into the sides of the tube, is that correct?

A. That is quite correct.

XQ. 653. Now, Dr. Lilienfeld wrote a letter to which you referred in your direct testimony, it was in the *Phys. Zeit.*, 1908. Have you that letter there?

A. The letter to Soddy?

XQ. 654. The letter to Soddy, yes.

A. I have it.

XQ. 655. That was Defendant's Exhibit No. 19. Will you read the footnote; have you that footnote?

A. I should have stated that I have only excerpts, or extracts from it.

XQ. 655a. I have here what purports to be a translation of the whole letter. Will you read the footnote; will you read it out loud? I understand it has now been found in your copy; is that the footnote?

A. Yes.

Mr. Darby: Page 131.

XQ. 656. Please read it.

A.

> "With constant cross-section of the tube (about 12 mm. diameter) the potential drop in the positive column is within wide limits directly proportional to the square root of the current strength when the observations are taken in the highest attainable vacuum (charcoal, liquid air)."

XQ. 657. Now, Dr. Lilienfeld found, did he not—in fact, I think you so testified, at least this footnote states, does it not, that he found that the drop in the positive column was proportionate to the square root of the current. That was translated by you, I think, to mean that the current was proportional to the square of the voltage; is that correct?

A. That is correct.

XQ. 658. So that here the law of this tube is a law that current is equal to the square of the voltage, or proportional square of the voltage?

A. That is hardly a correct interpretation to put upon my testimony. I stated that in a certain range, the current varied as the voltage to the 3/2 power above that range the current varied as the square of the voltage.

XQ. 659-60. Here is what he says himself:

> "The potential drop in the positive column."

That means the voltage as ascertained by these certain electrodes, does it not?

A. That is correct.

XQ. 661. Continuing the quotation, it says:

> "Within wide limits directly proportional to the square root of the current strength."

Is that characteristic of the tube in which the current is governed, or limited by space charge?

A. No. But I stated that this is so over a certain range, whether it is wide or not, is very definite. It is the upper range.

XQ. 662-63. Then in that range, you do not think that the current is being governed or limited by space charge?

A. In that range there is undoubtedly something else acting to vary the law from the 3/2 power law.

XQ. 664. Well, that range is by far the larger portion of the curves given in the article, is it not?

A. I do not so understand it.

XQ. 665. Now, is not this true, that as he works along in the article, and as we laboriously work along in the article after him, the first thing we come to is this J^2, the voltage is proportional to J^2?

A. I think we come first to the point where he says J 2/3 power, is it not?

Mr. Davis: Well, we will have to look at the article. Now, just go right through the article and find where he attempts to talk about J and J^2, or whatever it is. It will save time.

XQ. 666. The first reference which we find is his section IV, which is on page 699 of the original article. There may be others, of course. Do you find anything prior to that in the article?

A. As a matter of fact, in this reference book, page 699 does not appear.

XQ. 667. Then will you be good enough to look at this paragraph which I have? There is a section here on page 28 of this translation, said to be page 699 of the German, and I believe that the German is also here. Now, will you read that paragraph following that?

A.

> "Even during the first potential measurements by means of sounds"—meaning sound electrodes—"when the methods of evacuation had not yet been developed to the same extent as in the course of time, there was found to exist besides various irregularities and phenomena that always appeared in different form, a definite relation which could always be reproduced. It was found that when the discharge tube had been subjected to a proper previous treatment and the degree of vacuum mentioned in the introduction had been obtained, the relation between the current J and the potential gradient V could be expressed by (1) $J - av^2 + b$."

XQ. 668. That is equation 1 of his article.

A. Yes. "J equals $av^2 + b$. Where a and b are constants that will be more fully interpreted later."

XQ. 669. Now if I may call your attention to a diagram on page 701 of the article, it expresses this relation by a straight line, does it not? That straight line corresponds to the portion of the characteristic which is expressed by that formula V^2?

A. That is correct.

XQ. 670. And the lower part of the characteristic in that particular curve is a little erratic?

A. Quite right.

XQ. 671. And he calls attention to the fact that the ascending and descending curves are somewhat different. He continues in the article to make a further study of that little part of the characteristic down at the bottom, does he not?

A. Possibly.

XQ. 672. I have the German article here, by the way, if you want it. At any time you may ask for it if you doubt these translations at all. And he says here, "Whatever was said about the quadratic law"—that means square law?

A. Yes.

XQ. 673. "Whatever was said about the quadratic law holds for the better vacuum that could now be obtained with the help of newly installed equipment." It means he improved the vacuum and got this law?

A. He also means that the erratic results which you pointed out——

XQ. 674. I am coming to this. I am now talking about the part of the curve which is straight?

A. That is correct.

XQ. 675. He continues: "Also here every reduction in the gas pressure up to the limiting region to be considered later on causes a diminution in a." a was one of the constants in that equation?

A. That is correct.

XQ. 676. That means it causes a diminution of the current?

A. Correct.

XQ. 677. "Furthermore there are three peculiarities of the characteristics that always were found to exist . . . as can be seen from the lower parts of the diagrams when the points are scattered." So far he has still the square law as the law of the tube with an erratic little section down at the bottom that he does not yet understand and cannot yet regulate, is that right?

A. If you will omit the word "little."

XQ. 678. Let us look at it. Is it big or little?

A. It depends entirely on how you plot results. You can make a certain range appear little by plotting them——

XQ. 679. I did not plot this. To my untutored mind that looks like a little part of the curve.

A. Will you notice that it is plotted to V^2?

XQ. 680. I do.

A. And V^2 always compresses the lower portion and expands the upper portion.

XQ. 681. It certainly is little on the curve at least.

A. Quite correct.

XQ. 682. I do not know that it is important whether it is big or little, but I am simply trying to get the facts. Now then, he went on, did he not, and he plotted some curves 1 to 4 at page 704 of the paper. Those are characteristics of the tube, were they not?

A. Those were some characteristics.

XQ. 683. To avoid misunderstanding I shall state that when he has plotted each curve he has gone over a certain distance so as to avoid the curves being on top of each other?

A. Yes.

XQ. 684. They do not really represent the different values but simply to avoid confusion?

A. That is right.

XQ. 685. Now, the portion of the curve which represents the square law is the upper portion of the curve and down at the bottom is the part which turns out to be the 3/2 power law?

A. That is correct.

XQ. 686. He is still feeling around for some law for the lower part of the curve? He has found that the upper part of the curve follows the square law. He has a part of the curve that he has not been able to get steady enough yet to analyze at all. Then he describes how he made further experiments and gives us some more plots on page 709.

Mr. Haight: I think there is a question there to be answered. Mr. Davis' statement may have indicated that he acquiesced in it.

The Court: Do you want the question read?

Mr. Davis: I have not quite finished the question.

(The stenographer repeated the question as follows: "XQ. 686. He is still feeling around for some law for the lower part of that curve?")

A. He describes that it was necessary to improve the vacuum in order to bring the lower part of the curve into a definite mathematical law.

XQ. 687. That is another way of saying what I have said?

A. Probably is.

Mr. Davis: I have no doubt about that.

The Court: Is the lower part of the curve, that portion which you now contend is within the range of the 3/2 power law?

Mr. Davis: So far as our contentions are concerned, we say that he never had the 3/2 power law.

The Court: But I say, do you think it is now within the range of the 3/2 power law?

Mr. Davis: No, sir. The witness has testified that this announcement by Dr. Lilienfeld that he had found that his tube obeyed two laws, in one portion the 3/2 power law and in the other portion the square law.

XQ. 688. This lower part of the curve is the part of the curve which in your view he said was the 3/2 power law?

A. That is correct.

THE COURT: This gives it to me fully.

XQ. 689. Now, on page 709 there are further curves taken, are there not?

A. Yes.

XQ. 690. And here there is a certain erratic tendency in the lower portion of the curve. I think it is better to look at the actual paper because it has a better reproduction.

A. There is some variation in the lower part, but the curves, most of them, are quite parallel to each other.

XQ. 691. But the divergences where they exist are much more marked at the very bottom of the curves?

A. That I guess is practically true.

XQ. 692. And you notice that a number of points appear there?

A. Yes.

XQ. 693. So that he was studying that part of the curve carefully?

A. Quite right.

XQ. 694. Now, none of these curves come down to the origin, did you notice that?

A. Another way of stating that is that there was a factor which he corrected for.

XQ. 695. Let us get the fact first and the factor afterwards. It is a fact that it requires a substantial voltage to make any current pass through the tube?

A. If I recollect correctly, referring to the numerical values tabulated in the paper, some of them do go down to zero current with zero voltage; and because of this displacement which he incorporated into his graphs it is not so easy to determine whether the curve would go down to the origin or not.

XQ. 696. I am not talking about curves which he plotted after he got that mathematical transformation. I am talking about the curves from actual observation and my question is whether it is not true in that tube it required as far as this paper shows a substantial voltage to pass any current whatever through the tube?

A. No, I cannot agree with that statement unless I examined the paper a little more carefully with that point in mind.

XQ. 697. We may come back to that. Let us look for example at the curve at page 709. Curve No. 5, which I do not assume is displaced. Do you? You do not assume that that curve No. 5 is displaced?

A. Possibly not. There is a striking coincident that the curve comes down to just 10, which is the amount that he displaced the curve. I see no reason why he should displace this curve, but on the other hand it is not clear in my mind that it is not displaced.

XQ. 698. Suppose you look at page 711. Is that first curve displaced by that same amount or by a different amount?

A. Yes, that curve seems to be displaced by a different amount.

XQ. 699. So that you gather that I am right in my first suggestion?

A. There may be a displacement.

XQ. 700. That is to say, these curves show that it requires a definite voltage to pass current at all through the tube?

A. In some cases.

XQ. 701. In the cases to which I have called your attention?

A. With the reservation which I have put upon the first answer.

XQ. 702. And you will notice on page 47 of this translation which is 717 of the article, he describes the manner in which he, as he puts it, gets the law of the lower part of the characteristics. Have you that? Will you please explain to the Court how he got that law? First, I will ask you this question, did he get the law in a reasoned way, I mean, as reasoning from a scientific hypothesis or did he get the law by what are called the empirical methods?

A. I understand he got it entirely empirically.

XQ. 703. I wonder if we can make it clear to the Court. If a man has a theory why a thing happens, he may then deduce a mathematical law and check that law against the observation, is that right?

A. Correct.

XQ. 704. But if he has at the moment no theory he may nevertheless study curves and work out formulæ which are called empirical formulæ, is that right?

A. Quite right.

XQ. 705. And they have no relation to any theory of operation?

A. Not necessarily.

XQ. 706. That is, if you have a curve on a sheet of paper plotted from various observations, those are mathematical methods of deriving a mathematical formula, which will produce a line which will approximate that particular formula?

A. Yes.

XQ. 707. And that we call an empirical formula. I am not reflecting on empirical formulæ. Will you please state the method by which he derived that empirical formula? Remember it is the formula for the lower part of the characteristic.

A. My understanding of the process which he followed is this: He obtains certain observational results for the potential and the current. He assumes, as a working hypothesis, that those are related by some law. It is common practice in determining the type of law connecting two variables to test to see whether it may be a power law first. By a power law I mean one quantity is expressed in terms of another quantity to an exponent. The exponent may be a whole number or a fraction.

In order to determine that, the easiest way is to take the logarithms of the two observations and plot those logarithmically and determine if the resulting plot is a straight line or a curve. If it comes out a straight line it shows that the original assumption or hypothesis, that the results are expressable as a power, is correct within of course possible experimental errors.

My understanding is that Lilienfeld does exactly that and the diagram 20A in the paper is such a plot, consisting of two portions which are straight lines. It is this lower portion which conforms with the 3/2 power law.

XQ. 708. What has he plotted there?

A. He has plotted 100 times the logarithm to the base 10 of 10th to the 3rd power times volts square minus 11.

XQ. 709. That is a rather complex thing?

A. Yes, but not necessarily mathematically.

XQ. 710. One hundred is very simple. That is jnst a question of getting it down on paper?

A. That is all.

XQ. 711. And you have explained why the logarithm is used rather than the direct plot?

A. That is correct.

XQ. 712. Why does he subtract 11, what does he tell us for the reason for subtracting 11? Does he tell you why he subtracts 11?

A. As I remember he does not specifically state what this 11 is.

XQ. 713. Or why it is subtracted?

A. That is correct.

XQ. 714. And the magnitude of that change is a rather considerable one, is it not?

A. No, on the contrary I say it was rather small because he goes to values of 400, as I remember it, or 450, and the square of 450 is a very large quantity and if you subtract 11 from that it is not very much, that is, 11 in comparison with the square of 450 is an exceedingly small quantity.

XQ. 715. How much do you think it would amount to in volts?

A. I would have to calculate it.

XQ. 716. Well, it is over 100 volts?

A. The eleven?

XQ. 717. Yes.

A. I cannot say definitely without calculation.

XQ. 718. Will you please, then, just for convenience, write down on a piece of paper 0.001 V^2 minus 11? That is what Lilienfeld plots, is it not?

A. That corresponds to the abscissa scale.

XQ. 719. Now will you please write under that 0.001 (V^2—11000)? Have you done so?

A. I believe I followed your directions.

XQ. 720. They are the same thing, are they not?

A. I will have to ask you to repeat the directions.

XQ. 721. We first write down 0.001 V^2—11.

A. I have that.

XQ. 722. Then we write 0.001 (V^2—11000). The two expressions are just the same?

A. They are.

XQ. 723. So that your eleven has suddenly become 11,000 to be subtracted from the square of the voltage?

A. That is correct.

XQ. 724. Will you figure that back and see what that amounts to in volts at the origin? Suppose you take V^2 is 11,000, what does it come to?

A. Zero.

XQ. 725. What is V?

A. Approximately 100.

XQ. 726. That is what I said.

A. Yes.

XQ. 727. It is a little over 100, about 105?

A. Yes.

XQ. 728. So that 105 volts means no current in that tube?

A. Yes, in that case.

XQ. 729. That is his law of the tube?

A. No, he gives the law of the tube, that is, he deduces a law of the tube which is stated further on. This is analyzing his mathematical derivation of that law.

XQ. 730. His 3/2 power law is derived from his ¾ power law on page 718 of the paper which is J equals 100.70 $(V^2—11)$ ¾, is that right?

A. Yes.

XQ. 731. The 11 is still with us?

A. The 11 is still there.

XQ. 732. And the whole derivation of his alleged 3/2 power law requires that 11 to be there or requires that displacement of the curve; is that right?

A. That is right so far as that expression of it is concerned. Now I would like to add that although there is no definite reference as to what this 11 is, I interpreted it as a legitimate correction, because it must be understood that Lilienfeld was using a quadrant electrometer and every physicist knows that a quadrant electrometer is a fickle piece of apparatus and requires certain precautions to be made. I have put the benefit of the argument upon Lilienfeld in interpreting this article.

XQ. 733. That is a rather large man's size correction, 105 volts out of what you said, 300 or 400 maximum?

A. It is a large correction.

XQ. 734. And does he not give tables giving his corrections and a very accurate calibration of his electrometer on page 601?

A. But a calibration curve of an instrument may derive the law of the instrument which everybody will admit in the case of an electrometer is a perfectly definite law, but when that instrument is applied to a particular experiment there may be other corrections.

XQ. 735. So far as anything Lilienfeld derived or proved or showed or stated is concerned, his 3/2 power law was a law in the first place not of the tube, not of the voltage across the tube, like the law you first spoke of this morning, but of a measurement between two sounding electrodes somewhere in the tube; that is true?

A. Yes.

XQ. 736. And it is a law which means that no current flows at all until you get to 105 volts, that is true, is it not?

A. There still sticks in my mind the fact that I do not believe Lilienfeld, being an experienced physicist, would have stated in parentheses further down that the current varies directly as J to the 2/3 power without having a good reason for making the correction which he has made, but which he has not, I will admit, very carefully explained in his article.

Mr. Davis: I move to strike it out.

The Court: The answer not being responsive? What have you to say, Mr. Darby?

Mr. Davis: We are dealing with statements in a publication and the witness being shown the statement in the publication leading to an absurdity, the witness says, "I think he is such a good physicist he means something else."

Mr. Darby: I think Mr. Davis is putting his own interpretation on what the witness said. Mr. Davis himself is so intimately associated with this derivation of the 3/2 power law to this feature of the eleven volts that I think the answer is entirely responsive to the question.

THE COURT: My difficulty is that it is argumentative instead of direct. Had he answered yes or no with that further statement I could see no fault with the answer.

MR. DARBY: But I submit from a technical subject it is one of those subjects that you cannot answer yes or no.

THE COURT: You mean that he could not answer it without an explanation?

MR. DARBY: Yes, and I think that that explanation is in effect an answer. If Mr. Davis raises the question that he should say "yes" or "no," which is a phrase with which we are familiar—

THE COURT: That is the difficulty that I find with it and I do not see that it makes much difference because the explanation becomes a substantial part of the answer in any event, but if you press it, Mr. Davis, I shall strike it out on that ground.

MR. DAVIS: I do not press it, because I understand we want to adjourn for luncheon.

AFTER RECESS.

By MR. DAVIS:

XQ. 737. The characteristic difference between the Fleming valve and the DeForest audion is the presence of the third electrode, is it not?

A. That is correct.

XQ. 738. Now, when you are dealing with the modern tubes, you also have tubes with two electrodes or with three electrodes; we have had that before, I think, there are modern tubes with two and three electrodes?

A. Yes.

XQ. 739. And when you are taking the 3/2 power characteristic, or taking the voltage current characteristic, of a three-electrode modern tube, you ordinarily connect the grid or third electrode to the negative end of the filament, don't you?

A. Not always.

XQ. 740. I say ordinarily?

A. In taking the——

XQ. 741. If you want to take a characteristic current between the cathode and the plate, you ordinarily connect the grid to the negative end of the cathode?

A. I think not.

XQ. 742. How do you connect it?

A. We connect it with the plate, very often.

XQ. 743. You connect it with the plate; you have to connect it to something?

A. Oh, yes; it must not be left free in space, because then it will assume some potential, which of course is variable.

XQ. 744. That is what they call letting the grid float, is it not?

A. Yes.

The Court: That is what?

Mr. Davis: Letting the grid float—more of these slang terms of the art.

XQ. 745. Now, suppose you do let it float, to what potential does it tend to charge?

A. It will assume (meaning the grid) a potential dependent largely upon the initial velocity of electrons issuing from the filament and upon the amount of gas in the tube——

XQ. 746. Suppose we deal with a tube that has not any gas in it, enough to affect the action, it tends to charge up to somewhere near the negative potential of the cathode, does it not?

A. It will assume a potential not very far away from the potential of the filament.

XQ. 747. That is, regardless of where it is in the tube?

A. No. I would not say that.

XQ. 748. Well, it is regardless of where it is in the path between the cathode and anode?

A. Possibly, roughly so, within very narrow limits. That is, I do not mean by that, that you can carry it away a great distance.

XQ. 749. The more accurate statement is, is it not, that the grid left free to float will tend to charge up to the cathode potential less the potential corresponding to the initial velocity of electrons?

A. That is right, yes.

XQ. 750. That is right, and as that potential is usually small compared to the potential across the tube as Dr. Millikan said the other day, so small that you could usefully neglect it as a first approximation, you might say that that grid will tend to charge up to the negative potential of the cathode?

A. Yes, neglecting figures of the order of a few volts.

XQ. 751. Yes. I am only trying to get a rough idea of what is going on, and this will be true of a single wire placed in that space just the same as it would be with the grid, would it not?

A. Yes.

XQ. 752. And the potential between the cathode and the anode, that is the potential in the space, actually varies; that is, for instance, if you take the cathode as zero, the anode might be plus 100 or plus 200 in the space, the potential is actually varying, by a sort of gradient between those two points, is it not?

A. Certainly.

XQ. 753. And the electrons are speeding up, as they leave the cathode and approach the anode?

A. That is correct.

XQ. 754. And acquiring velocity all the way across?

A. Certainly.

XQ. 755. Not like rifle bullets after they leave the gun, but more like the rifle bullet in the gun, when the powder is pressing behind it; is that correct?

A. That is correct.

THE COURT: Is that due to the boiling temperature of the cathode or the pull of the anode?

XQ. 756. Will you answer?

A. Due to the pull of the anode, your Honor, the electron is in a field of force and acted on continuously by this pull, which of course speeds it up.

XQ. 757. I take it that therefore you agreed with J. J. Thomson in his book "Conduction of Electricity through Gases," to which Dr. Millikan, I think, referred, when he said on page 435 of the 1903 edition—suppose you read it there, just beginning at, "But the method," and through the next paragraph.

A.

> "But the method is a dangerous one when the pressure is very low, or when the wire is placed in the Crookes space where the conductivity is very low.
>
> Thus, to take an extreme case, suppose that a secondary electrode is placed in an enclosure in which there are torrents of negative ions but not positive ones, then the wire will go on receiving negative electricity until it gets so highly charged that it is able to repel the negative ions sufficiently to prevent any more striking it; when this stage is arrived at its potential may be lower than that at any point in the enclosure previous to its introduction."

XQ. 758. Thank you. Now, I will make my question more clear. The method referred to in this quotation you have just read, is the method of studying the distribution of potential along a tube by introduction of sounding electrodes, is it not?

A. That is correct.

XQ. 759. Do you agree with J. J. Thomson's statement that the method is a dangerous one when the pressure is very low?

A. I agree with the statement certainly in most particulars. I pointed out this morning that one must take certain precautions which is another way of stating that they may be dangerous.

XQ. 760. Do you remember what Richardson says on the same subject in his book, which has also been referred to in this record?

A. I do not.

XQ. 761. This is the edition of 1921 of the book entitled "The Emission of Electricity from Hot Bodies" by O. W. Richardson, F. R. S. This is the same Richardson whose law we have been discussing, is it?

A. The same one.

XQ. 762. Will you please read in here, on page 106?

A. (Reading):

> "J. Lilienfeld has investigated the potential gradient required to drive electron currents of considerable magnitude through long tubes under good vacuum conditions. He finds that over a considerable range the potential gradient is nearly proportional to the square root of the current and is constant along the length of the tube. If the last named result were strictly true it would follow from Poissan's equation that the volume density of the electrification must be zero during the passage of the current. To explain his results Lilienfeld adopts the rather heroic hypothesis

that the negative ions are compensated for by the presence of positive ions formed of the dissociation of the vacuum. It appears, however, that under the conditions of this experiment, even if there are no positive ions, the volume density of the negative electrification would not be large, and it is doubtful if the measurements of the potential gradient are accurate enough to detect the expected variation along the length of the discharge. The difficulty of determining the local potential by means of sounding wires in a unipolar discharge is well known. Minute traces of gas would also greatly reduce the negative volume density and it may not have been possible completely to remove them even with the very elaborate precautions in this respect, which were taken by the author. At any rate it is clear that there are a number of possible explanations of a rather ordinary character which have still to be disproved. In fact a careful examination of these papers does not reveal any conclusive evidence that the potential gradient was constant along the path of the discharge under high vacua conditions."

XQ. 763. Now, on this question of precautions, J. J. Thomson says a little more—I am going to ask you to read. By the way, there is no question about J. J. Thomson being a very skilled and important person, is there?

A. No, not the slightest.

XQ. 764. He was director of the Cavendish Laboratory at Cambridge, was he not?

A. He was.

XQ. 765. Just before the part I asked you to read, he discusses the conditions in which in his judgment such a method would be successful. Would you mind reading that, page 435, beginning "Four methods——"?

Mr. Darby: Just a minute, Mr. Davis, I understand that you asked the witness a question about the article that he read?

Mr. Davis: I will ask him if he agrees with what J. J. Thomson says.

Mr. Darby: So far as it stands at the present time, he is simply putting on the record what somebody else has said, and I object.

Mr. Davis: I want to get the connection here.

The Court: On that understanding, Mr. Davis, you may proceed, but if by any chance you feel, Mr. Darby, that at any stage of the case that that has not been done, you may move to strike it out.

A. (Reading.)

"Four methods such as those just described to be successful, the secondary electrodes must take up the potential of the gas with which they are in contact. To enable them to do this quickly there must be a plentiful supply of both positive and negative ions in the gas, which, by giving up their charges to the wire, can raise or lower its potential to equality with the surrounding gas. The results obtained seem to justify the assumption that at moderate pressures, secondary electrodes do in most parts of the discharge, acquire the potential of the gas, but the method is a dangerous one."

XQ. 766. And there you have already read, and I won't ask you to read any further. Do you agree with Richardson's views as to sounding electrodes expressed in the quotations which you have just read from his book?

A. I think I agree in most part, yes.

XQ. 767. And do you agree with the statement that you have just read from J. J. Thomson's book?

A. Yes, and I think that is consistent with my previous testimony.

XQ. 768. Now, then, how do you justify the use of these sounding electrodes in the Lilienfeld experiments?

A. In our discussion, we are dealing with the potential difference, supposedly given by these sounding electrodes between two definite places in the discharge tube. We are not moving them up and down as one of these references implies. We are then using these sounding electrodes to determine the variation of potential between those two electrodes as the current densities vary. Now, I will admit that possibly there may be a constant error; in other words, that possibly the potential of one of those sounding electrodes may have shifted with respect to the actual potential existing in the gas; that is, I will admit that for the time being, simply for the argument. If that is so, the other one must have shifted by the same amount or practically the same amount, except for the difference that exists between them. In other words, there may be an error in the use of one single electrode, but that same error would be introduced into the use of the other one; so that the difference between them may perfectly, well, I believe, give a true value of the potential difference or the variations of potential difference as it is effected by the variation of current.

XQ. 769. Now, if you should take defendant's H tube, and I only take that as a type, I say take any tube of that general type or any modern tube having an anode and a cathode—I mention the H tube because one of those tubes has no grids, and it simplifies the discussion.

A. I am not familiar with the H type tube.

XQ. 770. Do you know what is called a kenetron?

A. Very well.

XQ. 771. Take a kenetron and put two electrodes in the path between the cathode and the anode, one is nearer the cathode and the other is nearer the anode, you have told us that both of those would tend to charge up to the negative potential of the cathode, have you not?

A. Within a small difference which we spoke of.

XQ. 772. And they will be practically at the same potential, will they not?

A. May I ask are these two to be placed different distances from the cathode?

XQ. 773. We will assume that the anode and the cathode are an inch apart. You may call it a centimeter or some other unit. One unit apart. And one-quarter of that unit from the anode you put the first of these electrodes and one-quarter of that unit from the cathode you put the other electrode. Will they not tend to charge up to practically the same potential?

A. Possibly, but that is quite a different case from the one we are discussing.

XQ. 774. I do not think that I suggested that it is the same case. I am trying to get you to bring out the difference between them.

A. What is the difference? The difference is that in the Kenetron tube we are near the electrodes. In the Lilienfeld, Dr. Lilienfeld purposely placed his sounding electrodes a long distance away from the cathode and the anode in a long tube. I consider that that makes a different experiment.

XQ. 775. I have not the slightest doubt that it makes a different experiment, Professor. I was trying to see just what the difference was. The structures are different.

A. The structures are different.

XQ. 776. We cannot question that, can we? You told me, generally speaking, of the high vacuum tube, that there was a tendency for any electrode, floating electrode in the space, to charge up to the negative potential of the cathode less the initial velocity voltage, whatever that might be. Why isn't that true in Lilienfeld's tubes?

A. I think the conditions would be altered. In fact, I should have remarked that we were speaking about the floating electrode and certainly that potential would be determined provided there was no plate voltage impressed. Suppose a plate voltage is impressed——

XQ. 777. There is always a plate voltage, isn't there? I mentioned a one hundred plate voltage when I asked you the question.

A. I had forgotten that point at the time. I think perhaps I can explain the difference or rather, attribute the difference entirely to the difference in structure of the two cases, one is a long tube and the sounding electrode is a long distance away with a space of uniform cross section through which the current is travelling and it is more or less like a wire through which the current is travelling and of course we know then that you can obtain a difference of potential between any two points by putting on what is equivalent to sounding electrodes. In the other case it is different, it is equivalent to a very large conductor.

XQ. 778. Let us follow that analogy a little. When a current flows through a wire there is something obstructing its flow and there is a drop of potential due to that obstruction. When these electrons flow through this long tube of Lilienfeld, which by the way is a small diameter tube, is it not?

A. Relatively small, yes.

XQ. 779. Do you think there is something there that obstructs there corresponding to this resistance in your wire analogy?

A. Possibly.

XQ. 780. What is it?

A. The effect of the walls of the tube.

XQ. 781. What is that effect?

A. They may charge up.

XQ. 782. Suppose they do, what will that do?

A. Then there will be a repulsion of the charge that exists on the walls of the tube and the electrons that are passing through.

XQ. 783. But in your analogy the drop in voltage corresponded to a loss in energy. What is the corresponding loss of energy in the Lilienfeld tube?

A. I did not refer to any loss of energy.

XQ. 784. I want to push the analogy as far as I can go. If I push it too far say so. Logically there should be, should there not, if your analogy is good?

A. Do you mean that with a drop of potential or because of a drop of potential there is a loss of energy there?

XQ. 785. Along the wire there was a loss of energy.

A. In the case of the wire where we admit there is resistance.

XQ. 786. But not in the tube?

A. It is conceivable to have a drop in potential and a current passing without anything analogous to an energy loss in the form of heat there.

XQ. 787. Then in that case there is nothing to prevent the electrons from doing in the Lilienfeld tube what they do in an ordinary tube, that is, to increase the velocities as they pass the length of the tube?

A. That is right, provided you eliminate the bombardment of the walls.

XQ. 788. Do they or do they not increase their velocity as they go along the tube?

A. As I say, if we neglect the bombardment of the walls for the time being they will increase their velocity.

XQ. 789. I am trying to find out what really does happen.

A. They do increase their velocity further.

XQ. 790. You do not know?

A. I am not absolutely positive.

XQ. 791. Is there any giving up of energy to the walls as they come along?

A. If they strike the walls they would give up energy to the walls.

XQ. 792. Actually in the operation of the tube is there or is there not a giving up of energy to the walls?

A. In Lilienfeld's experiment?

XQ. 793. Yes, the 1910 paper?

A. Yes, I believe there is.

XQ. 794. That is rather considerable.

A. He speaks of it as heating the walls.

XQ. 795. Very hot?

A. I do not remember the exact words.

XQ. 796. I have just this morning, at luncheon time, been able to look over the *Leipziger Berichte* article. It is my impression that he said in that article that they get so hot that he saw the color of sodium, do you remember that? On page 536 of the article, about three or four lines down the page, does it not say:

> "With this current strength" which was ten milliamperes, "the glass walls were heated so strongly that under certain conditions the glass was covered with intense sodium light."

A. That is correct.

XQ. 797. Then there must have been a pretty substantial loss of energy there?

A. Under those circumstances, yes.

XQ. 798. If the tube does not consume energy corresponding to the potential drop as you go along, that is, if the electron on the whole does not give up as much energy as it gets coming through the tube, on account of being nearer the anode, it must increase its velocity?

A. Yes.

XQ. 799. And if the velocities are different then the sounding electrodes become meaningless?

A. There probably would be a slightly different potential assumed, because of the difference in velocity striking it, but if there are positive ions there as of course as I have stated there are positive ions no matter how high the vacuum may be, it is conceivable that the positive ions may be sufficient to take care of that change of potential.

XQ. 800. But J. J. Thomson said that in order to do this there must be a plentiful supply of both positive and negative ions?

A. That is an indefinite term, of course. The necessary supply would depend somewhat, I think, upon the instrument used to measure the difference of potential, upon its electrostatic capacity, upon the leakage between the terminals.

XQ. 801. Did you have an opportunity to look up the Lilienfeld-Rosenthal paper?

A. Yes, I did.

XQ. 802. And what did you find?

A. I found a reference as I had stated in the Rosenthal paper.

XQ. 803. Let us take first the Lilienfeld-Rosenthal paper, if we may. All right, go ahead. Please finish your answer.

A. On page 10 of the translation I find this statement:

> "The heat current"—meaning the current which heats the filament—"remains constant. It corresponds to the one in a medium strong incandescent lamp according to the number of watts used up."

XQ. 804. You are reading the translation there?

A. Yes.

XQ. 805. Would you mind putting that into simpler language?

A. Simply stated the current heating the filament during the operation of the device was maintained constant, which is, as I stated this morning, that the variation of hardness of the tube was obtained by varying the voltage in this auxiliary circuit.

XQ. 806. In the auxiliary circuit?

A. Yes.

XQ. 807. It may be that we were laboring under a misunderstanding this morning.

A. Both are true. I stated both.

XQ. 808. The variation of the voltage in the auxiliary circuit brings about a variation of the voltage in the main circuit on account of the drooping characteristic of the transformer?

A. Yes.

XQ. 809. Will you tell what we mean by a drooping characteristic?

A. If the voltage of any device is measured as the current drawn from that device is increased, one might plot the current vertically and the voltage horizontally. The curve which you get may fall or droop as Mr. Davis stated.

XQ. 810. The saturation curve of the Fleming valve or drooping curve has the same thing?

A. Yes, but for another reason.

XQ. 811. To come back to this question of the expenditure of energy in this tube, if you look at page 725 of the 1910 paper, I will ask you to please read this paragraph on page 725 and it is understood I am using the defendant's translation; is that right?

Mr. Darby: Yes, that is right.

A.

> "This leads in fact to the important conclusion that the energy used up in a given volume of the discharge tube is *not* added to the kinetic energy corresponding to the stream velocity of the electrical carriers. On the contrary this energy is converted entirely, in the volume in question, into the energy of agitation of the molecules (heating of the walls of the vessel)."

XQ. 812. Now, having disposed of our difficulties with reference to variation of voltage, can we take up the question of what I thought was a misprint in the article as to the connections of those anodes and cathodes and things? I called your attention this morning to the fact that the electrode marked 2 in that drawing was electrically connected to the electrode marked 4. I also called your attention to the fact that the description says,

> "The discharge taking place between 3 and 4 supplied by the city network or another suitable current source, will hereinafter be called the primary discharge."

I intended to say just now in asking the question that I called your attention to the fact that the electrode 2 was connected electrically to the electrode 3. If I said anything else I am sorry. I called your attention to this statement in the article itself. You agree then, I take it, that the auxiliary circuit is from 3 to 4?

A. I ~~do in~~ this particular case here. I did make the mistake in tracing out this morning the small wire connections, that the connection was made between 2 and 4. I see now that it is made between 2 and 3 in this particular drawing, but my memory was also affected by the reading, I think, of the Lilienfeld patent which describes a similar tube and he shows there quite a number of different connections and I am under the strong impression that the connections of some of those drawings were as I stated.

XQ. 813. Perhaps you were deceived by the statement on page 3 of my translation. It says: "The energy of the cathode rays of this discharge is received by the anti-cathode 4 connected with 3."

A. That is undoubtedly true in this case.

XQ. 814. In this particular case that cannot be true, it seems to me, because the anti-cathode is evidently 2——

THE COURT: I am wondering what the witness meant "in this particular case."

XQ. 815. Will you please explain that, what did you mean by "in this case"?

A. I meant if the tube were used as shown in the drawing of the Lilienfeld article that the energy of the primary discharge would be dissipated on the terminal 4, that I had made a mistake in tracing the wires.

XQ. 816. The energy of the primary discharge?

A. The energy of the primary discharge.

XQ. 817. But it says in this thing I have just read you, he is speaking of the high voltage discharge at that point and I suggest to your consideration that 4 is a misprint for 2 at that point. Do you agree to that?

A. I shall have to see the reference again to which you refer. I thought you were speaking of the primary discharge. That I believe to be a mistake undoubtedly. The energy must be dissipated on terminal 2.

XQ. 818. Now, look again on that same picture. The information you were kind enough to give us this morning about the different distances between 2 and 3 becomes useful to us.

A. In this particular case, yes.

XQ. 819. Can you give us the same information about the distance between 3 and 4, because that is what we really want, is it not?

A. I thought I indicated this morning that it is very difficult to put any distances upon this drawing. No scales are shown. It may not even be a drawing to scale.

XQ. 820. You were assuming this morning it was about an eight-inch bulb?

A. Yes, but without any knowledge whatever about it.

XQ. 821. Six to eight inches would be a reasonable assumption for the bulb?

A. I would say probably from 4 to 6 inches. I have forgotten what I actually said.

XQ. 822. Now, I think we developed this morning that according to the formula which Dr. Lilienfeld gives as the result and fruit of his work in his 1910 paper, the law of the discharge is something as follows: Up to 105 volts across the sounding electrodes there is no current at all. Then a current passes which follows the law which he prefers to express as the 3/2 power law, but which is actually the 3/2 power law of the voltage minus 105 or something of that sort, and thereafter he follows what he calls a square law; is that correct?

A. I would not state it in those words, no.

XQ. 823. How would you state it?

A. To my mind, and as I testified, Dr. Lilienfeld derives certain conclusions from his numerical observations. To my mind he has made certain corrections and he has arrived at the law of the tube which he has stated in words, which is to the effect that under a certain range of voltages the current increases as the voltage to the 3/2, and above that range the current increases as the voltage square.

XQ. 824. Do you think in a tube such as that shown in this 1910 paper, if you should put 100 volts across the tube, any current would flow?

A. Probably not, any appreciable current. It might be a very small current.

XQ. 825. You do not know whether it would flow or not?

A. No, I do not know whether any current would flow or not.

XQ. 826. Suppose you put one thousand volts across, what would happen?

A. There certainly would be a great probability of current flowing with one thousand volts.

XQ. 827. Now, in these tubes of the issue, if you put 100 volts across the tube you do get a current, do you not?

A. You do.

XQ. 828. Now, wherein lies the reason that in the tubes of the patent in suit, you do, and in the other tubes, you do not get a current flowing with 100 or 1000 volts across the tube?

A. I have not admitted that you would get any current.

XQ. 829. Wherein lies the reason that makes you unwilling to say positively that you would get a current?

A. The very great difference in structure, the dimension, the great difference in the shape of the two.

XQ. 830. Do you think that the current when it does flow, is limited by space charge?

A. Absolutely.

XQ. 831. Now, Dr. Lilienfeld repeatedly states that he does not have a space charge, does he not?

A. I am not aware of that.

Mr. Davis: I am sorry to take so much time, your Honor, but it is hard to find my way among these papers.

XQ. 832. If you will be kind enough to refer to page 538 of the 1911 paper, you will find a little mathematical formulæ——

Mr. Darby: That is not in the reference book.

XQ. 833. Well, look at it here. This is 1911 (indicating) the *Leipziger Berichte* article, is it not?

A. It is.

XQ. 834. And on page 538 it says, does it not:

> "It follows, therefore, as regards the potential function"——

and then follows a Greek letter and a formulæ, and then he says, does he not:

> "An expression showing that in the discharge path there is present no volume density of electricity."

Is that correct; I mean, am I reading that correctly?

A. You are reading correctly, yes.

XQ. 835. Volume density and space charge, I believe you have already testified are the same thing?

A. The same thing.

XQ. 836. There is not any question that the tube referred to in the 1911 article is that same tube referred to in the 1910 article, is there?

A. I do not believe so; I think it is the same tube.

XQ. 837. Well, now, have you a translation of the Lilienfeld-Rosenthal paper there; will you look at Section 3, "General Considerations"? Will you read beginning with the small "a"?

A.

> "The construction here described owes its being to the considerable studies I have carried on in connection with discharges in extreme vacua. The latest report in this connection was published in Volume 43 of the——"

XQ. 838. Suppose you put that in English for convenience?

A. Yes, "Journal Mathematics of Physics"——

XQ. 839. The Royal Society?

A. Royal Society of Knowledge, Leipsic, 1911, pages 534 to 539.

XQ. 840. And the next sentence is——

A.

> "This publication brings a new construction for the fact that, in case the current density discharge in extreme vacua exceeds a perhaps very small minimum value, there is an equivalent number of positive charges to offset the negative electrons which serve the current transportation."

XQ. 841. My translation, I think, is a little better, do you agree:

> "This publication brings forward a new formulation for the fact——"

A. Instead of "construction."

XQ. 842. Yes.

A. I think that is all right.

XQ. 843-44. Now, will you look a little farther down the same paragraph, and my translation reads:

> "If one now removes to a great degree the matter out of the space."

Have you such in the same paragraph?

A. I have that.

XQ. 845. Read that to the end of the paragraph.

A. Beginning at that point?

XQ. 846. If you please.

A. "Now, if matter is considerably removed from space by excluding slides,"—it is here, which probably means ground joints.

XQ. 847. If you will let me read, maybe I think it is smoother.

> "If one now removes to a great degree the matter of the space by using the best available means for producing a vacuum, it is to be expected that the number of positive charges and therefore also the special density of these charges will become progressively less, and it is to be expected that finally a vacuum will be reached in which the

transport of electricity will be entirely carried by negative electrons emitted from the incandescent cathode; as an actual fact, the reverse takes place as established above."

Is that a reasonably correct translation?

A. A translation, yes.

XQ. 848. Yes. So Dr. Lilienfeld's position is clearly stated, is it not—it is clearly stated, is it not, that there is no space charge in his tube?

A. No. I do not believe so. He was there discussing a certain theory which he had as to the operation of the tube.

XQ. 849. I thought you read a place where he said there was no discharge?

A. That is also, I believe, a statement of his theory.

XQ. 850. I was not intending to ask you, Professor, whether you agree with Dr. Lilienfeld on this point. I am just now asking you whether it is not true that he repeatedly states there is no space charge in his tube?

A. I believe it amounts to that, yes.

XQ. 851. And his theory is that there is a breaking up of space into positive and negative carriers, is it?

A. Yes, I so understand it.

XQ. 852. And a formation of positive ions unaccompanied by matter?

A. Yes.

XQ. 853. Do you agree with that theory?

A. I do not.

XQ. 854. He demonstrated that theory to his own satisfaction by these experiments, did he not?

A. I can not say as to that.

XQ. 855. The papers give that impression, don't they?

A. Very well.

XQ. 856. I said, to his own satisfaction; is that right?

THE COURT: That is the question the witness answered.

MR. DAVIS: I beg your Honor's pardon. Strike that out then.

XQ. 857. Not to your satisfaction?

A. That is correct.

XQ. 858. And he also takes the position that his energy is consumed in the tube as he goes along, does he not?

A. He makes the statement that energy is consumed. I am not sure whether he draws the conclusion that energy is always consumed under all conditions.

XQ. 859. Does not he say "entirely," or don't you remember?

A. Well, I don't remember.

XQ. 860. If it is not—of course the sounding method becomes inaccurate, does it not?

A. To the extent which I have stated, that if the electrons are increasing in velocity, there will be a small difference in the potential assumed by the electrodes, on account of the difference in velocity.

XQ. 861. I am not going to read it out loud, but I am going to ask you to read to yourself, to save time, page 725, as translated, and then when you have read it, I will ask you a question. It is down to there (indicating).

A. All right.

XQ. 862. Does not that indicate that Dr. Lilienfeld believed that energy was consumed as he went along?

A. It does.

XQ. 863. Completely?

A. He says "entirely."

XQ. 864. Now, do you disagree with him on that also?

A. I am not sure whether I have in mind all the points.

XQ. 865. Do you remember he calculates that the drop is a function of the cross-section of the tube somewhere?

A. I have a vague recollection, yes.

XQ. 866. And is independent of the position in the tube, that is his theory all the way along, the tube is the same?

A. That is, it makes no difference whether it is in one position or in another position in the tube?

XQ. 867. Yes. I assume in that narrow part of the tube, Professor?

A. Of course.

XQ. 868. Do you remember that?

A. I think he does.

XQ. 869. Otherwise, the charge remains symmetrical and does not change anywhere along the tubes; it is always the same?

A. Yes.

XQ. 870. And that justifies the use of the exploring electrodes——

The Court: What is that?

XQ. 871. And that justifies the use of the exploring electrodes or sounding electrodes—I am trying to use the same expression?

The Court: I missed your word entirely.

XQ. 872. Does it not, Professor Chaffee?

A. I think that helps to justify it, yes.

XQ. 872a. And the velocity of the electrons then remains constant over the whole length of this tube, that is, the part of the tube we are talking about, according to Dr. Lilienfeld?

A. According to Dr. Lilienfeld.

XQ. 873. And you do not know whether that is so or not?

A. No, I do not.

XQ. 874. Do you agree that if it were so, it would justify the use of these sounding electrodes?

A. I agree if it were so, that there would be no correction to be applied to the sounding electrodes on account of a difference in velocity.

XQ. 875. You do not agree, I take it, that the conditions which J. J. Thomson considers necessary for the proper use of sounding electrodes are present, namely, the large number of positive as well as negative charges in the space?

A. I indicated the large number there as a relative term, and I think perhaps there would be enough positive ions inside although a very small number, in order to——

XQ. 876. That is, you think there may be enough ionization in the tube to correct the sounding electrode difficulties?

A. Well, I stated that as a possibility. I cannot go any further.

XQ. 877. And I take it you do not agree with the statement on page 735 of the 1910 paper:

> "We can on the other hand adopt a view that since the number of positive charges produced (other things being equal), is independent of the number of molecules, there is no causal connection (from the above mentioned maximum gas density downwards) between the positive charges and matter. This means that these positive charges arise and continue to exist in empty space (in the ether) outside the molecules."

A. No, I do not agree with that, and I might say in that connection that of course, that was written in 1911, and since that time we have had a great deal better knowledge of phenomena than existed at that time. That was a theory on Dr. Lilienfeld's part.

XQ. 878. You read some of the general conclusions at the end of the article. You did not read:

> "The conclusions reached in this way led to the consideration of the existence of positive charges which are independent of matter."

Did you?

A. I did not.

XQ. 879-80. For the very good reason that you did not agree with it?

A. Because I do not agree with it, that being a theoretical deduction from the paper, or hypothetical deduction.

XQ. 881. Now, I am going to make a suggestion to you of a method of reconciling what appeared to me to be discrepancies, and that is, that in the Lilienfeld tube, the mechanism of conduction is this: Electrons are emitted from the hot cathode and strike the walls, charge up the walls, the function of the starting electrode is to make this possible, the starting electrode Z, which you may remember, the walls ultimately charge up to such an extent that the next electron which comes along knocks off an electron, which being in the field is carried on further along the walls, and again strikes the wall, and charges the walls, this continues until the whole tube is charged, and the mechanism of conduction thereupon is a continual secondary emission from the walls, going a little way and sticking to the walls, and so on. This, of course, would account for the liberation of energy along the walls, and the tube getting hot, for the drop being uniform, for the fluorescence of the walls mentioned in some of the papers, for the sodium spectrum mentioned in some of the papers, and for the fact which it seems to me to be deduced from the formulæ that no current would flow through the tube at all until you had a very high voltage across. What is your view as to that suggestion?

A. I think you have correctly stated the view, if you confine your remarks to the portion of the curve which he deduced where the current varies as the square of the voltage. That is exactly my explanation of the operation of the tube in that region. Below that region secondary electron emission has not the great effect that it has in the upper part and I have considered that in this lower region, the secondary electron emission is so small that he practically deduced a 3/2 power law, which we know exists in high vacuum devices.

XQ. 882. The critical test would be as to whether current flowed through the tube at reasonable voltages, would it not?

A. No. Because the structure, the length of the part is so great.

XQ. 883. Of course your suggested theory—I want to be respectful to it—your suggested theory completely justifies the use of sounding electrodes, so far as concerns the square part of the tube, but it seems to me that on that theory the use of sounding electrodes becomes entirely unjustified on the lower part of the curve?

A. I think you may remember that I admitted that if the velocity of the electrons is changed, there may be a difference in potential introduced, because of this difference in velocity, but there may be sufficient number of positive ions there, no matter how small, in order to compensate for this difference.

XQ. 884. Now, suppose it should turn out that no current flowed through the tube to a given voltage, and then the current began to flow, would you regard the tube as following the 3/2 power law?

A. If the current began suddenly, it certainly might; that is, meaning that the tube would not function below a certain voltage, so that you could not reduce the voltage below that voltage.

XQ. 885. But the 3/2 power law we have been talking about is the 3/2 power voltage across the tube, is it not?

A. That is correct.

XQ. 886. And if the tube follows the 3/2 power law, it will have some current flowing at any voltage, would it not?

A. Not at all.

XQ. 887. Why not?

A. Because it may follow the 3/2 power law over a certain region. I do not mean by that it will follow the 3/2 law throughout the operation of the device, I have already stated that it does not.

XQ. 888. But if it did follow the 3/2 power law, it would have to be the 3/2 power of the voltage across the tube, would it not?

A. Yes, within the region.

XQ. 889. Not of the voltage plus 105 or minus 105, or something of that sort?

A. You are quite right.

XQ. 890. Page 73 of the Reference Book, used in the interference, there was an article by DeLand, which was put in evidence by Arnold's counsel, but which you have not put in in this case; is that true?

A. That is true.

XQ. 891. That describes does it not, the manufacture of incandescent lamps?

A. So the title reads.

XQ. 892. What is the date?

A. 1897.

XQ. 893. And it describes the manufacture of incandescent lamps without mentioning any heating of the bulb, would it not?

A. I will have to look through the article to make quite sure.

XQ. 894. Will you please; it is very short?

Mr. Darby: I do not know how far Mr. Davis is going into the cross-examination on an article by this witness that this witness has not referred to.

The Court: So far as the present question goes, it is harmless, is it not?

Mr. Darby: Yes, sir.

The Court: And then if another question is objectionable, I will hear you.

A. The article does imply heating of the walls, because it states:

> "After the forks are properly fitted and the pumps are working nicely, the current is sent through the filament and gradually increased to full incandescence, as the gas held in occlusion is eliminated or removed."

Further on it states:

> "Thus the process includes something beyond the mere removal of so many cubic feet of air, which is a very simple problem; it means the removal of the occluded gases, which adhere to the side of the bulb, or to the filament, and serve as conducting gases; for it is the presence of these gases that prevents a stable vacuum from being maintained."

XQ. 895. But the heating that he gets is due to the fact that the filament is lighted?

A. So far as we can judge from the article, but that will produce some heating you must admit.

XQ. 896. I intended to ask you whether there was any separate artificial heat applied to the bulb?

A. No.

XQ. 897. I would like to take up the Bessel-Hagen article, Exhibit 4. Have you read that article?

A. I have gone through the article. I read it in

German because I have not had an English translation available.

XQ. 898. He says in the article, does he not:

> "The electric current requires the ponderable gas particles as carriers, in order to cross from one electrode to the other;"

A. You have correctly read it, I believe.

XQ. 899. You spoke of his getting eight-thousandths of a micron. He says, I believe, that is what the pump will produce, is that right?

A. Correct.

XQ. 900. When he comes to talk about tubes as distinguished from pumps he says:

> "The Geissler tube shown in plate III, Fig. 7, [not reproduced here] was evacuated to .009 mm."

A. Correct.

XQ. 901. About one thousand times, more than one thousand times the atmosphere than .008 microns?

A. But that does not indicate that that is the limit of evacuation.

XQ. 902. Then he goes on:

> "Then electric discharges from a static machine were passed through it for a while; the gas glowed feebly, the glass phosphoresced brightly."

That all shows gas?

A. Yes.

XQ. 903.

> "When the pressure was measured again it was found to be .017 mm.—had therefore increased to almost twice its previous value."

Then he says how he pumped it out again to .009 millimeters and after five minutes discharge the pressure had gone up to .013 millimeters, is that right?

A. Quite right.

XQ. 904. And he goes on to explain how this could not have been caused by the rise of the temperature of the gas and must have been gas coming from the walls or elsewhere within the tubes?

A. That is right.

XQ. 905. Now, you spoke of the footnote in your direct testimony. What you said gave me the impression that he knew how to get out mercury vapor?

A. That is the impression I meant to convey.

XQ. 906. Would you mind translating the footnote?

A. I have the German.

XQ. 907. That is footnote No. 2 on page 441.

A. That is not the footnote to which I referred.

XQ. 908. What was the footnote to which you referred?

A. The footnote is footnote 2 on page 441 of the original article in which he refers to the presence of mercury vapor and to the fact that it can be gotten rid of by the use of gold foil.

XQ. 909. Now, will you please give us the exact language or would you like to have one of our German experts suggest the language for you?

A. I would prefer that.

THE COURT: Can it be written out?

MR. DAVIS: Yes.

THE COURT: Let it be written out and dictated to the stenographer. We will now take our afternoon recess.

(After a short recess.)

XQ. 910. I would suggest that the translation of this footnote might be as follows:

> "It is assumed that in a vessel which is sealed in on all sides and still contains only mercury vapor, it is not possible to absorb the mercury vapor by some sort of chemical reagent, for example, by means of metallic gold."

Is that a correct translation, Professor?

A. No, sir, I do not think so.

XQ. 911. How would you translate it?

A. Dr. Lilienfeld has translated it, being more familiar with German.

XQ. 912. Dr. Lilienfeld is not on the stand at the moment. You simply do not like my translation?

A. I do not.

By The Court:

Q. 913-14. Do you mean you have available another translation which you think after checking up is accurate?

A. Yes, your Honor.

By Mr. Davis:

XQ. 915. You have compared this with the German yourself?

A. With my limited knowledge of German, but the German language has peculiar construction and may imply something that I cannot see myself.

XQ. 916. Will you read the translation which you think is correct?

A.

> "However, this would be true only if we should not succeed by introducing some chemical means into the closed vessel, in absorbing the mercury vapor, for example, by introducing metallic gold."

XQ. 917. In either case there is no definite statement it can be done?

A. There is a statement that the introduction of metallic gold would probably remove the mercury vapor.

XQ. 918. Do you think it would?

A. Provided there is not too much mercury vapor, yes. I think it would remove it, not completely, but to a considerable extent.

XQ. 919. Let us assume that the amount of mercury vapor is that corresponding to the fact that the device is being pumped out by a mercury pump at room temperature?

A. Yes, and in this article this footnote referred to a statement of the pressure of mercury vapor at room temperature.

XQ. 920. I did not quote those figures because I thought they were wrong. Is that so? It is very high.

A. I do not remember the figures, but I think they were high. The values of mercury vapor given here are high.

XQ. 921. That is 0.148 millimeters at zero degrees C. and .02 at 20° C.?

A. It is about ten times too high.

XQ. 922. But assuming the values which you believe to be correct, that is, about one-tenth of these values, you think that the introduction of gold leaf into the tube between the pump and the tube being exhausted would protect the tube against mercury vapors?

A. I think it would materially help in removing some of the mercury vapor.

XQ. 923. Did you ever try it?

A. I never have tried it, but I do know that the gold has a very great affinity for mercury. And that gold leaf would unquestionably act upon the mercury vapor passing through it or by it.

XQ. 924. We come now to the Soddy Patent No. 859,021, Defendant's Exhibit 17. What is it that Soddy is trying to accomplish in that patent?

A. The object as stated is to obtain high vacua.

XQ. 925. Referring to Fig. 1 of the patent, what is the device which is being exhausted?

A. An X-ray tube.

XQ. 926. And you think that the exhaustion means shown was suitable for the exhaust of an X-ray tube?

A. I think it is, yes, in conjunction with other pumps.

XQ. 927. I mean as used—that is the patent itself calls for a vacuum pump to be connected at the point e in Fig. 1.

A. That is correct.

XQ. 928. And then in this same figure, that is, device c, which I understand is a device in which calcium is introduced in some way——

A. That is right.

XQ. 929. And you think that the combination of this instrumentality shown used as described is suitable for the evacuation of an X-ray tube?

A. I see no reason why it could not be used for that purpose.

XQ. 930. This was the old-fashioned X-ray tube?

A. Yes.

XQ. 931. I think you spoke of an upper enlarged part, do you remember using that term, into which the sodium vapor would flow?

A. I do.

XQ. 932. Will you point that out in the drawing, Figure No. 1?

THE COURT: This patent was cited against the first patent or against some others as well or the first patent only?

MR. DARBY: The vaporizable reagent and in so far as it relates to using that towards obtaining the vacuum or assisting in the obtaining of a vacuum.

MR. DAVIS: So that it is really cited against all four.

MR. DARBY: No, I do not think it is cited against the first patent.

THE COURT: Not against the vacuum patent.

MR. DARBY: Not against the vacuum patent.

A. Referring to Fig. 2, the upper enlarged part is the part immediately surrounding the letter L.

XQ. 933. And in the question I just asked you I may have said sodium when I meant calcium.

A. Calcium is the material used, yes.

XQ. 934. I think you said that calcium will absorb residual gases. Do you know anywhere where it says that in the patent?

A. Yes.

XQ. 935. Just read what it says.

A. On page 1, line 55, the portion which I quoted in my direct testimony:

> "One of the reagents I may employ is the metal calcium. I have discovered that the metal calcium under suitable conditions absorbs rapidly and completely nearly all gases, including not only oxygen and nitrogen, the two chief constituents of atmospheric air, but also hydrogen, carbondioxid, carbonmonoxid, water vapor, acetylene, ammonia, sulphur dioxid, and even such a complex mixture as coal gas."

XQ. 936. It does not say mercury?

A. It does not.

XQ. 937. In speaking of these charcoal tubes contained in liquid air, you spoke of them yesterday as pumps?

A. In a sense, yes.

XQ. 938. It is another form of pump?

A. Yes.

XQ. 939. And this device going back to Fig. 1, B-C, is essentially another pump, is it not?

A. That is one way of looking at it.

XQ. 940. That is all there is to it?

A. No.

XQ. 941. What more is there to it?

A. It is perfectly conceivable that some of the calcium vapor which is vaporized may enter the vessel being pumped, in which case the pumping action may persist after the device is sealed from the pump.

XQ. 942. You see that little constriction in the tube between the X-ray tube and the rest of the system?

A. I do.

XQ. 943. What is that for?

A. To assist in the sealing-off process.

XQ. 944. Wouldn't that have the effect of preventing——

A. Naturally, it would cut down both the speed of pumping or the rate of diffusion of anything back into the system.

XQ. 945. Then it is hard for me to understand your position. You think there is a possibility or that it is conceivable that some of this metal might get out of the place where it is intended to be, which is the place surrounding the part L, and run along the long tube and get into the construction, and get into the X-ray tube?

A. That is true and Soddy is definitely attempting to prevent that because it is an X-ray tube which must remain clear such as in the electrical lamp art.

MR. DAVIS: May I ask Mr. Darby if he has put in the Soddy article in the Royal Society.

MR. DARBY: I do not think so.

XQ. 946. There is a Soddy article in *Nature* which is Defendant's Exhibit 18. I would like you to look at that for a moment. This is a letter to the editor of *Nature* appearing in the issue of November 21, 1907. It begins with the statement as to the Edison effect and the investigation of the Edison effect by Richardson and the Wehnelt cathode.

A. That is correct.

XQ. 947. And then he speaks of mounting in a tube provided with a Wehnelt cathode, an anode of metal calcium, and he speaks of this Royal Society paper, which is not in evidence, as showing that calcium at its volatilizing temperature absorbs instantaneously and almost perfectly all known gases and vapors. He says when a good vacuum is obtained in this tube with the calcium anode, currents of 250 volts will pass through the tube. Then will you please read on, beginning with "The gasses evolve"——

A.

> "The gases evolved from the anode and tube under this particular treatment were absorbed by the calcium in the furnace. The current was regulated by a resistance to about 1.2 amperes, and was interrupted at intervals to give the evolved gases time to flow out of the apparatus."

XQ. 948. What was the furnace?

A. As I understand it, he put the calcium in a little porcelain tube which was introduced into the chamber. That tube was heated in order to volatilize the calcium.

XQ. 949. That is, the tube was something like that tube in the patent we have just been looking at?

A. I believe it was more intimately connected with the chamber being exhausted than shown in the other patent.

XQ. 950. It does not say that, does it?

A. From a casual reading of that, I do not find any reference. That was my distinct picture.

XQ. 951. Will you continue to read from where you left off, beginning: "When the gases."

A. (Reading):

> "When the gases had been for the most part removed the current was passed continuously, heating the calcium anode up to its volatilizing point. Quite suddenly and completely the current through the tube stopped, and at the same moment a copious mirror of calcium was volatilized from the anode. In a little while a very feeble glow started and passed intermittently from time to

> time, but it was not enough to move the ammeter needle, and was most likely due to a further slow evolution of gas from the still heated surfaces."

XQ. 952. That is enough. You may read the next sentence.

A. (Reading):

> "A current could be passed by a coil from the hot kathode to a third electrode as anode without causing any appreciable resumption of the flow in the 250 volt circuit."

XQ. 953. And he goes on to say that he let a little gas in and repeated the experiment, and again the thing stopped, and you read the other day:

> "This experiment shows that in a sufficiently high vacuum——"

Please read that: "This experiment shows"?

A. (Reading):

> "This experiment shows that in a sufficiently high vacuum the Wehnelt electrode ceases to be effective."

XQ. 954-55. Thank you. I am told that I have committed an error there, that instead of letting in gases, he evolved gases by heating the tube, or something of that sort.

A. That probably is correct.

XQ. 956. Now, this publication teaches that if you make the anode of the tube of calcium, and pass current through it, and boil the calcium, which condenses over the inside, you can not get any current through the tube; that is the way it teaches, does it not?

A. It does not teach that.

XQ. 957. What does it teach?

A. It says the current was not detectable on an ammeter which is rather a coarse instrument for detecting small currents.

XQ. 958. It actually says, does it not, "Quite suddenly and completely the current through the tube stopped." That is in the third paragraph of the article?

A. Yes, that is correct, but I am looking for another reference where he refers to an ammeter. Yes, a little further on on line 55, beginning line 53:

> "In a little while a very feeble glow started and passed intermittently from time to time, but it was not enough to move the ammeter needle."

XQ. 959. That is, it stopped and started again?

A. Yes.

XQ. 960. Some evolution of gas taking place in the meantime?

A. Yes.

XQ. 961. And then he let in some more, he heated it somehow so as to get more gas in there and again passed a current and then the current stopped again?

A. That is correct.

XQ. 962. May we now look at Defendant's Exhibit No. 20 which is a paper by J. L. Hogg, "Friction in Gases at Low Pressures"? Now, we are not dealing here with a vacuum tube at all, are we, a thermionic tube at all?

A. Not a thermionic tube.

XQ. 963. Or any kind of a tube intended to carry current?

A. That is correct.

XQ. 964. This gentleman was investigating, as I understand it, or trying to find a device for measuring low pressures?

A. And also investigating the friction existing in low pressures.

XQ. 965. That was because he was interested in this little rotating vane as a measure of low pressure, was it not?

A. Yes. My difficulty is that I do not know that that was the sole purpose, but that was one purpose, certainly.

XQ. 966. So far as the article shows what he is trying to do is to use these little radiometers that we see in the window of the optician stores, those little bulbs, to use that as a means of measuring low pressure, is that it?

A. No. He was dealing with a disc of some material, which was caused to rotate or oscillate and he was measuring the rate of dying-down of that disc. It was not the radiometer principles.

XQ. 967-68. And he states on page 16, in substance, does he not, that the reason why it is desirable to work out a thing of this sort is that the McLeod gauge introduces mercury. And he says in the last paragraph but one on that page, it is desirable to have a gauge that will not introduce any impurity.

A. I would like to have the question read, please. (Question repeated as recorded.) I believe that is correct.

XQ. 969. And he found it impossible to exclude mercury vapor absolutely from the apparatus, did he not?

A. Absolutely, yes, of course; but he states that the mercury pressure is reduced to something of the order of 16 with 7 zeros in front of it, millimeter pressure.

XQ. 970. On page 1, speaking of the prior investigations he criticizes those prior investigations, because of the presence of mercury vapor, does he not; the point here is he has got better ways of getting out mercury vapor?

A. I did not hear all of the question.

XQ. 971. I am sorry. I am not talking very clearly. Read that, Mr. Smart. (XQ. 970 repeated as recorded.)

A. Yes, that is correct.

XQ. 972. The article emphasizes, does it not, the extreme slowness of the movement of gases at these low pressures?

A. It does.

XQ. 973. For instance, in one case on page 8, liquid air was kept around the charcoal for eighty hours and during all those eighty hours, there was a gradual reduction of pressure?

A. Yes, but in his experiment the apparatus which was being exhausted was connected by rather a long small tube, and of course, the rate of effusion from a very large piece of apparatus which he was exhausting through this very small tube, was of course, great, that would not be the case if a small device were exhausted while being connected with a short large tube to the liquid air.

XQ. 974. On page 9, he speaks of the McLeod gauge, and how little value to give to the measurement of pressure by the gauge, where a column of mercury, a fraction of a millimeter high requires to be measured?

A. He does.

XQ. 975. And then he speaks of the factor of the gauge used as 95,813; what is the factor of the McLeod gauge?

A. That is a factor which must be multiplied into the observed difference in level of mercury on the gauge—cut that out please, Mr. Stenographer——

XQ. 976. Putting it roughly this is the ratio between the original quantity of gas before it is compressed, and the quantity after it is compressed. The point of the McLeod gauge, is you take a rather large bulb and connect it with the thing of which you want to measure the pressure, and then you transfer all the gas in that bulb into a very small bulb or a very small tube; is that right?

A. That is correct.

XQ. 977. And this factor is the ratio between the volume of this large bulb and the volume of the final little tube into which you transfer it?

A. That is correct.

XQ. 978. You remember that he found that even slight changes in the level of the liquid air surrounding the charcoal made differences, for instance, on page 11?

A. I do.

XQ. 979. I refer now to the Hupka article, Defendant's Exhibit No. 21 of 1909; have you the whole article there?

A. No, only that portion which is in the reference book.

XQ. 980-81. What was he trying to do?

A. Hupka was endeavoring to measure the change in mass of the moving electron, moving electricity.

XQ. 982. That is the Einstein constant?

A. That is not the Einstein constant.

XQ. 983. Well, I notice the Einstein theory on the first page. It is a highly scientific, physical constant, he is trying to get?

A. Yes.

XQ. 984. That is, there is no suggestion here of vacuum tubes or usable apparatus of any kind?

A. There is no suggestion of a practical use of this device other than for the experiment.

XQ. 985. It was really a sort of photo-electric tube, was it?

A. It was.

XQ. 986. And of currents of the order of magnitude of which we have been considering in these photo-electric tubes?

A. Very small current, I do not remember the exact value.

XQ. 987. Cold electrode?

A. Cold electrode, yes.

XQ. 988. Very small amounts of energy?

A. Very small.

XQ. 989. You spoke of his getting 90,000 volts, I think not passing current across the tube, of course, he did not carry current under those circumstances, did he?

A. I believe not. He states that he was able to impress 90,000 volts without getting a discharge, that is an instantaneous discharge. He may have gotten a discharge with or when the plate was illuminated by light, because he was working with photo-electrons. In fact, he states that he tried 90,000 volts without light, and then put ultra-violet light on, which if allowed to fall on the cathode, a bright spot appeared, so that he was actually using 90,000 volts.

XQ. 990. There is a Von Bayer article in the *Phys. Zeit.* of 1909, Defendant's Exhibit No. 22. This also is a photo-electric tube so far as concerns the current that it carried, is it not?

A. I think not.

XQ. 991. I mean so far as concerns the order of magnitude of the currents?

A. No. I do not believe that is true. He was using a heated filament as the source of electrons, and could, of course, obtain considerable emission.

XQ. 992. You said on page 173: "He is really continuing the work of Lenard," to which I referred yesterday, except that Lenard utilizes photo-electrons instead of electrons from a heated wire?

A. That is quite right.

XQ. 993. What was his current; it may take some time, that question, Professor Chaffee, but a statement was made in the article that one of the devices was a galvanometer for measuring very small currents?

A. It does, but he also uses the galvanometer with shunts, so that he could measure very large currents.

XQ. 994-95. He gives his readings, without mentioning the shunt, does he not?

A. That may be true.

XQ. 996. And what are the currents that he got, what are the order of magnitude—I will put it this way—were the order of the magnitude of the currents such that space charge had any substantial effect in the flow of the currents on the tube?

A. I expect they were that order of magnitude.

XQ. 997. You have not calculated them?

A. I have not, because there was no data given here to tell us what the current that he used was.

XQ. 998. Do you know at what voltage the tube saturated—perhaps this picture will help you, referring to Figure 2 on page 169, that says a saturation about where?

A. In the neighborhood of about 24 or 25 volts.

XQ. 999. Von Bayer speaks of removing fat vapors; what does he mean by removing "fat-vapors"?

A. I suspect he means removing the vapors which may arise from the grease that is used in the ordinary stop-cock, a grease of very low vapor pressure.

XQ. 1000. He says, does he not, on page 170:

> "The pressure in this investigation was about .01 mm. However, an exact determination of the presure when glowing wires were used was excluded out of the question; for the same reasons I had to abandon investigation of different gases, as determinations of the increase of the gas content, due to the continuous evolution of gas from the wire and the continuously occurring occlusion of gases, it was impossible."

Is that correct?

A. Except for the fact that I think you said one-tenth of a millimeter instead of one-one-hundredth.

XQ. 1001. I meant one-one-hundredth. I am sorry if I said one-tenth. There is a rotating commutator mentioned in that article. Tell us what that was for?

A. Von Bayer was measuring the electron current and realizing that there was a considerable voltage dropped through the heated filament, he chose to eliminate the error caused by this voltage drop by arranging a commutator such that it would alternately heat the filament or pass the filament current, and then put on his measuring instruments, in that way to obtain an electron current measurement while no current was passing through the filament.

Mr. Davis: Perhaps I might save time by stating: The voltage across the tube, we first assume to be a fixed thing. Now, to heat the filament, you ordinarily pass electric current through the filament. That means that the two ends of a filament must be at some different voltage, and therefore the voltage from any particular part of the filament to the anode, is heated out to the voltage to some other part; that is correct?

The Witness: That is correct.

XQ. 1002. Professor Chaffee has told me, as I understand him, in order to eliminate any effect due to this difference, this author produced a rotating commutator which for one instant would open the circuit filament, and during the instant which the circuit would open, he would make the observation, is that correct?

The Court: I see.

A. That is so.

XQ. 1003. And that is a legitimate and proper thing to do, is it not, under the circumstances?

A. It is a thing which I have done myself.

XQ. 1004. So that while the measurement was being made, this drop in the filament did not exist. The filament simply stayed hot, as anything stays hot for a while until it cools; that is correct, Professor, is it not?

A. It is.

XQ. 1005. Now, I would like you to look at the Thatcher patent, No. 1,028,636.

THE COURT: If that is important, Mr. Davis, won't you give me that again? I may have it, but I have some doubt about having the exact point that you have in mind. Do you mind going over it again?

MR. DAVIS: The commutator?

THE COURT: I understand about the difference in potential in different parts of the filament.

MR. DAVIS: That is due, if your Honor please, to the fact that current is flowing through it.

THE COURT: The resistance?

MR. DAVIS: Yes.

THE COURT: All right. I understand then that the electrons emitted —that is, if I am correct, the electrons emitted from different portions of that filament are different; the electron emission is not the same from every portion of the filament, is that right?

MR. DAVIS: No, sir. I think the electron emission is the same, but if you had a filament, we will consider one end of the filament and suppose that it is 100 volts negative with respect to the plate, and that the voltage necessary to pass current through the filament is ten volts.

THE COURT: The temperature throughout is the same?

MR. DAVIS: The temperature is the same.

THE COURT: But the current is different?

XQ. 1006. The voltage is different; that is, the pull on the electron when it comes out, Professor Chaffee, tending to pull it towards the anode, is slightly different; is that right?

A. Correct.

XQ. 1007. Of course you may, as I think I stated in the opening, design a tube in which that drop in the filament is very large, compared with the voltage across the tube, if you want to. In the case of the tube such as used in ordinary broadcasting reception, Professor Chaffee, the drop in the filament is about five volts, is it not, the reception tubes?

A. Yes.

XQ. 1008. And you stated yesterday that the voltage across the tube was from 20 to 150, I think?

A. Correct.

Mr. Davis: So that your Honor will see in that case the disturbance will be rather small; but what ever the disturbance is, if you can turn the current off of the filament and quickly make a measurement, it would be eliminated.

The Court: Oh, yes, I have it.

Mr. Davis: The rotating commutator is a device which does that. I have one here (indicating commutator in courtroom). Perhaps Professor Chaffee will explain how it operated in a general way. He probably knows perfectly well.

The Witness (Referring to model): This commutator is driven by an electric motor. There are two portions to the commutator which are entirely independent; the portion at the left, this brush, makes continuous electrical contact to a segment of copper. In other words, this brush bears on a continuous ring of copper. This copper ring extends in a certain portion of the commutator to the left in this case, and a second brush bears upon the portion of the commutator such that this portion of the copper will intermittently touch that brush. The fact is when this rotates, there is an intermittent connection between that brush and the second brush. The same thing is true with respect to the other two brushes. Now, these two brushes and the commutator are so aligned, that the contact between the first two brushes is made while there is no contact between the second two, and *vice versa*.

Mr. Davis: Perhaps we might have it marked for identification, this commutator.

(The commutator was received and marked "Plaintiff's Exhibit A for Identification.")

XQ. 1009. This patent to Thatcher has to do with an evacuation by clean-up?

A. Yes.

XQ. 1010. A very brutal method of exhaust for lamps, at least?

A. He states that it is no harder on the filament than the chemical method of exhaust.

XQ. 1011. Do you believe it?

A. That depends upon how low the preliminary evacuation is carried—I will change that to high—how high the preliminary evacuation is carried.

XQ. 1012. You explained the other day that "blue glow" might under certain circumstances help the vacuum, and under certain other circumstances might injure it?

A. That is conceivable.

XQ. 1013. In any event, the importance of this particular patent in this case, so far as it has any, is simply as a particular method of exhaust; is that correct?

A. That is correct.

XQ. 1014. There is a Friedrich patent, No. 1,083,677, Defendant's Exhibit No. 24.

The Court: What patent is that?

XQ. 1015. The thing which he is trying here to do is to exhaust the X-ray tube; is that correct?

A. It is so described in the patent.

XQ. 1016. Do you think it is suitable for the purpose of producing the kind of a vacuum that an X-ray tube required in those days?

A. I should say so.

XQ. 1017. Article by Dember, Defendant's Exhibit 26. This was a photo-electric tube, was it not?

A. That is correct.

XQ. 1018. Used to produce very soft X-rays?

A. Correct.

XQ. 1019. He says on page 601:

> "Since in self-sustaining discharges the gas pressure continually changes in a way which can hardly be controlled, and therefore also the potential difference which accelerates the cathode particles, the hardness and the distribution of hardness of the rays in a Roentgen tube are very variable."

A. That is what he states.

XQ. 1020. That was true, wasn't it?

A. It may be true with certain types of tubes, not all of them.

XQ. 1021. This is 1911. It was true with all practical tubes then, wasn't it?

A. No, I do not agree necessarily.

XQ. 1022. It was true of the ordinary X-ray tube, was it not? He was only speaking of self-sustaining discharges?

A. Yes, in general X-ray tubes, for example, clean-up, the vacuum increases as they are operated.

XQ. 1023. That is, in the X-ray tubes with a self-sustaining discharge, to which he refers in this paragraph I have just read, as I understand it, the clean-up is going on all the time?

A. That is true at high voltages. My only reservation was that at low voltages the vacuum——

XQ. 1024. I was thinking of X-ray tubes.

A. Yes, that is correct.

XQ. 1025. Then the gases are coming out all the time and there is a certain tendency or balance between those two phenomena?

A. That is correct.

XQ. 1026. Is that correct?

A. That is correct, unless the terminals have been very completely denuded of gas.

XQ. 1027. What would happen in that case?

A. I think this is unimportant. The amount of gas coming out of the electrodes would, of course, then be less.

XQ. 1028. With the result?

A. That the final vacuum might be higher.

XQ. 1029. And the tube would stop?

A. Usually that is the result with an X-ray tube.

XQ. 1030. It has to be the result in the case you have imagined?

A. Yes.

XQ. 1031. So that the tube would be useless?

A. Unless the vacuum can be changed by some regulating means which is very often a part of the tube.

XQ. 1032. As a practical matter, are you familiar with the practical use of X-rays of this type with self-sustaining discharges?

A. Yes, I have used them considerably.

XQ. 1033. Then as a practical matter, when you get all the gas out of the tube, the tube very soon failed and had to be thrown away or re-evacuated or something done with it?

A. Yes, that is correct.

XQ. 1034. From the doctor's standpoint the tube became "cranky" as they call it, and finally went out and was finished, is that correct?

A. That is correct.

XQ. 1035. And to palliate these evils they sometimes would light a torch and hold it under the tube?

A. Sometimes that would cause the vacuum to come back to normal.

XQ. 1036. And then sometimes they had a little projection sticking out of it which contains some material which had absorbed gas?

A. I am familiar with that type of tube.

XQ. 1037. And they lighted a little spirit lamp or Bunsen burner and held it under the projection and in that way drive some of the gas into the tube?

A. Either that or drive an electric discharge through the side tube.

XQ. 1038. But none of these things were anything but palliatives. After a while the thing would go out and that was the end of it as a practical matter?

A. That is probably true, although the regulating devices allow a considerable increase of the practical life of the X-ray tube.

XQ. 1039. You notice on page 604 of this article which we are discussing, the Dember article, it says: "In order to prevent positive ions formed by collision ionization of the residual gas . . . by means of a sealed in platinum electrode."

A. I have not the complete article here.

XQ. 1040. I will give you the translation which the defendants have been kind enough to let me have. Have I read that sentence correctly?

A. You have read it correctly.

XQ. 1041. There is a Gehrts article in the *Annalen der Physik*, Defendant's Exhibit 27. What was the general purpose for which Gehrts was working?

A. Gehrts was working with photo-electrons and was studying the reflection and secondary emission due to photo-electrons.

XQ. 1042. This also is dealing with exceedingly minute currents?

A. Perfectly correct.

XQ. 1043. Can you find the place from which you quoted: "Up to the highest velocities used there was no trace of ionization"?

A. Do you mean in my direct testimony?

XQ. 1044. Yes, on page 551 of the transcript. Can you find it in the article?

A. Page 1007.

XQ. 1045. Would you mind reading the next two sentences?

A.

> "It was indeed necessary in these observations to greatly diminish the incident light intensity to avoid changing the measurement arrangement. It is therefore conceivable that with ionization, which cannot be noticeable at great intensities here escape observation."

XQ. 1046. Referring now to the Marshall patent, No. 1,205,002, Defendant's Exhibit No. 28, what does this add to the Malignani process as a practical matter of interest in this case?

A. In this patent the chemical getter was situated on such a portion of the lamp, namely, on the filament mounting such that after the lamp was sealed off the vaporization took place. I believe I am correct in that.

XQ. 1047. Is there anything here that makes it easier to get a vacuum, for example, than Malignani?

A. No, I think both processes are capable of giving a high vacuum.

XQ. 1048. Then this is merely cumulative to Malignani?

A. Cumulative.

XQ. 1049. I refer now to the Child article, *Physical Review*, 1911, Defendant's Exhibit 9. He says on page 494, that with clean platinum it is possible to get a large current, doesn't he?

A. I have not the complete article here.

XQ. 1050. May I let you see mine?

A. Yes.

> "With clean platinum it is possible to get a large current without changing the character of discharge, while with calcium oxide it requires but a very small current to produce this change."

XQ. 1051. Do you remember the publication, I think of Wilson, in which he found that by cleaning the platinum he reduced the current to 1/250,000th of its original value?

A. I do.

XQ. 1052. I pass now to the Majorona article of 1912, Defendant's Exhibit 30. This tube as shown by the curve saturated at 20 volts.

A. No, rather about 35 to 40 volts.

XQ. 1052a. Saturated at 35 to 40 volts?

A. Correct.

XQ. 1053. That is your judgment?

A. It is.

XQ. 1054. There was no disclosure there how the device was exhausted or treated; was there?

A. No, only that he used extremely rarefied gas. No description of the exhausting apparatus was given.

XQ. 1055. Referring now to the Kunz and Kemp, Defendant's Exhibit 32, you spoke of there being potassium or sodium in there, and the whole idea was to study the photo-electric properties of these alkaline metals?

A. That is correct.

XQ. 1056. So they put them in there to study their photo-electric properties?

A. Just a minute. Not the photo-electric properties, as I understand it, but the spectrum of the light produced.

XQ. 1057. The metal was put in there because they wanted to study some physical properties of the metal?

A. Quite right.

XQ. 1058. Not to get a vacuum or help to get a vacuum or anything of that sort?

A. Not specifically. But they made the remark, as I pointed out in my direct testimony, that potassium and sodium was placed in the bulb and vaporized and that a complete vacuum was produced, so that Roentgen rays were created without heating the Wehnelt cathode. That indicates whether or not they were using it for that purpose, that they made the observation that potassium and sodium did produce a very good vacuum.

XQ. 1059. They speak of the blue rays of electrons in this article. What do they mean by that?

A. By that they mean the light which is given out when the electrons pass through the vapors of these gases and ionize the gases which in turn causes the atoms to radiate light.

XQ. 1060. That is a blue haze?

A. That is a blue haze.

XQ. 1061. They also speak of getting X-rays from a cold cathode?

A. Yes, they speak of obtaining X-rays, but I am not sure whether the whole tube had cooled down to the extent that there was not sufficient vapor left in there to allow the discharge to pass.

XQ. 1062. In any event, the vacuum seems to have been a vacuum of the old X-ray tube rather than of the modern vacuum?

A. I do not think so.

XQ. 1063. Yet they got X-rays without——

A. As I have stated, it is perfectly conceivable that they might have tested their device after heating the potassium and sodium, and that possibly the device had not been cooled down sufficiently to reach the highest vacuum or the high vacuum that would be reached on complete cooling.

I would like also to remark that sodium and potassium at room temperature has an appreciable vapor pressure. In fact, the reason for using magnesium in the fourth patent at issue, was because of the vapor pressure of sodium and potassium.

XQ. 1064. And when he actually did use these materials he got a lot of fireworks, didn't he, finally, four plainly separate strips of different colors?

A. That is correct. That must have taken place when the apparatus was sufficiently heated to raise the vapor pressure considerably.

XQ. 1065. The object of the experiment was to get just that kind of an effect?

A. Exactly.

XQ. 1066. You quoted from an article by Dr. Whitney at page 190 of your deposition, Defendant's Exhibit 33. Do you agree with the portion which you read?

A. I will have to reread it.

XQ. 1067. Will you please reread it? It is your answer to Q. 30 on page 190.

A. Yes, I believe I agree with those statements.

XQ. 1068.

> "In case of incandescent lamps where the voltage is above 50 for a fair brilliancy of filament, a blue discharge passes through the bulb and this blue quickly disappears when such vapors are introduced. The blue discharge seemed to be necessary for any considerable improvement of the vacuum, due to such vapors as phosphorus . . ."

A. Yes, I agree in the main with that. There is an improvement in vacuum due to the vapor itself, but when a blue glow is established there is a further improvement in vacuum or perhaps we may say a more rapid improvement of the vacuum.

XQ. 1069. The doctor said that the blue discharge seemed to be necessary for any considerable improvement of the vacuum, due to such vapors as phosphorus. You say you agree to that?

A. I do not know as to the relative efficiency of the vapor of phosphorus used with and without a blue glow in improving the vacuum. I have had no experience with that.

XQ. 1070. You would have some respect for Dr. Whitney's opinion on such a subject?

A. Yes, I have.

XQ. 1071. I come now to the Clarke Patent, 1,121,802, Defendant's Exhibit 34. Whatever this gentleman may have accomplished there is no question about what he was trying to do, is there?

(No answer.)

XQ. 1072. And that was to make a mirror on the inside of the bulb?

A. Quite right.

XQ. 1073. And the device was an incandescent lamp?

A. That is right. If I may I would like to read Claim 7.

XQ. 1074. You may, of course, read anything you like.

A.

> "The process of making an incandescent lamp which consists in forming the bulb, adding the filament, exhausting the interior, heating the filament, and a portion of the bulb and causing a vapor to condense on the interior surface of the unheated portion."

And the purpose of that was to make an incandescent lamp.

XQ. 1075. The purpose of condensing the vapor was what?

A. Explicitly for a mirror, but from what we know there must have been the improvement of vacuum.

XQ. 1076. I just asked you the purpose and not the results, the object as expressed in the patent. It was to produce a reflecting surface to reflect the light?

A. Explicitly, yes.

XQ. 1077. That is all he talks about, isn't it?

A.

> "My invention relates to a method for internally coating an incandescent lamp with a highly reflecting surface."

XQ. 1078. Article by Angerer, *Annalen der Physik*, 1913, Defendant's Exhibit 35. This is another very theoretical article, isn't it?

A. Yes, it is a scientific experiment.

XQ. 1079. And the currents involved are very small?

A. Not so small.

XQ. 1080. About how large?

A. The currents in one case were one-tenth of a milliampere and in the other it is one milliampere.

XQ. 1081. Where is the one-tenth?

A. On page 20. The reference to one milliampere occurs on the bottom of page 20. It says, "In spite of this a current of one milliampere passed through the tube."

XQ. 1082. And in the same paragraph it speaks of an intense fluorescence on the inside?

A. It does.

XQ. 1083. What is the significance of this citation, as you understand it, Professor Chaffee? Is it simply another way of getting a vacuum, or what is it?

A. The purpose is to show that Angerer used a thermionic device in high vacuum.

Mr. Davis: Perhaps your Honor, this is a good time to adjourn.

The Court: Ten o'clock tomorrow morning.

(Whereupon, at 5 P. M., an adjournment was taken to Friday, October 22, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del.,
Friday, October 22, 1926,
10 o'clock A. M.

SEVENTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

E. Leon Chaffee, resumes the stand.

Cross-Examination (Continued).

By Mr. Davis:

XQ. 1084. In answer to XQ. 1052, on page 365 of the typewritten record, you said that the tube disclosed in the Majorana article saturated at 35 to 40 volts. As a matter of fact Majorana himself says it saturates at 30 volts, does he not, on page 389?

A. I do not remember the Majorana article. I drew my conclusions from the place where the current has essentially become flat. As given in his diagram, there is of course no perfectly definite point where saturation is attained.

XQ. 1085. When I said page 389, I was referring to an arbitrary number. I should have said page 238 of the article. Just read from what he says there, "from such a curve——"

A. (Reading):

> "From such a curve, we see that the current of saturation is about two milliamperes with an e. m. f. minimum of about 30 volts."

I would like to add in connection with that, that on looking at the diagram of Figure 1, the curves become flat, or essentially flat at about 35 volts or 40 volts; so I feel that my statement was perfectly correct.

Mr. Davis: I understand, Mr. Darby, that the two Majorana articles, both of which appeared in the same volume of the *Atti Della Reale Accademia,* the two are included as one exhibit.

Mr. Darby: The only one I intended to be included is the one from which excerpts appear in this reference book.

The Court: Can you make it a little louder, Mr. Darby?

Mr. Darby: My impression is that it is only the one volume, Volume 21, pages 235 to 239 of 1912.

XQ. 1086. Will you look at the Mackay patent, No. 1,208,597, which is Defendant's Exhibit No. 37? On page 193 of the record you quote from the specification, beginning line 14, page 1, and it stands in the record that your quotation reads:

> "I have discovered that a markedly lowered voltage drop or loss in the arc is secured in a device of this type containing gases protecting the electrodes . . ." etc.

Could I trouble you to read the same sentence, including the part that is omitted, and indicated by the stars in the quotation in the record?

A. (Reading):

> "I have discovered that a markedly lower voltage drop or loss in the arc is secured in a device of this type containing gases protecting the electrodes from chemical deterioration and electrical disintegration."

XQ. 1087. Thank you, and the rest goes on as you have quoted it?

A. Yes.

XQ. 1088. It appears in the record as though you have omitted those words.

A. I had no intention of omitting them.

XQ. 1089. What is a device of this type, as stated in the paragraph beginning line 10 of the same page? Will you read that paragraph?

A. (Reading):

> "The present invention relates to inclosed arc devices having a cathode consisting of highly refractory material operating at incandescence in a gaseous atmosphere."

XQ. 1090. This was an arc lamp, was it?

A. The device is not used for the production of light, but rather as a rectifying device.

XQ. 1091. But it was a high pressure device, was it not?

A. Yes, quite high pressure.

XQ. 1092. It was not a matter of microns but of many millimeters?

A. Yes, or even centimeters.

XQ. 1093. Or even centimeters?

A. Yes.

XQ. 1094. And this is also true, is it not, of the Clough patent, No. 1,246,054?

A. Yes, that is perfectly true. The two patents are very similar.

Mr. Davis: That is the end of the cross-examination, Mr. Darby.

Re-Direct Examination.

By Mr. Darby:

RDQ. 1095. In your cross-examination, Dr. Chaffee, you have referred to the harmful effects in incandescent lamps of having too low a vacuum. Is it the degree of vacuum or the lack of the degree of vacuum that causes the trouble or harmful effects in the incandescent lamps?

A. No. The difficulty is largely the deleterious gases, that is, water vapor and oxygen and the like.

RDQ. 1096. Then as I understand it, it is not how much gas you have present, but rather of the type of gas that is present?

A. That is quite right, because we are familiar with the gas-filled tungsten lamp which has considerable pressure of nitrogen.

RDQ. 1097. You were asked in connection with the Edison patent, Defendant's Exhibit 5, No. 411,019, if you had ever heard of any one using the process of the Edison patent and I believe that you answered that you had not.

A. That is right.

RDQ. 1098. Have you ever heard of any one using the process of obtaining evacuation set forth in the Edison patent?

A. Yes, I visited the plant of the Westinghouse Company and there saw the evacuation of the thermionic device known as the 201-A, a modern three-electrode device, and in that process the lamps were connected to the pump by inserting the small tube through which the exhaust is obtained into a rubber connection and I understand that castor oil or some grease is used in order to make the connection tighter. Then the tubes pass on through a chamber which is heated and that is of course to drive off the occluded gases. The tube travels on through this chamber and then emerges from this heating chamber where the activating material is flashed and so forth and then after that the tube is sealed off.

XQ. 1099. Is it your understanding that the incandescent filament is heated while the lamp is being exhausted in the Edison patent?

> **Mr. Davis:** I rather object to the understanding of the witness. If the witness knows these things he may state them.
>
> **The Court:** Do you press your question?
>
> **Mr. Darby:** No, I will reframe it.

RDQ. 1100. Does the Edison patent state that the incandescent lamp is lighted while the process of exhaustion is going on?

A. That I shall have to refresh my memory on. That is my understanding that the filament is heated while it is being exhausted. I have not the patent here. I have neglected to bring it.

RDQ. 1101. Here it is.

A. No, I believe the filament is heated after. It speaks of heating the walls during the exhaust.

RDQ. 1102. With reference to the Dwyer patent, Defendant's Exhibit 7, will you please refer to line 75 and tell me whether or not that patent refers to prior art practices with respect to vaporizable reagents?

A. Yes, that patent does refer to prior art.

RDQ. 1103. Will you please just read that sentence?

A. Reading from line 75, page 1:

> "Arsenic has been proposed to be introduced as a vapor and is supposed to form a chemical combination with the residual gases of the lamp and go down as a solid deposit."

Still further,

> "it has been proposed to use a substance having in a large degree the power of absorbing gases, such as spongy platinum."

I do not know that that is important.

RDQ. 1104. With reference to the Merritt Patent No. 909,811, Defendant's Exhibit 13, I believe Mr. Davis called attention to the fact that the patent states at line 15 that prior to the exhaustion process the bulb is customarily heated in an oven to drive off the absorbed moisture and gases, and likewise called attention to your direct examination with respect to this patent, where you testified that during the exhaustion the bulb wa[illegible] heated or words to that effect. Will you please read the succeeding sentence, the following sentence, line 17, of that patent?

A.

> "Unless the exhaustion is effected rapidly, however, the subsequent cooling of the bulb causes a material reabsorption of those gases."

RDQ. 1105. What do you understand from that?

A. I understand from that that the bulbs were in effect hot or heated while they were being exhausted.

RDQ. 1106. What is the purpose of heating the bulbs?

A. The purpose of heating the bulb is to drive off the occluded gases on the inside of the bulb.

RDQ. 1107. And what actually does that?

A. The high temperature, the heat.

2 RDQ. 1108. So that if the bulbs were pumped while they were still hot, would the same effect be secured as though the bulbs were still being heated?

A. Absolutely.

RDQ. 1109. Do you know of any process in manufacturing thermionic vacuum tubes for commercial use that employs that process?

A. I have stated the practice in the Westinghouse Company plant as I saw it. There the bulb comes out of the oven before it is sealed off.

RDQ. 1110. I think you stated in cross-examination that you had never used one of the original Marconi-Fleming valves. Consequently you could not state from your own knowledge what the degree of vacuum was in those bulbs. What is your opinion as to what the degree of vacuum of the Fleming valves of the Marconi Company were?

Mr. Davis: I think some basis should be laid for the opinion before it is expressed.

The Court: I think Mr. Davis is right.

XQ. 1111. Reference has been made to employing the charcoal bulb, the charcoal immersed in liquid air. How is the charcoal bulb connected to the device which is being evacuated?

A. The charcoal bulb is ordinarily connected to the tube which in turn—the tube through which the tube is evacuated; that is, it is connected through the evacuating tube to the vessel.

RDQ. 1112. And when the vessel has been evacuated to the degree desired, what is done with the charcoal tube; that is, how is it taken away from the apparatus or the device being evacuated?

A. The device being evacuated is ordinarily sealed off, separating it from the charcoal tube.

RDQ. 1113-14. With reference to the Lilienfeld articles, I believe that you stated that Dr. Lilienfeld had advanced at the conclusion of his article some theories with which you did not agree, at least in whole, or did not wholly agree. Will you please state what relation there is between the theories and the work on which the theories were based?

Mr. Davis: I do not quite see the propriety of that question, if your Honor please.

(Discussion.)

The Court: You may take the answer.

A To my mind, the theories that Dr. Lilienfeld has advanced, do not alter in any way the facts that he describes in his paper, and I would like to make it perfectly clear that the purpose of putting that article in is as follows: Dr. Lilienfeld performs a scientific experiment. He describes in greatest detail his apparatus. He describes the method of obtaining a high vacuum, including baking the walls, bombarding the electrodes, all of the necessary requirements or precautions to obtain a very high vacuum; in fact, exactly the methods that are described in patent No. 1; but without question in my mind, and I think most people will agree, he had a very high vacuum in his device. Now, that is plain fact as read from the article.

Then he performs an experiment. He is performing these experiments to test a certain theory of his. Coming out of those experiments are certain observations. He deduces certain conclusions from that experiment. Those conclusions, I think I stated very clearly, and I will re-state them at this point. One is that he was perfectly well satisfied that his discharge was independent of gaseous ionization, or any effect of gas, and he states definitely that the discharge is independent of the gas pressure; that is the earmark No. 3. He also states that the discharge is independent of the cathode temperature. That is an experimental observation. That is earmark No. 1. Then he deduces a certain law for the discharge through his apparatus. I would like to remark that so far as I know, it was not until a year after that that Child had put in mathematical figures the 3/2 power law, and yet here Lilienfeld does arrive at that 3/2 power law experimentally, which is earmark No. 2.

Now, it seems to me that these experimental observations are quite aside from any theory which he may have advanced. He had the high vacuum. He showed methods of producing the high vacuum. He deduced certain laws or observational results, and these happened to come out with the three earmarks which we have been discussing.

Mr. Davis: If your Honor please, I had supposed the function of an expert was to inform the Court of the meaning of scientific terms and give facts. This may be very suitable for my brother's brief at final hearing, but I do not think it is an expert answer, and I move to strike it out for that reason.

The Court: I am inclined to disagree with you there, Mr. Davis. I think the line of demarcation between the one and the other may be very close, and it may be along the marginal line here, but it seems to me that it is proper for an expert, or a person familiar with the art, to be asked where the line of fact leaves off in the specification, and where the theoretical field begins; and it seems to me, if I understand the question and answer, that is what this witness has attempted to point out.

Mr. Davis: I thought he went considerably beyond that, your Honor.

The Court: I think possibly he did, in part, but I think it would be difficult to separate.

RDQ. 1115. With reference to this 3/2 power law, your attention was called to the fact that in the curve plotted by Dr. Lilienfeld, that part of it only followed the 3/2 power law, and the remainder thereof followed another law——

Mr. Davis: I do not think we said quite that; I do not think we admitted any part followed the 3/2 power law.

The Court: I think you are right, Mr. Davis, and to that extent I think your question does assume facts.

Mr. Darby: I will withdraw the question and put it this way:

RDQ. 1116. As I understand your testimony, it was your opinion that part of the curve followed the 3/2 power law, that is, part of the Lilienfeld curve, and the remainder thereof followed another law; is that correct?

A. That is correct.

RDQ. 1117. Now, as a matter of fact, do any of the so-called hard tubes of thermionic vacuum tubes follow the 3/2 power law throughout their range?

A. Certainly not. That is, as you increase the voltage, you reach a point where you have drawn all of the electrons from the filament. From that point on, the law changes, of course, from the 3/2 power law.

The Court: Do you mind stating what part of the curve marks the division between those two fields? I think I know, but I want to make sure I do.

Mr. Darby: In thermionic tubes?

The Court: Yes, sir. Here is the chart here.

A. The 3/2 power law—I beg your pardon, this will have to be plotted in another way. I think I can draw that.

The Court: Maybe you have it in your logarithmic part.

A. This is quite all right; I can use this.

Mr. Davis: Here is something (indicating).

The Court: He is referring to the chart on page 453 of the Langmuir article in the December issue of the *Physical Review*.

The Witness: Starting with low temperatures, reaching up to a point where the curve bends and becomes horizontal, that is the part where it does not follow the 3/2 power law.

The Court: What is the part?

The Witness: The part for the low temperature up to the bend, then the horizontal part does follow the 3/2 power law. I think that can be made clearer, if we use another diagram where the current is plotted against the voltage.

Mr. Darby: If you will refer to a curve where voltage is plotted against current, I think it will show.

The Court: That is the plotted temperature. Will you have some of those? Are not some of those on separate sheets, that somebody used?

Mr. Davis: That is the curve on page 1052 of the Interference record in the Court of Appeals.

The Witness: In this curve we have current through the device plotted vertically, and voltage horizontally. Now, the portion starting from that place up to, in this diagram, about 90 or 100 volts, obeys the 3/2 power law. The portion beyond 100 volts does not.

The Court: I understand. That is what I thought it was.

Mr. Darby: Has the page of this been identified, page 1052? I will put a mark on that.

Mr. Davis: Yes.

RDQ. 1118. Now, as I understand it, if you will refer to the same curve, the Langmuir curve plots volts against milliamperes; is that correct?

A. That is correct.

RDQ. 1119. That is, volts against current?

A. Correct.

RDQ. 1120. And in the diagram of Lilienfeld is that true?

A. Yes, the same is true except that the logarithms are plotted.

RDQ. 1121. And in both diagrams the portion of the curve which follows or tends to follow the 3/2 power law is the lower portion of the curve?

A. That is correct.

By **The Court**:

Q. 1122. Is the division point the point of saturation?

A. The point where saturation begins, yes.

By **Mr. Darby**:

RDQ. 1123. At the conclusion of the Lilienfeld article, under VI as a caption, appears a summary subcaption 1, "Experimental results," and I think you have read into the record in your direct examination C and D, the paragraphs being lettered. Is there any mention in this summary under "Experimental results," any theories of Lilienfeld which you have stated that you do not wholly agree with?

A. I do not see any.

RDQ. 1124. In your cross-examination you referred to blue glow and glass fluorescence. Do they mean the same thing?

A. Not at all.

RDQ. 1125. As I understand it, blue glow is a positive sign of ionization when you can see it?

A. It is.

RDQ. 1126. And is glass fluorescence a sign of ionization?

A. Not necessarily. Certainly not.

RDQ. 1127. In other words, you cannot have blue glow without ionization, is that correct?

A. That is correct.

RDQ. 1128. Can you have fluorescence without ionization?

A. Absolutely.

Mr. Darby: I would like to offer in evidence copy of the Coolidge Patent 1,089,233. I do not intend to ask any question about the patent.

Mr. Davis: I merely suggest that the Coolidge patent in question is in the transcript in the Court of Appeals in the District of Columbia so that it is a duplication which I have no objection except as to the printing.

The Court: Let it not be duplicated in the printing.

Mr. Darby: That is entirely satisfactory. The patent was in evidence there, I do not know how far it was gone into.

The Court: I have forgotten what your agreement is with respect to your exhibits in the Interference suit anyway. They are to be considered as exhibits here, the same as if independently offered.

Mr. Darby: That is my understanding. I would like to have this Coolidge patent given a specific exhibit number and it is satisfactory that it be not reproduced.

The Court: Is that in connection with the thoriated tungsten filament?

Mr. Darby: Yes.

The Court: And for use in connection with the thoriated tungsten filament patent in this suit?

Mr. Darby: Yes, patents 2, 3 and 4.

(Received in evidence and marked "Defendant's Exhibit No. 38." *See Volume V, Defendant's Exhibits, page 545.*)

By **Mr. Darby:**

RDQ. 1129. I hand you a certified copy of New Zealand Patent No. 35,611 accepted as of November 3, 1914, and ask you if you have examined that patent and can state whether or not it is directed to the same subject matter as the Langmuir Patent No. 1, the high vacuum patent in this suit?

A. Yes, I have looked over the specifications and it is directed to the same subject matter as Patent No. 1.

RDQ. 1130. Are the specifications the same as issued, as the specification of Patent No. 1?

A. I have not gone through it word for word. I cannot say as to that, but it contains the same subject matter.

RDQ. 1131. Is the specification of the New Zealand patent the same as the specification of the issued Patent No. 1?

Mr. Davis: I would like to reserve my objection until I see what this is about. I do not know yet.

Mr. Darby: I will state frankly the purpose of it. The foreign patent, if your Honor will recall the specification of Patent No. 1, refers to the use of magnesium, but unfortunately in the United States Patent No. 1, although applied for in October, 1913, was not issued until after Patent No. 4.

Mr. Davis: Then this is against the later patent?

Mr. Darby: Yes, this is against Patent No. 4.

Mr. Davis: Then I have no objection whatever.

Mr. Darby: These are foreign published patents more than two years prior to the filing date of Patent No. 4, using magnesium.

The Court: I see.

A. The material in the specifications of this New Zealand patent is the same or refers to the same subject matter as occurred in the specifications of the Patent No. 1 as of the time when this was applied for.

Mr. Darby: I might explain to your Honor that Patent No. 1 was changed materially during its prosecution.

I offer in evidence a certified copy of the New Zealand patent with certified copy of the patent grant attached.

(Received in evidence and marked "Defendant's Exhibit No. 39." *See Volume V, Defendant's Exhibits, page 556.*)

By Mr. Darby:

RDQ. 1132. I show you certified copy of Australian Patent No. 14,677 of 1914, and ask you if you have read over this patent and can state whether or not it is directed to the same subject matter as the Langmuir patent No. 1 as of about the date of filing in New Zealand.

A. That is correct.

Mr. Darby: I offer in evidence a certified copy of the Australian patent.

(Received in evidence and marked "Defendant's Exhibit No. 40." *See Volume V, Defendant's Exhibits, page 580.*)

RDQ. 1133. I hand you a photostatic copy of British Patent No. 15,788 of 1914, and ask you whether or not that patent is in whole or in part directed to the subject matter of the Langmuir Patent No. 1 at or about the date of filing.

Mr. Davis: This being also for the same purpose as the Australian patent and the New Zealand patent?

Mr. Darby: Oh, yes.

A. The British patent contains in the specifications the material——

Mr. Darby: Might I interrupt you just a minute? Mr. Richmond calls my attention to this fact, that there is an additional fact that it is fair to call to your Honor's attention and to Mr. Davis' attention. Your Honor will recall that the Langmuir application filed in the United States, there is a statement—I do not purport to quote the exact words, but to the effect that no prior devices embodying the invention or using volts so high and current so high were known to the applicant, except the Coolidge X-ray tube.

Your Honor will likewise recall that in the— I think I better use the exact words—in the application for Langmuir appears the statement: "With the exception of the X-ray tube described in an application serial No. 776,549, filed May 8, 1913"—which I will interpolate there is no question that was the Coolidge X-ray case—"no prior devices are known to me operating with currents as great as five milliamperes, with voltages about as high as 200 volts."

That was modified before the patent was allowed to issue in the United States by striking out the words "with the exception of the X-ray tube described in an application serial number so and so, filed May 8, 1913, no prior"—and the insertion of the words, "no prior hot cathode device." I think you will find this on page 3 of the original specifications.

The Court: I have it.

Mr. Darby: That reference was stricken out before the patent was allowed to issue. The British patent that I am referring to now contains that statement in the patent as issued. It was not stricken from it. I want that fact before the Court for such arguments as either counsel may make.

A. The specifications of British Patent No. 15,788 of 1914, does refer to the subject matter of Patent No. 1 as of the date of filing, which date was first of July, 1914, but in addition there is material in the specifications corresponding to a patent to White, No. 1,159,307. This patent to White was filed March 20, 1914, and issued November 2, 1915.

RDQ. 1134. Will you please state briefly the subject matter of the White patent?

Mr. Darby: I call your Honor's attention to the effective date of the White patent, which is issued to the General Electric Company as assignee.

The Court: An American patent.

Mr. Darby: An American patent. In England they combine both the Langmuir and White in one patent, and I call your Honor's attention to the date of the White patent in England and in the United States with respect to patents Nos. 3 and 4 in this case.

The Court: Do you recall the respective dates?

Mr. Darby: Patent No. 4, was not applied for until 1921. That is the magnesium patent. Patent No. 3 was applied for October 28, 1915.

The Court: In England it was some time prior to that?

Mr. Darby: In England they were not filed until 1914, but it was issued in 1915. If the issue date is early enough then the statutory bar comes in, but the filing date in the United States is early enough for the White patent. I might also state to your Honor that there will be some question of double patenting involved.

The Court: I see.

Mr. Davis: There being no double patenting in the pleading.

A. The White patent is directed toward a thermionic detector, describes a thermionic detecting device which is a high vacuum device, except that a certain amount of material is introduced to produce a certain vapor pressure. I can quote from the patent, line 40, page 3. He describes the evacuation.

> "The evacuation of the tube is carried out by the most approved methods of incandescent lamp exhaust, and the last traces of gas are removed by either a Gaede molecular pump or by some chemi-

cal evaporating means, such as the use of vaporized calcium or magnesium."

A little further on, line 71, page 3:

"When evacuation of the envelop has been carried to a pressure low enough to enable the pure electron discharge to take place an ionizable gas has been removed from the anode to a sufficient extent to prevent the blue-glow phenomenon which is an indication of positive gas ionization the envelop is sealed off."

That refers to the blue glow as an indication of ionization.

Then I will read claim 4, on page 5:

"An electrical discharge device comprising an envelop, an electron-emitting cathode, an anode, a discharge-controlling conductor located near said cathode, said device being deprived of gas to such degree as to be capable of operation with a substantially pure electron discharge at several hundred volts and a vaporizable substance in said envelop."

Mr. Darby: I offer in evidence a copy of the British patent to the British-Thomson-Houston Company, 15,788, of 1914.

(Received in evidence and marked "Defendant's Exhibit No. 41." *See Volume V, Defendant's Exhibits, page 592.*)

Mr. Darby: I offer in evidence a copy of White Patent No. 1,159,307, issued to the General Electric Company as assignee of the patentee, patented November 2, 1915, and application filed March 20, 1914.

(Received in evidence and marked "Defendant's Exhibit No. 42." *See Volume V, Defendant's Exhibits, page 604.*)

Mr. Davis: As I understand, this is against one of the later three patents.

Mr. Darby: This White patent is against Patent No. 3 and Patent No. 4. I would like to make application for leave to amend my answer by setting up the defense of double patenting, both with respect to the Coolidge patent and with respect to the White patent.

(Discussion.)

The Court: I understand it. I think the situation is, Mr. Darby, now, while his statement was in the form for a motion for leave to amend, he not having the papers ready and prepared, I take it that what his statement means in legal effect is merely a notice that at a later stage of this trial of this cause to present the proper papers accompanied by a motion then to amend.

Mr. Darby: Does your Honor wish a formal motion or is it sufficient that we draw a new paragraph?

The Court: Draw your amendment and your oral motions will cover it.

Mr. Darby: That completes the examination.

Re-Cross-Examination.

By Mr. Davis:

RXQ. 1135. You say the Westinghouse Company uses the process of this Edison patent in its commercial exhaust with 201-A tubes, Professor?

A. No, not specifically.

RXQ. 1136. I understood you to say that; was I wrong?

A. It uses the method of pumping after heating.

RXQ. 1137. That is all you said?

A. Continuing the pumping after heating.

RXQ. 1138. That was all you said, was it?

A. Possibly that is the purport.

RXQ. 1139. Now, there is, however, this difference, is there not, at this point, at least, that in the Westinghouse Company's practice, the heating is done while the tube is on the pump?

A. That is correct.

RXQ. 1140. And then they continue to use the pump after the tube has emerged from the heater; is that it?

A. Quite right.

RXQ. 1141. Now, you spoke of the fact that the Westinghouse Company uses a rubber connection for fastening the tube on to the pump in some way, or some part of the pumping system. The Westinghouse Company also uses, does it not, the means of getting the vacuum and holding the vacuum set forth in the fourth patent in suit?

A. That is correct.

RXQ. 1142. It is a fact, is it not, that if that means is used, certain precautions would be unnecessary; but if no such means were used they would be necessary?

A. I would like that question read. (Question repeated as recorded.) Of course the use of vaporizable reagent makes some difference.

RXQ. 143. Now, you spoke of the devices which were being evacuated ordinarily being sealed off from the charcoal tube. I think yesterday we spoke of this charcoal tube and liquid air as though it were a pump, did we not?

A. That is right.

RXQ. 1144. So that would amount to what they call sealing off from the pump?

A. That is right.

RXQ. 1145. As a matter of fact, Dr. Lilienfeld's 1910 article does not disclose any sealing off from the charcoal tube, does it?

A. No, he had no intention to seal off, except in the *Berichte* article he has a valve between the charcoal tube and the exhaust chamber, and in the Rosenthal article, or the Lilienfeld-Rosenthal article, he presumably, that is, he describes the previous work, and refers to its exhausts, I believe, in much the same way, and the device is sealed off.

RXQ. 1146. In the 1911 article, the *Leipziger Berichte* article, he shows the valve. He was interested to know what would happen if he could close the connection between the tube and the exhaust system; is that right?

A. Yes, that is correct.

RXQ. 1147. And he says in the article that he was unable to use a valve which would really close it?

A. Yes, that is quite right. There was some very slow diffusion through the valve which was not perfectly tight.

RXQ. 1148. He had to actuate a valve magnetically from outside the system, as the valve was in the tube; is that right?

A. Yes, as I remember, but of course that valve enormously decreased the rate of diffusion either way through the valve.

RXQ. 1149. Because in those very low densities, diffusion is a rather slow thing, as we pointed out yesterday?

A. Of course.

RXQ. 1150. Now, you said this morning in your re-direct examination, that this work of Dr. Lilienfeld was published before the Child formula was published. You were here when Dr. Millikan testified the other day?

A. Yes, I was.

RXQ. 1151. I understood Dr. Millikan to say that the Child formula was nothing but the J. J. Thomson formula, published long before; is that correct, in simpler form?

A. J. J. Thomson did not deduce the 3/2 power law. He set up the original equation from which the 3/2 power law can be deduced, but it had not been deduced until Child.

RXQ. 1152. It is already there in that Thomson formula, is that your view?

A. Anybody reading Thomson's formula, would not immediately see the 3/2 power law unless he made some mathematical derivation.

RXQ. 1153. Now, the Child law was announced as the law governing a current transported by ions, positive ions only, in the absence of electrons, between selected portions of two infinite parallel plane plates; is that right?

A. That is correct.

RXQ. 1154. It was not announced as a law, as to what would be the voltage on sounding, electrodes introduced into the actual tube?

A. No. It does not deal directly with sounding electrodes, of course.

RXQ. 1155. Now, I understood you to say this morning that in the normal tube, a modern tube, the tube of the patent, there is a departure from the 3/2 power law, which departure is in the nature of a bending over, which is called a transition, culminating in a horizontal portion of the curve called saturation; is that correct?

A. That is correct.

RXQ. 1156. That is the plot of voltage against current, and you instance that as an illustration—I should have said a current against voltage; that is, you plot voltage horizontally and plot current vertically—I am still incapable of remembering these differences sometimes—you mention that in connection with the fact that the Lilienfeld tube, in your judgment followed the 3/2 power law, and then departed from it; is not that true?

A. That is correct.

RXQ. 1157. Now, considering the portion of the Lilienfeld curve, which, in your view follows the 3/2 power law, and going up on that portion, at the same time thinking of the portion of the modern tube which follows the 3/2 power law, and going up on that, there is this difference between them, is there not, that the modern tube bends over, the curvature becomes less and less, and finally becomes horizontal, whereas in the Lilienfeld case, the curve increases to a square, instead of a 3/2 power law; is that right?

A. Quite right.

RXQ. 1158. So that when these tubes, in your judgment, go along hand in hand, for a while in 3/2 power law, when they separate, they separate in opposite directions?

A. That is quite right, but I did not imply they go in the same direction. In my answer, I was quite aware of that.

RXQ. 1159. And of course, for entirely different reasons?

A. Entirely different reasons, yes.

RXQ. 1160. And you now agree with all of those statements in the summary at the end of Dr. Lilienfeld's paper, or did I misunderstand you?

Mr. Darby: The question carries an implication that he has agreed with all of it.

Mr. Davis: I asked him, does he now agree with all the statements?

Mr. Darby: I still get the same implication.

RXQ. 1161. Do you or do you not agree with all the statements contained in the summary in the end of Dr. Lilienfeld's 1910 article?

Mr. Davis: Mr. Darby says that my question is broader than the question, so I will, with his assistance, reframe it.

RXQ. 1162. Mr. Darby tells me that the question he asked this morning had to do with the summary under the heading V. I. summary, under the subject-heading 1: "Experimental Results," and that it is his understanding that you testified that you agreed to all of those statements; is that correct?

A. I believe that is correct; that is what I certainly said; and it is my impression as I glanced through them, that I do agree. I had already read several of them in my direct testimony. As I remember, there is a mathematical formula in there which I did not scrutinize very carefully. Now, if that is pointed out—I was referring specifically to the worded statement there.

RXQ. 1163. You were speaking of them as experimental results, with reference to that particular tube?

A. Yes.

RXQ. 1164. You would not think of them as being applicable to tubes in general?

A. Oh, no; I was referring to Lilienfeld's work, of course.

Mr. Davis: I think that is all, Mr. Darby.

FRANK B. JEWETT.

Frank B. Jewett, called as a witness on behalf of the defendant, having been duly sworn, testified as follows:

Direct Examination.

By Mr. Haight:

Q. 1. Dr. Jewett, will you please give your full name, age and residence?

A. Frank Baldwin Jewett, forty-seven years of age, residence, Short Hills, New Jersey.

Q. 2. And what is your profession or business?

A. I am an electrical engineer by profession and the vice-president of the American Telephone & Telegraph Company in charge of its research and development work and also the president of the Bell Telephone laboratories, which is the research and development agency of the Bell Telephone System.

Q. 3. Prior to the formation of the Bell Telephone Laboratories, Incorporated, by what agency or by what company was the research work of the American Telephone & Telegraph Company carried on?

A. Subsequent to the latter part of 1906 or the early part of 1907, the research and development work was carried on as a part of the engineering department activities of the Western Electric Company, a subsidiary of the American Telephone & Telegraph Company. That condition continued until the first of January, 1925, at which time the activities had become so large that it seemed expedient to give them a different status and they were then incorporated as a separate research and development agency of the Bell System under their present title and status.

Q. 4. Now, does this corporation, the Bell Telephone Laboratories, Incorporated, carry on the research work for both the American Telephone & Telegraph Company and the Western Electric Company?

A. It does.

Q. 5. How many persons have you employed under you in the Bell Telephone laboratories?

A. About 3600. In the Bell Telephone Laboratories, to which should be added about 400 additional, who report to me in the American Telephone & Telegraph Company, they are really a part of the development organization.

Q. 6. How many of those are engaged in research work of one kind or another?

A. Roughly I should say about 2400 or 2500 of the 4000 are technically trained men, or men who had experience and have become technically trained, and who are engaged in research and development work. The remainder are the necessary service people, I believe, clerks and what not to act as assistants for these people. I have not an exact tabulation, but it is in the neighborhood of 2400.

Q. 7. Now, then, prior to your becoming president of the Bell Telephone Laboratories, Incorporated, what have been your positions with the Western Electric Company, which I understand carried on the research work of the American Telephone & Telegraph Company, as well as its own research work before that time?

A. I became associated with the Western Electric Company in the spring of 1912, prior to which time I had been a transmission engineer for the American Telephone & Telegraph Company. In April, I think it was, April or May, 1912, I became assistant chief engineer of the Western Electric Company, in charge of its research and development work, and had general direction of all of the laboratory functions, and some other functions of the engineering department, and I continued as assistant chief engineer until the latter part of 1916, when I became chief engineer of the Western Electric Company, in charge of all of its engineering work, which included all its research and development function, and I continued as chief engineer and as vice-president, until, I think, sometime in 1922, when I became the operating vice-president of the Western Electric Company, in charge, not only of all of its engineering work, but in charge of all of its manufacturing and service functions for the Telephone Companies; and I continued in that capacity until the first of January, 1925, when I returned to the American Telephone & Telegraph Company, and the position which I have indicated, which I now hold.

Q. 8. Now, you spoke of having been affiliated with the telephone company?

A. Yes, sir.

Q. 9. I mean directly, rather than indirectly, through the Western Electric Company, prior to some time in 1912, what time in 1912 was that?

A. My recollection of it was it was in the spring, either April or May; I have forgotten the exact date.

Q. 10. And what had been your position with the telephone company prior to that time?

A. I first became associated with the American Telephone & Telegraph Company in connection with research work which it initiated in 1904, and was in the laboratories which were then in Boston, until the summer of 1907, when those functions were moved to New York, and the laboratory functions were consolidated, as I have described, with the work of the Western Electric Company. From 1907 until 1912, when I went to the Western Electric Company as chief engineer, I was the transmission engineer of the American Telephone & Telegraph Company, in responsible charge of the supervision of all of its activities connected with the transmission of intelligence, and as such had general supervision over the research work done in the laboratories of the Western Electric Company, although I was not directly responsible for the details of that work.

Q. 11. Now, prior to coming to the telephone company in 1904, what had been your professional connection?

A. I had no professional connections before that time. I was graduated as an electrical engineer in 1898 from what is now the California Institute of Technology in California. It was then called Troop California Institute, and from 1908 to 1902——

Q. 12. 1898, you mean?

A. I beg your pardon. 1898 to 1902, I was a graduate student at the University of Chicago and the research assistant to Professor A. A. Michaelson, who was head of the physics department. I took my doctor's degree in 1902, and from 1902 to 1904, I was instructor in physics and electrical engineering at the Massachusetts Institute of Technology in Boston, and I went directly from that to my connection with the telephone company.

Q. 13. Now, do you recall when a transcontinental line, telephone line, from New York to San Francisco and the Pacific Coast, was first projected by the American Telephone & Telegraph Company?

A. Yes, sir.

Q. 14. When was that?

A. It was in the winter of 1909 and 1910.

Q. 15. And did you have anything to do with that?

A. Yes, sir.

Q. 16. Will you state the connection that you had with the working out of the plans, and so forth, of the building of this transcontinental line?

A. In the fall of 1909, I had occasion, as indicated —I was at that time transmission engineer for the telephone company, I had occasion to spend about three or four months in San Francisco and on the Pacific Coast in connection with transmission problems there. About the first of 1910 I was joined out there by Mr. J. J. Carty, who was then general engineer of the telephone company, and later Mr. T. N. Vail, who was president at the time, came to San Francisco. At that time, the people of the Pacific Coast were planning the Panama-Pacific Exposition, and were very anxious to have telephonic communication with the Eastern seaboard at the opening of their exposition, and they very strongly urged upon Mr. Vail the desirability of building a transcontinental line. At that time, the telephone art was such as to permit us to talk commercially only about half the distance across the continent. Mr. Vail consulted General Carty and myself with regard to what he could say to the people of San Francisco, and ultimately did promise to have a transcontinental line in operation by the opening of the Panama-Pacific Exposition at the beginning of 1915, I think it was. In making that promise, we had to commit ourselves to the advancement of the art beyond anything which we then knew how to do, but we felt—and acting largely upon the advice which I gave at that time—that the advances in general science, and particularly in physics, could probably be applied to the extension of the range of telephone communication and could be applied sufficiently early to permit of the early construction of a line which not only involved the stringing of telephone circuits westward from New York, but actually involved the building of a physical line for about half the distance.

Q. 17. Now, what was your particular function in connection with the development work leading up to that line, after that time?

A. After the commitment had been made, the responsibility for making good on the commitment was assigned to me as the Company's Transmission Engineer in charge of its research and development work.

Q. 18. Now, did you take that work over with you when you became connected with the Western Electric Company in 1912?

A. Yes, sir.

Q. 19. And you still, after that, had charge of the transcontinental line project?

A. Yes, sir.

Q. 20. Now, will you please—possibly it is a convenient point to adjourn, because I was just going to take up another point.

Mr. Darby: May I interrupt? Mr. Davis in connection with the two additional questions of Dr. Chaffee wished to have him enumerate several references in which he referred to the alkali earth metals as vaporizing reagents, and the other referred to another point, and later on, interrupting Judge Haight who had started, Mr. Davis said it was entirely agreeable, and we ask your Honor's permission to have it dictated to the stenographer, and have it come in the proper place.

THE COURT: Is that satisfactory?

MR. DAVIS: Yes, your Honor.

THE COURT: As part of his testimony. Yes, all right.

AFTER RECESS.

MR. HAIGHT: Will your Honor pardon me just one moment? It is a question of a stipulation.

Yesterday, Mr. Darby requested a stipulation from Mr. Davis with respect to the relationship between the Marconi Company, The Radio Corporation and the General Electric Company. Mr. Davis said that he was quite willing to stipulate that relationship and wanted also at the same time to stipulate the relationship in this suit of the Telephone Company.

I am willing to stipulate that relationship and do so as follows:

After this suit was instituted on the patent No. 1,558,436, counsel for the Receiver of the DeForest Company asked the Telephone Company to make such of its witnesses as he might want to use, who had testified in the Interference proceedings on the question of priority of invention, available to testify in open court in Delaware, saying that if this were not done, he would be compelled to take their depositions *de bene esse*. The Telephone Company consented to comply with the foregoing request, and in addition, because of the great amount of work required to be done in the preparation of the defense of this case, and importance to the Telephone Company of any decision herein on the question of priority, it has and is through its counsel, assisting the DeForest Company in the presentation of the defense, that if there is patentable invention in the said patent in suit, Dr. Arnold was the prior inventor of such invention.

Perhaps we might have the stipulation as to the relationship of the three companies that I have mentioned at this same time, or would you prefer to leave that till later, Mr. Davis?

Mr. Davis: Very glad to do that now. I understand among the counsel mentioned of the Telephone Company are my friends Mr. Ballard, and Mr. Richmond, is that correct?

Mr. Haight: That is correct.

Mr. Davis: On the other matter, if your Honor please, in the months following the Armistice, that is, in the early part of 1919, representatives of the United States Government, asked the General Electric Company to form a Radio Corporation. The General Electric Company formed a Radio Corporation which was and is the Radio Corporation of America. Contracts were entered into with the American Marconi Company, whereby the Radio Corporation of America acquired in November, 1919, which was practically just after its formation, it was at the first active meeting of the Board, this organization was made—all of the assets of the American Marconi Company with the exception of what was called in the contracts "The Reserved Assets," which consisted of certain claims for past infringement of patents, principally I think a claim against the United

States Government for the use of patents during the war.

The Marconi Company of America continues in existence, and is endeavoring in the Court of Claims, and elsewhere, to collect those Reserved Assets and the contract provides what shall happen if, and when, collected.

The other assets were transferred on or about November 20th, 1919, to the Radio Corporation of America, which entered into a contract with the General Electric Company by which the General Electric Company granted to it an exclusive right for what the contract called "Radio Purposes," to use and to sell in the United States, under the patents, but only apparatus manufactured for it by the General Electric Company. Subsequently an arrangement was made by which the Westinghouse Electric & Manufacturing Company granted corresponding rights to the Radio Corporation under its patents, and by which the General Electric Company licensed the Westinghouse Company to make a certain part of the radio devices for the Radio Corporation under its patents, and the Westinghouse Company licensed the General Electric Company to make a certain part of the radio devices for the Radio Corporation.

The Radio Corporation at its organization, or shortly thereafter, issued two kinds of stock, preferred and common. A certain amount of the preferred stock was acquired by the General Electric Company for cash or property. That was a good deal less than half. That was a voting stock, and something over half, a little over half of the common, no par value common stock of the Radio Corporation was at that time acquired by the General Electric Company.

Since then, others have purchased treasury stock of the Radio Corporation, so that the present holding of stock of the General Electric Company is very much less than half of the stock.

I imagine that my brother will stipulate in addition, in fact I think Dr. Jewett practically said so, that from long before, and during all the time in which we are interested, up to and including the present, the Western Electric Company has been a company which was controlled by the American Telephone and Telegraph Company, which owns all but a very small fraction of its capital stock.

MR. HAIGHT: That is correct.

MR. RICHMOND: All but a very small portion.

Q. 21. Dr. Jewett, we reached the point before recess where you were telling about the responsibility of the transcontinental line having been placed on you. Now, will you please explain to the Court briefly and with as little reference to technical language as you can the difficulties from an electrical engineering standpoint which confronted you in the building of this transcontinental line? I do not mean the putting in of the poles and things of that kind, but the other things.

A. At the time we made the definite commitment to have this line if possible in service across the continent by the opening of the exposition, the telephone art so far as long distance transmission was concerned, was about in this state: It could only be done on open wires, that is, wires strung on cross-arms, and the telephone engineer at that time had the choice of extending the normal range of a pair of wires which were put up without any apparatus on them, extending that transmission range by one of two methods.

He could either employ what was known as loading, which was the application of an invention by Professor Pupine, or he could apply in some cases or make an extension by an application of an amplifying device which in common parlance was called a telephone repeater, a mechanical device which at the place where it was inserted took energy from a local source, a battery, and under the control of the weakened telephone current revivified the energy to go on.

He had the choice between those two things and in the then state of the art, except in very rare instances, he could not employ both; in other words, he could not add to the extension of the distance he could telephone by employing both means of extending distance.

And at that time we had substantially reached the limit of increasing distance for wires of a given size by means of loading and that distance fell some two thousand miles, roughly, short of spanning the distance across the continent.

The mechanical repeater, on the other hand, was of a character which, while one instrument could be inserted in a non-loaded line and extend its range, its characteristics were such that if you put two or more in a line at intervals, while they increased the volume, they distorted the quality so that you could not get intelligible speech.

Consequently, in order to solve the problem which we had set ourselves the task of doing, it was necessary to enlarge the art beyond anything that we knew and we were satisfied that we could do nothing substantially more than we had done with loading, and we were satisfied that he had exhausted or substantially exhausted the possibilities of mechanical repeating and we were satisfied that the answer could be found only by the development of some form of repeater which could either be used in multiple units so as to get a large number of them into the line or used in conjunction with loading.

I was satisfied at that time that the answer required the production of an amplifying device very different from the mechanical type of repeater which is essentially nothing more than a special form of telephone receiver talking into a special form of transmitter, and that the solution must be found in what was essentially an inertialess type of repeater, an amplifying device which involved the discharge of electricity through some sort of conducting medium that did not involve the moving of actual physical matter.

I was also satisfied that there was a good chance, from what I knew of the development in the realm of physics and what we had already more or less experimented with in the applications of those developments, there was more than an even chance that if we could apply the proper talent to the problem it was a soluble problem and it was on that that we staked the promise to put this line through. So that immediately upon my return to New York from this conference in San Francisco, I set about in conjunction with the men in the laboratories and with the officials of the Telephone Company, securing the type of men to work on this problem that we required. They were essentially physicists that were required to solve this job. It was a job of the application of the last word that was then known in physics, to a specific telephone problem.

Q. 22. After you had taken this matter up with the men in your laboratory, did you make any effort to get from the outside someone who by training or reputation you thought was equipped to solve this problem for you?

A. Yes, sir.

Q. 23. And please tell us what efforts you made and what you did.

A. After I had satisfied myself that we had no one in our organization who in our judgment was competent to attack this problem and after I had received confirmation from my associates as to my belief as to the direction in which we would have to seek, I got in touch with Professor Millikan, who was then professor of physics at the University of Chicago, where I had taken my doctor's degree, and he was considered the leading man in that particular branch of physics, to inquire of him whether he could recommend to me a man or men who in his judgment were competent to attack this problem. I outlined to him what the problem was, the character of the man that I thought was needed and sought his advice and help in getting such a man or men.

Q. 24. You have spoken of Professor Millikan being the leader in that branch of physics. When you used the expression "that branch of physics," what did you refer to?

A. I was referring to the branch of physics in which Millikan has so signally specialized himself, the branch of physics which has to do with gas ionization and production of electrons and the measurement of the ultimate unit of electricity and the whole realm of what is known as modern electronic physics.

Q. 25. Did he recommend anyone to you?

A. Yes, sir.

Q. 26. Whom did he recommend?

A. He recommended a young man who was then in the laboratory working for his doctor's degree, a Dr. H. D. Arnold.

Q. 27. And was Dr. Arnold employed by the telephone company?

A. He was, yes, sir. He was employed by my recommendation by the Western Electric Company in its research department as I remember it, took up his work about the first of the year 1911.

Q. 28. Before he came to the telephone company was it made known to him what his particular work was to be?

A. Yes, sir.

Q. 29. And what was it that you told him his particular work was to be?

A. As I remember the conversations I had with him, I outlined to him the general problem which was confronting us and advised him that what we were desirous of having him undertake was the study, and if possible, the development of a repeater or amplifier of the type that I have indicated to you, one which would be suitable for use on the character of line which we could build across the continent.

Q. 30. When he did come to you was he put to work on that particular problem?

A. As I remember it on that problem and that only.

Q. 31. And you say he came to work in the early part of 1911?

A. Yes.

Q. 32. Do you know of your own knowledge whether he worked on that problem between that time and October of 1912?

A. Yes, sir.

Q. 33. And what was his success, what did he accomplish or succeed in producing?

A. After Dr. Arnold had had sufficient time to acquaint himself with the general conditions underlying, general requirement conditions underlying successful repeater operation, he surveyed his knowledge of the possibilities of the then existing physical science and came to the conclusion that the solution of the problem was most likely to be found in a form of repeater or amplifying device employing mercury vapor in an evacuated vessel.

The mercury arc was a form of device which was well known in the art for other purposes and it was a form of device on which we ourselves were experimenting with as negative resistance repeaters. He had an idea, however, that a different use of that device might result in a successful telephone repeater. He convinced us that it was a feasible line in which to work and he then did work on that line with the result, as I remember it, that by the summer of 1912 or the early fall of 1912, he had so far succeeded as to have produced satisfactory, essentially distortionless amplifying devices employing mercury arc instrumentalities.

Mr. Davis: I object to that as a conclusion, as to the production of satisfactory devices.

The Court: You want that stricken out?

Mr. Davis: Yes.

The Court: That portion of the answer containing the conclusion may be stricken out.

Q. 34. He had produced a mercury arc repeater, is that right?

A. Yes.

Q. 35. And when do you say that he had brought that to completion?

A. My remembrance is by the summer or early fall of 1912.

Q. 36. And was it demonstrated to you?

A. I might qualify that, Judge Haight, by saying that it was successful——

Mr. Haight: This was stricken out.

The Court: That is his conclusion. You may get the facts, of course.

Q. 37. Was it demonstrated to you?

A. In the laboratory, yes, sir. We had not yet reached the stage of actually trying the thing under field conditions.

Q. 38. In the laboratory did it work?

A. Yes, sir.

Q. 39. And did it seem to justify to you further exploitation?

A. Yes, sir.

Q. 40. Now then, under whom did Dr. Arnold immediately work?

A. Dr. E. H. Colpitts.

Q. 41. And Mr. Colpitts' position in the company at that time was what?

A. In general charge of the research laboratories of the Western Electric Company.

Q. 42. And to whom did he report or who was his immediate superior?

A. His immediate superior was an assistant chief engineer of the Western Electric Company, and after April or May, of 1912, I was that Assistant Chief Engineer.

Q. 43. So in the fall of 1912, Mr. Colpitts was directly under you and Arnold was directly under Mr. Colpitts?

A. Yes, sir.

Q. 44. Do you recall a visit by Dr. Lee DeForest to you in October, 1912?

A. Yes, sir.

Q. 45. Will you please state the circumstances of that visit, how it was arranged and what took place up until say November first?

A. Until or including November first?

Q. 46. Until but not including November first.

A. Some time in October, about the middle of October of 1912, General Carty communicated to me either by telephone or verbally in one of our conversations the fact that Mr. John Stone Stone——

Q. 47. Who is General Carty?

A. He was then the Chief Engineer of the American Telephone & Telegraph Company, in general charge of its broad policy of research and development as well as of other engineering matters.

Q. 48. Now proceed with your story, if you will.

A. He communicated to me the fact that Mr. John Stone Stone, who had at one time been employed by the Telephone Company had called his attention to an invention of Dr. Lee DeForest and had stated to him his belief that this invention in his judgment offered possibilities of development and use as a telephone repeater for the purposes which it was well known among the telephone people we were seeking to accomplish, and he suggested to General Carty that it would be well for Dr. DeForest to exhibit his invention to us.

General Carty told me he would like to have Dr. DeForest bring his apparatus to the laboratory and to have him demonstrate it and to form a judgment as to whether the thing he exhibited to us was either itself directly applicable to our problem or could be made applicable to our problem and in line with that understanding Mr. DeForest did come to see me under date of October 30th, that date I fix by looking up the records of the visit.

Q. 49. October 30, 1912?

A. Yes. He came to my office, which was then on the twelfth floor of the Laboratory Building on West Street, New York, and he said that he was ready to exhibit his apparatus which was quite simple and I called in Mr. Colpitts who had charge of the laboratory and after introducing him to Dr. DeForest, turned Dr. DeForest over to him to make a demonstration. Mr. Colpitts took Dr. DeForest down to his office, which was then on the eighth floor of the building and provided the very simple facilities that were required. I did not see Dr. DeForest again on that day, but on the following day Mr. Colpitts, late in the day, called me up and said that Dr. DeForest had substantially completed his demonstration and was about to leave and asked if I would come down to see if there was anything further that he might want, or to satisfy myself of anything that they did not cover, and I did go down to Mr. Colpitts' office and there had a few words with Dr. DeForest and witnessed a very simple demonstration of the simple apparatus which he brought to the laboratory. After which Dr. DeForest left the building and left the apparatus in the room.

He left it with us for further experimentation. We told him that we would like to have the apparatus to experiment with further, and he very gladly left the apparatus there.

Q. 50. Tell us the result of that simple demonstration that you say took place, how did the apparatus function?

A. The simple apparatus which he had there consisted of an audion device, three-element device in a simple one-way circuit, that is, it would pass current in but one direction only. The equipment that he had set up was in effect a simple telephone receiving apparatus on the receiving side and a very simple form of transmitter on the transmitting side.

As he demonstrated it that day, when he talked into the transmitter in low tone of voice the observer at the receiving end was conscious of a very decided amplification of the currents that came over the line. It was a purely qualitative experiment.

Q. 51. But it did amplify?

A. Yes, sir.

Q. 52. You have spoken of the device as the three-element device. Is that what we all know now as the three-electrode vacuum tube?

A. Yes, sir.

Q. 53. Commonly referred to as the audion?

A. Yes, sir, the thing that is so common in all modern radio sets.

Q. 54. Did you have anything further to do with this apparatus on the following day?

A. Yes, sir.

Q. 55. If so, please state the circumstances.

THE COURT: That is November 1st.

MR. HAIGHT: Yes.

A. That is November 1, 1912. Sometime in the morning of November 1, 1912, Mr. Colpitts asked me if I would not come down to his office to consider further this DeForest invention. I went down and I found Dr. Arnold with Dr. Colpitts. They apparently had been discussing the DeForest apparatus and experimenting with it and Mr. Colpitts asked me to indulge in some further experiments with the thing because of certain characteristics that this particular device had.

We made some further tests on this simple apparatus with the result that it was shown to me that while this apparatus did amplify very weak sounds it would not in its then existing form handle the amount of energy which any telephone repeater must handle if it was to be a successful repeater.

Q. 56. How was that manifested, Doctor?

A. It was manifested in a number of ways. When an attempt was made to have it amplify at the energy level at which a telephone repeater must operate to work successfully, the quality of speech was very badly distorted, frequently interrupted, made erratic, and the device exhibited a characteristic phenomena which was not present at other times, namely, a blue haze, a blue light inside of the bulb. That blue light was always connected with the attempts to make the device operate at an energy level corresponding to that of a telephone repeater operation. I might explain that the reason why I have used the term "the energy level of the telephone repeater operation" is that there is quite aside from the repeater itself and its characteristics, an energy level on a telephone line below which you cannot go and have successful commercial telephony.

That level is determined by interference phenomena that come on from inductive exposure to high tension lines, so that there is a certain lower limit of energy level that any telephone repeater must handle if it is going to operate successfully as an amplifying device on telephone lines, and when we attempted to reach that energy level with this device it failed to function as it did at the lower level.

Q. 57. You used the expression energy level. Is that in any way affected by the loudness of the voice speaking into the telephone transmitter?

A. Yes, sir.

Q. 58. Just explain that, will you?

A. In general with the ordinary transmitter, the energy in the alternating current wave that goes out from that transmitter, is dependent upon the loudness with which the person speaks, that is, the louder he speaks the more he agitates the diaphragm of the telephone transmitter and the greater is the amount of energy in the alternating current which is the reproduction of the voice frequency.

Q. 59. You spoke of this apparatus amplifying when you spoke in low tones. What happened when the voice was raised?

A. When the voice was raised the quality of the speech as heard on the receiving side first became impaired, erratic, and sometimes completely interrupted and simultaneously there appeared in the tube a blue haze which was not present with the thing used as Dr. DeForest had exhibited to me on the previous day. That blue haze also appeared when an endeavor was made to raise the energy level by increasing the voltage of the battery which was connected between the filament and the plate.

Q. 60. Was this condition that you have spoken of, this unsatisfactory condition when the voice was raised, due to the raising of the energy level that you have spoken of?

A. Yes, sir.

Q. 61. Have I correctly expressed that?

A. Yes, sir.

Q. 62. Was the audion in that condition a satisfactory instrumentality for telephone repeater service?

A. Decidedly not.

Q. 63. Why?

A. It was entirely unsuited because it would only amplify energies which were very much lower than the energies which would be present on the telephone line at the point where the telephone repeater had to be installed.

Q. 64. When you saw this blue haze, did that indicate to you what was taking place within the audion?

A. It indicated to me one thing that was taking place in the audion.

Q. 65. And what was that?

A. That there was some form of gas ionization. I knew enough—while I was not an expert in the sense of being then a laboratory man—I knew enough from my past experience and general observations in the laboratory to know that that blue haze was connected with ionization of some residual gas in the tube.

Q. 66. Now, after that condition had been noted, was there anything said by Dr. Arnold as to whether or not the condition could be cured?

A. Yes, sir.

Q. 67. Please tell us in your own way the conversation now that took place.

THE COURT: The same day?

MR. HAIGHT: Yes, at the same time.

A. There were present at this conversation, as I have indicated, Mr. Colpitts, Dr. Arnold and myself. Dr. Arnold having been called in by Mr. Colpitts, because he was the man in our organization who presumably and actually did know the most about the general type of phenomenon that was involved. The obvious amplification of weak currents as demonstrated by DeForest and as shown when you used the device with low energy level, made it a matter of considerable interest to us because it was a simple device; the amplification was, at these low energy levels, apparently very considerable and the quality was good and because of our great interest in this solution of this problem we were anxious to follow up every lead that was at all hopeful and it immediately arose in our minds the question as to whether this very desirable characteristic at one energy level could hope to be obtained with this device at some other energy level and the discussion of that morning ran toward the question of what, if anything, could be done to improve the device which we then had before us with a view to making them available for these repeater purposes, and Mr. Colpitts and I questioned Dr. Arnold with regard to some of these things.

The most obvious characteristic of the apparatus then before us was this blue haze which occurred when attempts were made to have the device operate at relatively high levels and the question was whether that defect could be eliminated, and Dr. Arnold stated very positively that he could make a device which was better than the thing which we then had before us and that he could remove the gas and that by so doing he would reduce, if not entirely eliminate, this characteristic of gas ionization which obviously at times made the De-Forest device inoperative.

We then also discussed certain other matters which pertained to the problem in question, the device we had before us was obviously of flimsy construction and not at all suitable in that mechanical form for use in the telephone and the telephone plant——

Q. 68. Before you go into that, did he tell you how he proposed to correct the defects that you have just described?

A. Yes.

Q. 69. What did he say?

A. Take more of the gas out, take out more of the residual gas.

Q. 70. When he said that, do you recall whether Mr. Colpitts asked him any specific question?

A. Yes.

Q. 71. What did he ask him?

A. Mr. Colpitts, as I remember it, inquired whether if the gas were taken out, this residual gas were taken out, the electrons emitted from the filament would not immediately pass over to the plate under the influence of a relatively small voltage so that we would not in effect have any increase in energy used up in the tube itself.

Mr. Colpitts said that he had understood that there were questions of that kind that had developed in the course of physical discussion. Dr. Arnold stated very decidedly that while it is true that there had been discussion of that kind it was well established in his judgment that that was not the case that the removal of the residual gas in there and the making of the device essentially a pure electron device would require the application of considerable voltage to move this stream of electrons to the plate; that in answer to a further question that Colpitts raised as to why that was so, he pointed out that these electrons being all of a similar sign had a certain amount of mutual repulsion among them which would require the application of an external electromotive force to overcome and make them move in considerable quantities across the space between the filament and the plate.

Q. 72. You speak of them being of the same quality, did you use the expression?

A. The same sign.

Q. 73. Do you mean by that being all negative?

A. All negative.

Q. 74. Do you recall whether he discussed how he would get a high vacuum or the methods he would employ to get a high vacuum?

A. So far as I recall he did not.

Q. 75. You are not positive whether he did or did not?

A. No, I am not positive, but as far as I know he did not.

Q. 76. Were you familiar with methods of procuring high vacuum?

A. Yes, sir.

Mr. Davis: I object to that as immaterial.

Mr. Haight: I think it bears on this. If the method was not specifically discussed, it is probably——

The Court: I think I am not prepared to say at this time that it is immaterial. It may become immaterial, but as I now see it, it does not appear to me that it is not and so I shall overrule the objection on that ground.

Q. 77. Do you know whether Dr. Arnold knew whether you were familiar with them?

A. Yes, sir.

Q. 78. How do you know that?

A. Dr. Arnold in the first place knew that I was a trained physicist and that I had taken my doctor's degree at the University of Chicago and that I was familiar with the work that he had been doing on this mercury arc device and he knew also that at the University of Chicago the thesis work that I did required me to secure reasonably high vacua and that in general I had the knowledge which then existed among physicists at least as to the rudiments of securing high vacua. He also knew that I knew something about producing high vacua in incandescent lamps.

Q. 79. Had you discussed the matter with him theretofore in connection with his work of producing the mercury arc repeater?

A. Do you mean in detail?

Q. 80. I mean from time to time.

A. So far as I know, not. It was a matter purely of detail in connection with his work. So far as I know I would have no occasion to discuss that.

Q. 81. Were there other characteristics of the audion that seemed to make it in its then condition unadaptable to telephone repeater work?

A. Yes.

Q. 82. Will you please tell us about that?

A. I think I have mentioned the fact that as it was exhibited to us it was essentially a flimsy type of construction, no two of these devices that Dr. De Forest left with us were of that degree of uniformity which would be essential in the operation of telephone apparatus, mechanically flimsy, if you will.

The other characteristics which raised some question in our discussion was with regard to the filament which was used. The filament which was used in this device was tantalum wire and we knew from our general knowledge of the incandescent light art that tantalum was a relatively fragile thing, probably of not too long life, and in a thing like a telephone repeater, reasonable length of life and reasonable certainty of operation over a period of time was essential.

If it should fail at any given time, suppose in the middle of a conversation, the conversation was immediately cut off. Also there was the question as to whether this particular filament was the best electron emitter that could be put into that type of device.

As I remember our conversation then we were interested in discussing all of these points with a view to seeing whether it looked feasible to overcome them and produce a satisfactory telephone amplifier out of the thing which DeForest had exhibited to us and which obviously did have amplifying qualities under certain conditions.

Q. 83. Now, then, did the first defect which you have referred to, namely, the inability of the audion to function properly on high energy levels present to you an obstacle which, if not solved, would render the audion utterly unadaptable to telephone repeater work?

A. Yes, sir.

Q. 84. How about the latter two defects?

A. Not nearly so important. The mechanical parts of the thing were quite obviously susceptible of rectification. So far as the filament was concerned, even though it were fragile, it would have been possible to have operated with that type of filament. It would have meant that we would have had to have an unduly large maintenance bill and unduly irritating interruption of the service, but we could have operated.

Q. 85. Now, as I understand it, Dr. Arnold said that the first difficulty could be overcome by producing a high vacuum; is that right?

A. Yes, sir.

Q. 86. And did he and Mr. Colpitts discuss that question further than you have already detailed?

A. I think so far as I was concerned substantially not. I was satisfied at the end of the conversation that the device could be improved; that Arnold knew how to do it, and that the prospects of a successful telephone repeater from an improvement of the DeForest device, by the means that Arnold had in mind, was sufficiently promising to justify us not only in attempting to do that but in securing the rights to do it; and I authorized then and there Mr. Colpitts and Dr. Arnold to go ahead and take whatever steps were necessary so far as the physical laboratory was concerned, to carry out Dr. Arnold's ideas.

Mr. Davis: I object to the conclusions of what Dr. Jewett was satisfied of at the end of that inquiry.

Mr. Haight: I think that is very important.

The Court: I am not sure I get your objection.

Mr. Davis: I understood Dr. Jewett to say that he was satisfied at the end of the interview that the device could be made to be of service, or something of that sort, and I wondered whether his state of mind at that time was evidence, that is all.

Mr. Haight: I think it depends on the disclosure of Dr. Arnold very materially because——

The Court: I am wondering, Mr. Davis, whether his statement under these circumstances is not a fact.

Mr. Davis: I am quite willing, if your Honor please, that he say that he was sufficiently encouraged to go ahead and authorize these other gentlemen to go ahead and work. I do not object to that, but I thought he said he was satisfied the thing would work, and I object to that.

The Court: That discloses his state of mind. Just at the moment I am doubtful as to whether that is not an evidential fact, that is, whether his state of mind under the then existing circumstances is not different from the ordinary conclusion of a witness. I suppose your objection stands. I will not grant the motion to strike out at the moment, but if it appears to me at any time that it should be stricken out, I shall so order.

Mr. Haight: May I just add this, in case your Honor does come back, my thought on it; it shows there was a disclosure of what we claim was Dr. Arnold's invention at that time that was so full and complete as to satisfy a man skilled in the art, and acting on that he authorized the further investigation of the audion.

Mr. Davis: It seems to me, if your Honor please, the facts to which the witness has testified, when we leave out impressions and opinions, are, first, that whatever was there was sufficiently interesting to justify him to authorize Mr. Colpitts to spend money, and he did authorize Mr. Colpitts to spend money.

THE COURT: It is a narrow question, but how far it may be used along the lines suggested by Judge Haight, of course is not for me now to determine. I am inclined to think that the state of mind of this witness at that time under those circumstances has some evidential value. I may be wrong. If so, I will grant the motion.

Q. 87. Now, Doctor, you stated that you authorized Mr. Colpitts and Dr. Arnold to go ahead with whatever was necessary. Was there anything which you knew at that time and which was discussed at that time, necessary to be done in order to find out whether or not this apparatus would fit in a telephone system; that word "fit" is probably an inaccurate way of expressing it, but do I convey my meaning to you?

A. Let us see if I get this correctly. You mean as something outside—pertaining to the plant outside of the element itself?

Q. 88. Yes.

A. Yes, most assuredly.

Q. 89. Now, just tell us what that was, will you?

A. This device is essentially a one-way device. In other words, it amplifies in one direction only. To be useful in a telephone repeater, the amplifying device must amplify equally in both directions, since speech carried on between two people is a two-way affair. Now it had long been known in the art and implied——

Q. 90. Pardon me. Do you mean by that if one spoke in one direction in the audion, that some one on the other end of the line, could not speak in the other direction immediately?

A. No. What I mean is that the device, the arrangement which DeForest exhibited to us, and which I participated in the test of, was an arrangement employing this audion in which you could produce the effect only by talking at one end of the circuit, and listening at the other. You could not reverse the operation; that is, the thing would not work in the reverse direction. Consequently, even if it did amplify, it was of use only in a one-way circuit. The ordinary telephone circuit has a two-way circuit; both people have to have the ability to talk and to listen, and that instantaneously, interchangeably.

Now, in that respect, the DeForest audion was in no wise different from the mechanical repeater which was in itself a one-way device and could operate only in one direction. It had long been known in the art and practice with regard to mechanical repeaters how to make a one-way device produce a two-way effect. It was done and is done by circuit arrangements employing well-known electrical principles, which cause the apparatus to amplify equally in either drection; but in order to apply any given amplifying device, as a two-way telephone repeater between two given lines, to the apparatus by which you interject into the lines, has to be proportioned to correspond to the characteristics of the device, and simultaneously to correspond to the characteristics of the lines in which it has to be connected.

To make use of a thing like an audion, therefore, and devise this connecting apparatus, it was essential that we should know what the normal characteristics, the constants of this audion were, in order properly to design the apparatus, so that there was a big problem quite aside from the question of the unit itself that would have to be investigated and solved before we could hope to make use of the device even though we had a perfect device.

Q. 91. Yes. Did you give any instructions regarding that, any specific instructions, or was that left?

A. So far as I know, none. That was so much a part of the problem that we were investigating. Arnold already had gone through that with regard to his mercury arc repeater, that specific instructions of that kind were not required.

Q. 92. Now, do you know whether subsequent to this time, negotiations were undertaken with Dr. DeForest to secure a license under his patents for the Telephone Company?

A. I do.

Q. 93. And do you of your own knowledge know the difficulties that were encountered in procuring the license other than negotiations for the money to be paid for it?

A. Yes, sir.

Q. 94. Just tell us some of those, will you?

A. I know of a certain amount of the difficulties, because I was called in in connection with some of them; but while I do not know all, I do know that in an attempt to secure rights under this patent, or these patents, I think there were more than one, it became evident, very early, that the title to these did not necessarily rest wholly in DeForest, but was probably involved in some of the preceding business arrangements that had been made; and I know that it took a considerable length of time before the Telephone Company felt, in purchasing these things that had been offered, they were purchasing a thing with a clear title.

Q. 95. A license was eventually secured?

A. Yes, sir.

Q. 96. Do you know about when?

A. In two parts, as I remember it.

Q. 97. When was the first one secured?

A. My recollection is that it was about the middle of the year 1913, some time in July.

Q. 98. Yes. Now, let us go back a moment; did you have anything to do with authorizing the purchase of a Gaede molecular pump?

A. Yes, sir.

Q. 99. Just tell us generally the circumstances connected with that purchase and your connection with it?

A. My connection with it was relatively incidental in that it involved the authorization, my formal authorization of the right to spend the company's money for such a piece of apparatus. As I remember it, some time subsequent to this first of November, shortly subsequent to it, Dr. Arnold or Mr. Colpitts, told me that in connection with the further work on these evacuated devices, it seemed desirable to purchase a recently developed vacuum pump, a pump that had been recently developed in Germany, and they asked my permission to purchase this piece of apparatus, which I gave.

Q. 100. Yes. Do you recall the circumstances of the pump arriving, or don't you; you know nothing about that?

A. No, I know very little of that.

Q. 101. Do you know whether a satisfactory audion was produced by Arnold?

A. Yes, sir.

Q. 102. Was it or was it not?

A. It was satisfactory, yes.

Q. 103. About when?

A. I should say in the spring of 1913.

Q. 104. Yes.

A. I fix that time because of the fact that later in that year or summer, the development involving the audion had gotten along sufficiently far, so that after we had the right to use, we were very shortly in a position to extend our laboratory tests to a field test, involving actual telephone lines.

Q. 105. Did you do so?

A. Yes, sir.

Q. 106. About when?

A. My recollection is it was in the summer of 1913. I do not remember when the installation was actually started, but, along in September or October of that year, the tests were under way in actual lines in the telephone cable from New York toward Washington, with the repeaters installed at Philadelphia.

Q. 107. Now, was this audion subsequently used in the first transcontinental line?

A. You do not mean the particular audion?

Q. 108. No. I mean the audion as developed by Arnold?

A. Yes, sir.

Q. 109. And when was the first transcontinental telephone message transmitted?

A. I cannot give you the exact day, but it was in July, 1914.

Q. 110. And what were used as repeaters?

A. The improved audion, although I will say that at that day the first conversation was over the circuit, the loaded circuit, equipped with audion amplifiers. Subsequently on that same day, and for the purpose of comparative test, we carried on, or attempted to carry on, conversations using both the mercury arc amplifier of Arnold and mechanical repeaters of the Shreeve, the so-called Shreeve type. I use the words "attempted to carry on" advisedly, because of the inferiority of mechanical repeaters in that installation. We actually in installing that line, put in initially three types of repeater at each of the amplifying points.

Q. 111. And what finally evolved as the means which was to be used?

A. The audion amplifier.

Q. 112. And has that been used since that time on?

A. Yes, sir, and so far as I now know, there are no mechanical repeaters in use in connection with commercial telephone lines. The original installation, as

I have indicated, and the transcontinental line, was a loaded line with a loading very specially designed to be used with repeaters, and a limited number of these audion repeaters. With the improvements in circuits, and the improvements in the repeater circuits that have gone on since, the present transcontinental line, in so far as it involves open wires, is not a loaded line. It is a non-loaded line with more amplifying devices than were in the original installation. In other words, taking off the loading coils and reducing the efficiency of the line, that has been compensated for by the putting in of more repeaters or placing them closer together. That could not be done at first and required time, because there is a considerable technique and art involved in using these amplifying devices in multiple.

Q. 113. What use was next made of the audion as developed by Arnold, after the transcontinental line had become a reality?

A. Almost immediately following the initial conversation of July, 1914, and before the line was officially opened for service, which was about the first of the year 1915, our attention was directed into quite a different field through what we learned about these devices in the course of our work. It was directed toward the use of these devices in connection with the generation of high frequency currents to be used in connection with radio telephony, and some preliminary experiments were made in 1914, and in early 1915, successful telephone conversations were carried on between a station which we set up down on the outer end of Long Island and points along the Atlantic Seaboard, so successful in fact that the company authorized the very considerable expenditure needed to extend these experiments in an attempt the reach transoceanic distances, and in 1915, in the spring and summer of 1915, conversation was actually carried on between the transmitting station of the Navy at Arlington and such distant points as the Eiffel Tower in Paris, Panama, Honolulu, and other points, the transmitter being connected by telephone lines, ordinary telephone lines, to transmitters in New York and other places.

Q. 114. Did you keep track, close track of the work that Arnold was doing in the development of the audion repeater after the conversation of November 1st, 1912?

A. Yes. That close track of an executive directing a technical department. I had many duties at that time, particularly connected with other phases of this transcontinental development, which took up a considerable part of my time, but I kept very closely in touch with the general trend of his work, either through direct conversation with him or through my assistant, Mr. Colpitts, who was in responsible charge of the work which Arnold was doing.

Q. 115. Do you know whether Dr. Arnold was given more assistance after November 1st?

A. He was, yes, sir.

Q. 116. And for what purpose?

A. To enable him to proceed with this work which was added to the other work which he was doing in connection with the mercury arc investigation.

Q. 117. And did you attend any demonstrations in the spring of 1913, after the arrival of the Gaede pump of the audion which Arnold had produced?

A. I remember no demonstrations or tests until those which took place involving the use of the devices on actual lines in the summer of 1913.

Q. 118. At that time did you know what the vacuum was?

A. I knew it was a very much higher vacuum than had existed in the original device which was submitted to us.

Q. 119. Now, I do not know whether you have answered this question or not, Doctor; if you have not, I am going to ask you please to answer it. At this conversation on November 1st, did Dr. Arnold state what the erratic action of the audion which you have described, was due to?

A. He did, yes.

Q. 120. And what did he say?

A. Due to gas ionization.

Q. 121. And then am I correct in understanding he said, if you take out the gas, and get the high vacuum, that difficulty would be overcome?

A. Yes, sir.

Q. 122. And then you had the discussion as to whether the apparatus would work, if that were done?

A. Yes, sir.

Q. 123. And he stated that it would?

A. Yes, sir.

Q. 124. Now, what was the procedure in the Western Electric Company at that particular time in reference to applying for patents on inventions made in the laboratories?

A. The general procedure then as now was to apply for patents on all things which the man making the invention or what he thought was an invention, brought to the attention of the Patent Department, or on those things which the Patent Department in connection with their intercourse with the engineers, thought involve patentable novelty.

Q. 125. Whose duty was it to bring these matters to the attention of the Patent Department?

A. In most cases substantially the duty of the individual himself or of his immediate superior, if he with a broader vision thought that the matter had patentable novelty and the man himself might have overlooked it.

Q. 126. Did you bring to the Patent Department of the Western Electric Company any information at that time of what Dr. Arnold had disclosed at the conversation of November first, 1912, in respect to the pure electron discharge?

A. I did not.

Q. 127. Why did not you?

A. At that conversation at that time I was not thinking of inventions or patents. I was interested in the solution, in the question of whether this device could be made to work, and I assumed, if I assumed anything at all, or thought anything at all, that if there was anything in the disclosures that were made that was patentably novel, that in due course would eventuate in a patent application.

Q. 128. Well, the application was subsequently filed on behalf of Arnold?

A. Very much subsequent.

Q. 129. By the Western Electric Company?

A. Yes, sir.

Q. 129a. Do you know the circumstances under which it was filed and why it was filed, confining your answer to your own knowledge?

A. Yes, sir, in a general way. Very considerably subsequent to the incidents of October and November, 1912, we learned indirectly that an application had been filed for Langmuir of the General Electric Company on the so-called high vacuum. We were considerably at a loss to know the basis on which such an application could be filed, and the patent issued. We got some light, as I remember it, on the thing from what we learned from a patent of Langmuir in England, and we came to the conclusion that if this thing which Arnold had suggested to Colpitts and me of November first, was a patentable novelty, the patent belonged to Arnold, and it was agreed that under the circumstances that we should find out, and file an application, and if it was possible, to produce an Interference with the Langmuir application, and that was done. My recollection is that that was two or three years subsequent to the incidents of 1912.

Mr. Haight: Yes, I understand. I think I have reached a point where I am through with Dr. Jewett, but I would just like to check up with some of my associates and see if there is anything that I have neglected.

The Court: All right. We will take a short recess now.

(After a short recess.)

Q. 130. Do you know whether Dr. Arnold had anything to do with the installation of the audion in the first practical test on commercial lines, as I understand you testified to, or anything to do with the development of it, leading up to that during the summer of 1913?

A. I think not. I think that he did not. My recollection is that Dr. Arnold was ill a considerable part, or the latter part of the spring of 1913 and the summer of 1913. The installation, I believe, was actually under the direction of another man, a man by the name of Kendall, and while I think that possibly in the early stages of the thing Arnold may have had something to do with it, I am quite sure when it came to the actual installation and try-out, that Arnold was not involved.

Q. 131. Will you explain the relation between what you spoke of as "energy level and voltage," or if they are same thing, say so?

A. Well, they are directly connected. In the ordinary telephone transmitter, such as are used in the common desk stand, if you speak in a very low tone of voice into the transmitter, agitating the diaphragm, a very small amount, you have superimposed on the direct current, which feeds energy to the transmitter, a very feeble alternating current which follows the voice oscillations. Alternating current has a relatively low voltage. If you talk more loudly, you tend to raise the voltage of this alternating current, and by the same token, you raise the current value of the current, and as the energy is a product of the voltage and the current with proper phase correction on the thing, you have in general increased energy or increased energy level connected in some way with the increased voltage characteristic in our telephone equipment.

Q. 131a. Then when one spoke loudly in this audion, that DeForest brought there, and which you saw demonstrated, the voltage was increased; is that right?

A. The tendency was; yes.

THE COURT: What is the answer? (Answer repeated as recorded.)

THE COURT: Did it increase the voltage as it passed through the gas in the tube?

Q. 132. Will you answer that?

A. Of course it did not increase the voltage of the B-battery which connected the filament to the plate. That was fixed on the outside but it tended to change the amount of the potential drop which occurred between the plate and the filament, that part of that voltage which was dissipated in the tube itself.

By THE COURT:

Q. 133. And thereby changing the potential of the two electrodes?

A. Yes, sir.

Q. 134. That is the different potentials of the two electrodes?

A. Yes, sir.

By MR. HAIGHT:

Q. 135. Did the question of abundant electron emission from the filament come up for discussion on November 1st, 1912?

A. My recollection is that it did.

Q. 136. Was there any discussion on that point in connection with the filament?

A. Yes, sir.

Q. 137. Just tell us what Dr. Arnold said on that subject?

A. I think I have previously referred in a way to that. That question of the amount of electrons producible at the filament was discussed, and the question as to whether the form and type of filament in the DeForest thing was satisfactory; and I remember Arnold pointing out that it had already been discovered by a man by the name of Wehnelt that profuse electron emission was possible from heated filaments which were coated with certain alkaline earth oxides, and there was question as to whether we would not find it advisable to use something other than a pure metal, such as tantalum for the filaments of our tubes, and we subsequently did use the very type of filament he then called to our attention.

Mr. Haight: I think that is all.

Cross-Examination.

By Mr. Davis:

XQ. 138. You have spoken, Dr. Jewett, of some work which Dr. Arnold did on the mercury repeater. That was along the lines of Dr. Hewitt's work, was it not?

A. No. I would not say that, although it involved the use of a mercury arc.

XQ. 139. It involved or was supposed to involve some of Dr. Hewitt's patents, did it not?

A. Yes, that is right.

XQ. 140. Do you remember an agreement of December 16, 1912, between Dr. Hewitt and the A. T. & T.?

A. I remember the agreement but I do not remember the date.

XQ. 141. I have here a transcript of the record in a suit which Dr. Hewitt brought against the American Telephone & Telegraph Company. Do you remember that suit?

A. I do.

XQ. 142. To collect royalties?

A. Yes, sir.

XQ. 143. An exhibit here is an option agreement. You were familiar with this agreement although you do not remember the date of it, is that it?

A. I remember that we had such an agreement under which we were licensed under the Hewitt patents for the use of those inventions in connection with telephone repeaters.

XQ. 144. In this record I find this option agreement on page 14 of the transcript in the Hewitt suit in the Court of Appeals, Second Circuit, and the date is December 16, 1912, for the consideration of the sum of $30,000, Dr. Hewitt agrees in substance that if the American Telephone & Telegraph Company pays him $110,000 additional within one year he will execute certain license agreements. Is that a correct statement of what the trade was?

A. I cannot answer as to that. I do not think I ever knew.

XQ. 145. You do not think you knew what actual amount was paid?

A. No, I do not. My recollection of the thing is that we did secure a license from Hewitt, which involved the annual payment by us of a certain minimum royalty and as I remember it, certain unit royalties based on the number of elements that we might employ which involved the Hewitt patents.

XQ. 146. Attached to this is another exhibit marked Agreement A, which is a certain so-called

United States license dated December 15, 1913, between Peter Cooper Hewitt and the American Telephone & Telegraph Company, which has a very complex, or what seems to me a very complex royalty schedule. Would you mind looking at it?

A. Certainly. I never saw that before.

XQ. 147. You are an officer of the company and you accept this record as showing that you did pay substantially $30,000 for an option to pay $110,000 and then a royalty afterwards if you used the invention?

A. While I am an officer of the American Telephone & Telegraph Company at the present time, I was not an officer of the company at that time and I was not concerned in the details of the financial arrangement with Mr. Hewitt. As far as I know I certainly have no recollection of ever having seen that paper.

Mr. Haight: If the paper is relevant and material for any purpose in this case, we will not object to the printed copy thereof as appears in the record that Mr. Davis has before him.

Mr. Davis: I would like to have the record marked for identification.

Mr. Haight: You do not need to.

XQ. 148. You spoke of three types of repeaters which were installed in the original Transcontinental Line in each repeating station.

A. Yes, sir.

XQ. 149. Those were the mechanical repeater, the mercury arc repeater and the audion?

A. Yes, sir.

XQ. 150. You spoke of conversations being carried on by wireless on the occasion of the test between Paris and Honolulu. Those were one-way conversations?

A. Yes, sir.

XQ. 151. They were one-way conversations?

A. In all cases one-way conversations so far as the radio was concerned. In many of the cases they were combinations of wire and radio as for instance someone talking in New York to Paris or to Honolulu, the conversation went by the ordinary telephone line to the transmitting station at Arlington and then by radio to the distant point.

XQ. 152. Do you remember on Easter Sunday, 1915, there was a demonstration between Montauk and Wilmington?

A. Yes, sir.

XQ. 153. You were present?

A. I was present at Montauk.

XQ. 154. Dr. Millikan was there and Dr. Colpitts and Dr. Van der Bijl?

A. I do not remember Van der Bijl. There were others present besides those you have mentioned. General Carty and a number of telephone officials.

XQ. 155. The reason I ask you, Dr. Jewett, is that Dr. Millikan testified in the Interference between Arnold and Langmuir as to a conversation in which you informed him on that very day, he says, the very day of this talk from Montauk point to Wilmington, you informed him that you had just learned that Dr. Langmuir had been developing tubes like this which his company had had in actual use for more than a year, and that the General Electric Company had approached the Telephone Company with the object of interesting them with this development. I am wondering whether this testimony fixes more clearly in your mind the date of that talk that you refer to in your direct testimony?

A. Do you mean the talk——

XQ. 156. In your direct testimony you spoke of a conversation which you had at which it was decided to file an application for Arnold or something of that sort.

A. I do not think I referred to any conversation, Mr. Davis. I think I testified at a very much more subsequent date to 1912, we heard that the General Electric Company had filed an application for Langmuir for patents on high vacuum. That date was considerably subsequent to the period which you are here talking about. No, I am not sure that it is either.

XQ. 157. That would be more than two years after this November interview.

A. Well, it was.

XQ. 158. And the statement Dr. Millikan made was that you had just learned that Dr. Millikan had, and so forth?

A. I do not remember that conversation with Dr. Millikan; that is, I do not remember what he testified to there and I do not associate the first knowledge that I had of the filing of the Langmuir application with anything connected with Montauk.

XQ. 159. Does this refresh your recollection? I am reading from this Interference record on page 875, the testimony of Dr. Millikan:

> "When Dr. Jewett asked me what I thought about their going into interference with Dr. Langmuir, I told him that I thought it was a public duty"——

he is still speaking of that day.

A. I remember discussing the question of the advisability of our filing applications on this thing with a number of people and I think it was Millikan. Whether I did it on that day or not I have no present recollection.

XQ. 160. You have no recollection inconsistent with Dr. Millikan's?

A. No, no recollection inconsistent. I remember that particular occasion very decidedly because of the circumstances surrounding it, but I do not remember the conversation.

Mr. Davis: That is all.

RE-DIRECT EXAMINATION.

By MR. HAIGHT:

RDQ. 161. Mr. Davis has directed your attention to a license presumably taken by the telephone company and the Western Electric Company, I do not know which, from Peter Cooper Hewitt?

A. Yes, sir.

RDQ. 162. Did you have anything to do with the determination to take that license?

A. I did to the extent that my advice as the technical adviser to the telephone company was sought in connection with the technical side of what we would get from such a license. I had nothing to do with the negotiations.

RDQ. 163. Do you know why the license was taken?

A. Yes, sir.

RDQ. 164. Will you tell us?

A. The license was taken because we were advised on this work of Arnold's, advised by our patent and legal people that this work of Arnold's on the mercury arc repeater was probably underlaid by certain claims of the patents belonging to Hewitt and in order to secure freedom to use this thing which we had developed, this Arnold repeater, it would be necessary for us to secure the rights under these earlier patents.

RDQ. 165. I notice that this license agreement is dated the 16th of December, 1912?

A. Yes, sir.

RDQ. 166. Do you know whether at that time Dr. Arnold had succeeded in developing a satisfactory filament for the audion?

A. I think not at the time of the date that you have mentioned. It is so shortly subsequent to Arnold's association or knowledge of the audion that I think probably not, although I do not recollect certainly. The date that you mention was December of that year?

RDQ. 167. Yes. I referred to an option agreement there. It appears that the license agreement was entered into on the 15th day of December, 1913. Had it by that time been determined whether or not you were going to use or whether or not you would definitely discard the Arnold mercury arc repeater?

A. Yes, sir. That is December, 1913?

RDQ. 168. Yes.

A. Yes, sir.

RDQ. 169. Then why did you take the agreement in 1913?

A. As I remember it, the reason that we exercised the option and completed it, was that Hewitt alleged and later brought suit against us on a similar allegement that these patents of his covered the audion and if I am not mistaken we exercised our option and completed that license as a matter of protection, even though we had no intention of using the device for which the negotiations had originally started. So far as I know we never had but one installation of the mercury arc repeaters. Of course, that installation involved five or seven repeater stations.

RE-CROSS-EXAMINATION.

By Mr. Davis:

RXQ. 170. But six months later on this transcontinental line you did have mercury arc repeaters installed?

A. That is the one I referred to.

RXQ. 171. But that was six months after this contract was signed?

A. You say it was signed December 13th, and I said that the first talk was in July, 1914. Yes, six months. But the installation had been begun long before December, 1913. As I remember it, the original installation of repeaters on the transcontinental line for each type involved five or seven repeater stations scattered across the country so that there was a considerable amount of equipment that had to be built and a very large amount of measurement work and laboratory testing so that I have not the slightest doubt but what the actual work of installation or preparation for installation of all of the repeater stations was begun prior to December, 1913.

RXQ. 172. But for six months after that you continued to do work of installing the thing that you knew was not good and which you knew would not work?

A. We let that work go on and actually tried the thing out. As far as I know the device of the mercury arc was never used except in an experimental way on the Transcontinental Line.

RXQ. 173. What we are interested in, Dr. Jewett, is really I think the reason for the execution of this contract in December, 1913, which seems to involve first the payment to Hewitt of $110,000 and second the admission of the validity of his patents and the obligation to pay royalties. It is your understanding that that was done because you were afraid that these patents would cover?

A. It was alleged that they would cover and actually Hewitt brought suit against the Telephone Company on that allegement.

By The Court:

Q. 174. Would cover what?

A. Would cover the audions. And if he had won, under our license, our liability was limited by the terms of the license. If we had not exercised the option and his contention were correct, we would have been with a certain device in considerable operation with no understanding with the man holding the underlying patents.

By Mr. Davis:

RXQ. 175. You were willing to take the burdens involved in the admission of the validity of the patents in order to protect yourself at any cost against having this Transcontinental Line stopped?

A. I presume so.

Mr. Davis: That is all.

(Witness excused.)

U. S. District Court, Wilmington, Del.,
Wednesday, 20th October, 1926,
at 10 o'clock A. M.

FIFTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Haight: We desire to call Dr. Millikan, and his engagements are such that he must leave for California tomorrow morning. I have asked Mr. Davis how much longer he expects to take with Professor Chaffee, and he is a little bit uncertain, but thinks it will be quite a while, and he has very generously offered to let Professor Millikan go on at this time, and in order to insure his getting away tomorrow morning or tonight, I think we had better put him on at this time, if agreeable to your Honor.

The Court: Very well.

ROBERT A. MILLIKAN.

Robert A. Millikan, was called as a witness on behalf of the defendant, and having been duly sworn, testified as follows:

Direct Examination.

By Mr. Richmond:

Q. 1. Please state your name, age, residence and occupation?

A. Robert A. Millikan; aged fifty-eight; residence, Pasadena, California; occupation, physicist.

Q. 2. Please outline your training and experience as a physicist?

A. I graduated——

Mr. Davis: If your Honor please, we all know that Dr. Millikan is an eminent physicist, and his qualifications are outlined on page 102 of the Interference record. I do not object if they want to go ahead, however.

Mr. Richmond: It will be my preference to have the Court hear him run over those briefly.

The Court: You have established your right to spread the qualifications at large in this record, and I will reverse one of my own rulings so that you may proceed as you desire.

A. I took my A. B. degree from Oberlin College in 1891; Ph.D. from Columbia in 1895; then three semesters in Germany. I was teaching in physics and doing research work in the University of Chicago for twenty-five years thereafter. When the war broke out, I was called to Washington and acted as head of the Science and Research Division in the Signal Corps, and afterward of the Bureau of Aircraft production. I was also connected with the work of the Anti-Submarine Board of the Navy on Detecting Devices. After the war, I went to California as Director of the Norman Bridge Laboratory of Physics of Pasadena.

Q. 3. In 1911, you were awarded the Comstock prize of the National Academy of Sciences. In 1922, the Edison medal of the American Institute of Electrical Engineers. In 1926, the Gold Medal of the Society of Mechanical Engineers. In 1923, the Hughes Medal of the Royal Society. In 1924, the Faraday Medal of the London Chemical Society. In 1925, the Mateucci Medal of the Royal Society of Italy. In 1923, the Nobel Prize of the Swedish Academy of Sciences. This is correct, is it not?

A. I believe that is correct, yes.

Q. 4. You are past president of the American Physical Society and foreign secretary and member of the Council of the National Academy of Sciences, are you not?

A. I am.

Q. 5. On what work was the award of the Nobel prize in physics in 1923 based?

A. There were two counts, one was for the isolation and measurement of the electron and the other one was for photo-electric work in high vacua.

Q. 6. Are you acquainted with Dr. H. D. Arnold, and if so, where did you know him and when?

A. Dr. Arnold came to the University of Chicago as a graduate student in the fall of 1907, and was there for four years with us with an intermission of a few months, I do not remember how long, six months or so, during one of those years, except for this he was with us until 1911, January, 1911.

Q. 7. Please tell about his studies at the University of Chicago and his experimental and research work that were done within your knowledge from 1907 to the first of 1911?

A. Dr. Arnold entered one of my classes on his entrance to the University of Chicago and was with me in course work and also in work which I directed experimentally, research work, practically through the whole of his stay at the University of Chicago and I knew him very intimately then because of this association and because of seeing a lot of him in the laboratory. He was assisting me in some of the work which I was doing.

Q. 8. What was his specialty?

A. He was on electrical problems practically throughout, one sort or another.

Q. 9. Please tell especially about the instruction that he received and the work that he did there in producing high vacua in glass vessels, particularly electric discharge devices.

A. The high vacua problem was one which I went at specifically at about 1900 or 1901. There was none of it done before in the laboratory and it was the field which I cultivated intensively, developing modifications of exhausting pumps in one or two instances and having a very considerable amount of work going myself on it, with a certain number of students working upon it also.

Dr. Arnold came there in 1907, was engaged in assisting in some of these researches, and he was familiar with all that was going on in that field, and there was a lot of it going on because it was one of the things that we were specializing on in the laboratory.

Q. 10. Please tell a little more particularly about the details of procedure that were practiced then and with which he was familiar as you say.

Mr. Davis: My difficulty is this: Of course, there is no prior invention or prior use in this laboratory pleaded. If the purpose is merely to show Dr. Arnold's training, we have no objection. If the purpose is to create a substantive defense by Dr. Millikan's work, we do object.

The Court: It is not your purpose——

Mr. Richmond: My purpose is to show Arnold's training.

Mr. Davis: In that case we make no objection.

A. In our high vacuum work we always used gauges which would read to a millionth of a millimeter or perhaps to be very conservative to one one-hundred thousandth of a millimeter or from one one-hundred thousandth of a millimeter to a millionth of a millimeter, and they were good for exhausting vessels down to that pressure so far as the permanent gases were concerned. The volatile vapors like the mercury which was always there, because we were using largely mercury pumps, were condensed out with liquid air and we also had on practically all our devices charcoal bulbs immersed in liquid air for condensing the condensable gases and for absorbing the residual gases that might come out of the walls at any time.

That is the technique that was universal in our laboratory so far as means of getting the gases removed from the vacuous chamber was concerned.

For getting occluded gases off from the walls; we always used electrical furnaces which we built around our tubes, which were heated up to 400 degrees Centigrade—it was a regular practice to heat all our tubes to 400 degrees C., just beneath the softening point of the glass which we were then using. We took that precaution to get the glass walls denuded as well as we could from occluded gases.

We always denuded our electrodes by high potential discharges from very large induction coils which we had there, which we used regularly. In fact, it was regular technique in any laboratory that was familiar with what was known at that time to pass high potential discharges after they had exhausted down to a high vacuum with the pumps.

In those discharges we purposely heat the electrodes by, it amounts to electron bombardment, but the electrons were not released from thermionic filaments, they are released in the way in which they are released in X-ray tubes generally, gas tubes, so-called, by the ionization of the residual gases that were in the tubes.

As a matter of fact, I got for this purpose, I had two big Sheidel coils which were used all over the laboratory that were 100,000-volt coils which had secondaries with specially large windings on them, for they were made for rapid X-ray work at that time by the Sheidel Company of Chicago. I had two of those big expensive coils carried all over the laboratory for the sake of preparing vacua in the rooms in which we were doing that type of work.

Q. 11. Do you recall any specific piece of work that you could mention that was done by Dr. Arnold employing such processes as you have mentioned?

A. Oh, yes, I probably could recall more than one. In one particular case we were trying to get some spectroscopic work at low temperatures on pure hydrogen and we wanted to get out all traces of other gases. It was the problem on the breadth of the spectral lines at low temperatures and we did not want our spectrum to be modified by impurities, and Arnold definitely assisted in that research in preparing the tubes using all the technique which I have mentioned for baking and for denuding, heating his electrodes up to red-hot heat definitely before letting in, or in the process of getting other gases out before the pure hydrogen was admitted.

Q. 12. Was the practice in your laboratory that you have described something peculiar to your laboratory?

Mr. Davis: Now, if your Honor please, that is where I think we depart from the instruction which Dr. Arnold received.

The Court: I will hear you, Mr. Richmond.

Mr. Richmond: I think it would be legitimate information to bring out how this practice stood in the art at the time.

The Court: As pertinent to what issues here?

Mr. Richmond: To the question of whether Arnold really knew these things and had learned them. There was an abundant literature that was coming along at this time and I do not want to restrict the source of his knowledge to just the operations of that one laboratory, but I would like to have it shown that they were only an example of a widespread practice. It makes his knowledge sure.

Mr. Davis: I think that perhaps Dr. Arnold would know better than Dr. Millikan of just where he got his knowledge other than what he did get from Dr. Millikan.

The Court: I have doubts about it, Mr. Richmond, but not being certain that it should be excluded I will let you put it into the record and overrule the objection, although I do not see that it is directly pertinent to Dr. Arnold's training.

Mr. Richmond: With your permission——

The Court: You may put it into the record. I have some doubt, but you may put it into the record.

(The stenographer repeated the last question.)

A. I should answer that certainly in the negative, because I was—I knew what was going on in the literature—and I was in the laboratories of Berlin and Leipsic in 1912, and they were using exactly the same technique that we were using, except that Lilienfeld had liquid hydrogen and I did not have it; we had liquid air instead of liquid hydrogen, but the methods were just the same.

Mr. Davis: If your Honor please, I move to strike out the reference to practice in foreign laboratories.

(Discussion.)

The Court: Unless you are going to connect the visit to Berlin in 1912 with a prior knowledge of the uses there found, and the practices which there obtained, the motion will have to be granted.

Q. 13. For the sake of clearness, I will ask you to state again how the practice in your laboratory, prior to 1911, compared in these respects with other laboratories?

A. It did not differ materially from that used in any laboratories that were doing work of this kind, and that were familiar with the technique that had then been developed. All the methods which I have indicated; all the procedures which I have indicated, were procedures which I myself got from the literature, and got from the practice of others, and introduced into the practice of the Ryerson Laboratory; the denuding of the electrodes with high potential discharges was not original with me at all. I got these things out of the literature. The baking of the electrodes was also not new to me.

Q. 14. The baking of what?

A. Of the glass walls. This had all been done specifically by Lenard in his researches in 1900. They were old at that time, and not new.

Q. 15. Please state your recollection of the circumstances of Arnold's leaving the Ryerson Laboratory and going with the Western Electric Company?

A. Dr. Jewett, who had been intimately associated with me in the early days in Chicago from 1898 to 1903 and who was an intimate friend of mine, being at the time of which I am going to speak, in the employ of the telephone company, I think as transmission engineer, came to me in the summer of 1910 with the statement that the officials of the company had asked his department if possible to get through to San Francisco by 1914, with long distance telephony. He said it was utterly impossible by the extension of the loaded lines of the type used then between New York and Chicago, because the expense was completely prohibitive of getting long distance telephony that way, and there was not any way to do it except by developing a telephone relay or amplifier, and he said to me that from his point of view, the best bet was in the electronic discharges which we had been working with for ten years in the laboratory, and he asked if I could not turn over to the telephone company a very competent man to put on that particular problem. I told him that fortunately I had a man there who was taking his degree that fall, so that he could go into the employ of the telephone company, if they could make arrangements with him right away, that his name was H. D. Arnold; that I had intimate association with him ever since 1907; that I regarded him as one of the ablest men whose research work I had ever directed, and whom I had in classes, and also I know him intimately as a man of the highest character in every particular, and a man who would be satisfactory for the purpose he had in mind; and suggested that he go and see Arnold and see if he could secure his services, and he did so, and Arnold went to their employ for that purpose, as I supposed, because I gathered that from his conversation in January, 1911.

Q. 16. Are you familiar with the DeForest three-electrode audions as they existed in 1912?

A. I am, yes.

Q. 17. Please describe briefly what the structure is that you are referring to?

A. Well, it is simply a hot filament from which the electronic discharge goes and the plate to which it goes and the grid in between, and variations in potential on the grid modify currents from the filament to the plate past the grid.

Q. 18. And how are those parts supported or enclosed?

A. All enclosed in exhausted tubes.

Q. 19. And by a tube, you mean in this case what might be called a bulb?

A. Glass bulb, yes.

Q. 20. Now, please state whether the methods of procuring high vacua, which you have testified were employed in the Ryerson Physical Laboratory of Chicago when Dr. Arnold was there, and which methods were taught to him, whether those methods were applicable to the exhausting of such audions?

Mr. Davis: If your Honor please, is this witness called as an expert of what could be done? I was told he was a fact witness.

Mr. Richmond: He is an expert witness, too.

Mr. Davis: And the question is as to the witness's judgment as to whether a certain process could have been applied to the audion; is that the question?

Mr. Richmond: Whether the process was adequate.

The Court: Read the question, Mr. Smart.

(Question 20 repeated as recorded.)

Mr. Davis: I do not object.

A. They would be certainly applicable to the exhausting of any tubes that you wanted to get a high vacuum in.

Q. 21. Did these audions present any different problem for evacuation than the other devices that had been customarily evacuated in the Ryerson Laboratory?

A. Not so far as I can see, not the slightest.

Q. 22. Would these methods have been sufficient to exhaust DeForest audions so that they would operate to 100 volts, say?

A. Why, certainly; no question about it at all.

Q. 23. I am going to ask you a question about electron emission from hot electrodes in evacuated vessels? I wish that first you would just explain simply what that phenomenon is and how it is regarded?

A. It is popularly speaking, the boiling of electrons out of a hot filament by high temperatures, which, according to the point of view developed as early as 1901, by Richardson is primarily a Kinetic phenomenon, the electrons boiling out for exactly the same reasons, and in exactly the same way as molecules boil out of a liquid when the temperature is raised sufficiently high, and evaporate from its surface. That was the theory universally held—I say universally, advisedly. There may have been an individual exception, but I do not believe there was among physicists, prior to about 1912, when some questions were raised and very quickly settled and answered negatively, but some questions were raised regarding the current theory as to the way in which the discharges occur from heated wires.

Q. 24. And this theory went by what name, did you say?

A. We called it the Richardson theory, or I called it, I think, the Kinetic theory, or the evaporation theory of getting electrons from hot metal.

Q. 25. What instruction did Dr. Arnold receive from you at the University of Chicago in regard to the theory of electron emission from hot cathodes, and in regard to the effect or necessity of gas in this connection?

A. Very complete instruction, because I used in my course on electron theory always J. J. Thomson's text as a basic reference text, the text on The Conduction of Electricity through Gases, and so far as I know, no other theory is mentioned in it. That is the theory that is there taught. Furthermore, I was continually, in all my lectures, reviewing the present state of the theory; in fact, I always based my lectures, and do to this day, on articles taken from magazines, largely using the Thomson text as a basic reference text for the outside work of the students. Now, Arnold was completely familiar with the current theory of the nature of thermionic discharges and the current theory of thermionic discharges never had anything to do with—assumed the absence of gas or at least the effective functioning of gases—assumed the lack of any effect of gases on the emission of electrons from hot filaments.

Q. 26. You spoke of the date 1912, for some slight questioning of that theory. Can you refer to some authority at about that time on the subject?

A. I do not think I ever heard of any other theory myself, despite my familiarity with the literature, at least the literature written by physicists, until 1912, when I was in Rutherford's laboratory in Manchester, and he said "What do you think of these experiments of Pring and Parker's," which had just come out recently, which were done in the Chemical Laboratory at Manchester, not Rutherford's laboratory, but the Chemical Laboratory that adjoined his, and I said: "This does not mean anything." I took no stock in them at all, and he said: "Well, they ought to be looked into anyhow; they may mean something"; and those Pring and Parker experiments certainly were my first introduction in any conscious way to any doubts about the recognized theory, which was the temperature theory of electronic discharges.

There were other experiments that came at about the same time, some made in Germany, I think at Leipzig, on photo-electric effects which also raised some question as to the validity or the correctness of the accepted theory and the matter was discussed for perhaps two or three years beginning in 1912, and then practically disappeared again because the evidence was so practically conclusive in favor of the old theory.

Mr. Davis: If your Honor please, I move to strike out the statement with respect to conversations held with Rutherford in England.

The Court: The testimony may be taken as rebuttal testimony of the statement which I am informed is contained in the Interference record made by Dr. Langmuir. I do not see that if it can be considered as rebuttal testimony, that the place in which the statement was made to the witness is material or renders the evidence inadmissible. The motion is denied.

By Mr. Richmond:

Q. 27. You had finished your answer?

A. That my memory is not in error and that I was not alone in holding what has been here named the orthodox theory, is sufficiently proved by a little book which was published by H. A. Wilson in 1912, entitled "The Electrical Properties of Flames and of Incandescent Solids." Wilson is an authority in this field. He was one of the men who contributed to it. As a matter of fact, Rutherford was not a man who contributed to it. His field was radio activity.

Wilson said, if I may read, on page 2:

> "O. W. Richardson examined the current from hot platinum in a vacuum and explained its variation with the temperature by supposing that the electrons in the metal to which its conductivity is due, escape at high temperatures. Richardson's theory is now well established as the result of many investigations by himself and others."

And on page 6 again:

> "The variation of the thermionic current from hot platinum in a vacuum with the temperature of the platinum was first investigated by O. W. Richardson who at the same time put forward an elegant theory to account for it, which is now firmly established."

Q. 28. Who was H. A. Wilson; tell us more about him?

A. H. A. Wilson is the professor of physics now at Rice Institute and one of the men who has contributed very substantially to the development of our present electronic knowledge. He was a product of the Cavendish laboratory, J. J. Thomson's laboratory, at Cambridge, of about the period of Rutherford, that is, he took his work there in 1898 and 1900, and actually was the—I think I am right in saying that he was the first to apply the term dynamic equation to this phenomenon of the escape of electrons under the influence of temperature from hot filaments.

So that he has very substantial credentials in that field.

By The Court:

Q. 29. Where is Rice Institute?

A. Houston, Texas.

Mr. Haight: We would like to mark this book that Dr. Millikan referred to for identification.

The Court: Do you want further proof concerning it?

Mr. Haight: I had not considered whether we were going to put it in or not.

The Court: Then just let it be marked for identification.

Mr. Haight: I do not want to fill this record with a lot of things from which there is nothing more to be gained than what has already been quoted, and it seems quite useless.

(Received and marked "Defendant's Exhibit I" for identification.)

By Mr. Richmond:

Q. 30. What instruction did Dr. Arnold receive from you to your knowledge in the University of Chicago, when he was there, in regard to the so-called space charge effect as a factor limiting the current in an evacuated vessel?

A. I have already stated that I used in all my electron courses J. J. Thomson's book on the conduction of electricity through gases as the prime reference text and indeed it was used the world over in such courses, and what is now known as the space charge effect was very completely treated by J. J. Thomson in that book, not under the name of space charge; but the phenomenon of high or rapid change in the potential gradient near the electrodes in partially exhausted tubes was attributed by him to what we would now call the space charge effect, that is, the predominance of one kind of ion over the other, and actually and mathematically treated as completely as it has been treated, more completely than it was treated when the 3/2 power law was developed, because what Thomson did was to take account of initial velocities and it is the neglecting of initial velocities which introduced a simplification in Thomson's theory which leads to the 3/2 power law.

The actual theory is practically all contained in J. J. Thomson's book, published first in 1903, and then in 1906, but without this simplifying assumption, which is an incorrect assumption, but legitimate because these velocities are small, and it was well worth while to find what the equations are with the neglecting of initial velocities.

That matter was all gone over very carefully in my courses. Arnold was completely familiar with it as was evidenced by the fact that he sent me a letter, I think, in the very earliest part of 1913, and in the letter he had developed the 3/2 power law himself quite independently by simply neglecting the initial velocities; Child was earlier, but it was completely unknown to Arnold at the time, because he did not refer to it. He sent me later the fact that he had dug up Child's paper and found that the matter was completely covered by Child.

There is not the slightest uncertainty about Arnold's entire familiarity with the theory that existed up to that time, and that theory covers practically completely from a theoretical point of view space charge effect.

Indeed, what we call the Poisson equation is an equation which gives the changes of potential gradient with a free charge in its path. When there is only one kind of charge there, the free charge is simply the amount of the number of electrons there of the positive or negative sign.

Q. 31. Please describe the so-called three-electrode test for vacuum.

A. The three-electrode test consists simply in passing a negative electron current through the so-called vacuum in sufficient amounts, so that it ionizes by electron impact some residual gases that may be present in the tube, and then pulling these positive ions thus formed to a third electrode and measuring the amount of current carried by these positive ions in comparison with the current carried by the negative electrons.

In view of the enormous range in which we can measure current, it is extraordinarily sensitive in the sense that we could measure a postive current that would be a millionth or a hundred-millionth of a negative current. I can even make it stronger than that.

That means that no matter how good your vacuum is, no matter how good it is so far as the practical matter of getting it, you can always put your negative current up until you can get your positive current up to a measurable value and further than that it is a quantitative test and it is by all odds the most reliable test, the best test that we have unquestionably and the most universally used where anybody wants to go to high vacuum.

Indeed it is pretty nearly the only test that for high vacuum is quantitative. It is not strictly quantitative, although it can be made strictly quantitative. There may be a factor of portionality which may vary from a ratio of one to two and possibly three, but in comparison with the other methods which do not give you anything quantitative at all, they will tell you whether you have got a vacuum, but they will not tell you the character of the vacuum. The third electrode test is incomparably superior to any other that I know.

Q. 32. How does it compare with the 3/2 power law test?

A. The 3/2 power law is not a quantitative test and would not be a quantitative test of the amount of vacuum. It is a sort of a measure of whether you have got a vacuum good enough, lower than a certain limit, but that is all that it is. I do not think it is very good for the simple reason that it is limited to certain shaped tubes, certain geometrical construction of your filaments and plates. But you can produce a tube which has not got a good vacuum which will still follow the 3/2 power law, and you can produce tubes which have the very best vacuum and do not follow the 3/2 power law and not different from tubes that are commercially used, too, so that I do not consider the 3/2 power law as a good test of vacuum at all.

Q. 33. Have you in mind some other important test to be mentioned for comparison in this connection, a test for vacuum?

A. In our laboratories the simplest thing and one very good thing, is to, for example, measure your current at say a thousandth of a millimeter or a ten-thousandth of a millimeter, and then pump 999/1000ths of what is left, reduce your pressure still further, and see if it modifies your current.

If it does not, then you have not got any gas in there that is modifying the current. You have not got a gas that is doing anything appreciable to your electronic current. That is the test that we use everywhere in our laboratories. It is the simplest thing and that is a good test.

Also it is not a quantitative test in the sense that the third electrode test is quantitative, because it only tells you that you have or have not a good vacuum and it is in that respect similar to the 3/2 power law, although very much better than the 3/2 power law.

Q. 34. This test that you have just mentioned in the last answer then is not applicable to a sealed tube, is it?

A. No, because you have to change your pressure and it is not applicable unless you can open your tube and change your pressure. You have to have a measure of pressure of some kind like a McLeod gauge, but in our experimental laboratories we very often work with tubes that are not sealed off. In fact, it is the most usual way of doing it, probably.

Q. 35. Please describe the proper procedure to ascertain the degree of vacuum in a given sealed three-electrode tube.

A. In a sealed three-electrode tube?

Q. 36. Yes.

A. The best way to do that is to build another tube geometrically just like it in which you can make a comparison between your currents obtained and the pressure with some standard gauge. Then when you duplicate your currents you must duplicate your pressures and you are assuming nothing but that duplicating conditions will duplicate results. That is a way that can be employed and is employed where you have complete sealed off tubes for using the third electrode test.

Q. 37. When you build this duplicate tube, tell us a little more in detail what you do with it, how it stands in your system?

A. You have a gauge of some kind, the McLeod gauge is a standard type of gauge, upon the duplicate tube and you measure the positive current that you are getting to your third electrode at different pressures and you calibrate your positive currents against your pressures and then you go to your other tube and measure your positive current, you cannot measure your pressure. And then you duplicate the conditions and in that way duplicate results.

Q. 38. I asked you about the applicability of the methods that Arnold learned at the University of Chicago in respect to the DeForest audions of 1912 and you said that the methods of evacuation that he learned were adequate to evacuate such a tube, so that it could be operated to 100 volts. Let me ask you the same question for 200 volts?

A. We can go much higher than that if you want. We can get just as good vacuum then as we do now. Arnold knew how to get it.

Mr. Richmond: You may cross-examine, Mr. Davis.

The Court: We will take our short recess at this time.

(Here a short recess was taken.)

Mr. Richmond: I have one or two more questions I would like to ask to clear up possible obscurities.

Q. 39. When you spoke of operating the DeForest audion to 100 or 200 volts, as might be done by evacuation by such methods as Arnold had learned at the University of Chicago, what kind of operations at those voltages did you have in mind—what kind of operation did you mean?

A. I meant regular reproducible operation, such as would be demanded in a tube that is going to be practical.

Q. 40. What operation with respect to harmful ionization, we will say?

A. Of course, I meant there would be no positive ions formed that would be harmful to the operation of the tube.

Q. 41. What study of the current literature of the art did Arnold make at the University of Chicago while he was with you?

A. Well, I conducted a seminar course in which the assignments were all from the current literature, and Arnold took that course. Furthermore, as I have already indicated, I usually gave my own lectures by reference to the current literature, and referred all students to the literature from which I cribbed my own lectures, so that he should have been familiar with everything that was going on in the field; that was the field covered by those courses which were courses of the electron field, covering thermionic discharges.

Q. 42. You have told about the bombardment of electrodes or discharges that result in bombardment of electrodes, and of baking bulbs, and so on. Can you comprehend all those methods in some simple statement of object?

A. The object of them all is simply to free the enclosure from traces of residual gases that can be sufficiently appreciable to interfere with operation.

Q. 43. And what physical agent is it that is involved there that accomplishes this freeing?

A. On the walls and the electrodes, in my judgment, it is wholly temperature, it is wholly heat, the denuding is done by the heating, and if I am correct, at any rate, it makes no difference whatever how the heating is brought about, so long as you get the temperature. Denuding is better the higher the temperature.

Mr. Richmond: Your Honor, at Mr. Davis' request, the cross-examination is to be deferred till just after lunch, if agreeable.

The Court: All right.

AFTER RECESS.

Robert A. Millikan, resumed the stand:

CROSS-EXAMINATION.

By Mr. Davis:

XQ. 44. You spoke of using liquid air rather frequently. When did liquid air become available?

A. About 1905, maybe in 1906. At any rate, that is the time at which it began to be used for these purposes, that is about the time of Dewar's work in which he got high vacua by it. I think liquid air became available a little earlier than that.

XQ. 45. But in quantity it was about that time that it became available?

A. For these purposes it became available in 1905.

XQ. 46. You spoke, Dr. Millikan, of some experiments in which you passed current through hydrogen in which Dr. Arnold assisted you?

A. In which the problem was spectroscopic study of very pure hydrogen and in which he assisted in the production of the tubes.

XQ. 47. In getting the spectrum you passed some current through the hydrogen?

A. Yes, that is the way they are excited for spectroscopic purposes.

XQ. 48. What was the order of magnitude of the current?

A. I should have to guess at that, because we do not ordinarily measure those in spectroscopic tubes, but I presume of the order of a hundred milliamperes, something of that sort.

XQ. 49. And what was the order of magnitude of the current which you used in this photo-electric work which you have mentioned?

A. Those would be very small, at least in the early stages of that work, of the order of 10 to the minus 11th or 12th amperes. Later I have used much higher ones. In fact, we are now working with photo-electric currents of the order of 10 milliamperes or even more than that.

XQ. 50. A great change in photo-electric tubes has taken place?

A. There has not been much of a change in the tubes, because these alkali metals were used for photo-electric tubes in the early days. I myself in my work was first working with aluminum and the metals that are not easily volatile and it was in that work that the currents were 10 to the minus 11 or 12. In the photo-electric work with sodium and lithium and potassium, and even in my work they would be higher but still small in comparison with thermionic currents.

XQ. 51. My recollection in the Interference between Arnold and Langmuir is you testified that your experience in this high vacuum had been 10 to the minus 9th amperes?

A. Well, it would run up to that. Of course, you measure all the way down. I could measure up to 10 to the minus 9th in some instances. I might have said so and been correct.

XQ. 52. You spoke of J. J. Thomson's work on space charge. That was an application of the Poisson equation?

A. Yes.

XQ. 53. How old is that Poisson equation?

A. It is about a hundred years old or more.

XQ. 54. I have 1803 here as the date.

A. Yes. That is merely a mathematical equation that gives the relation between the potential gradient and the density of electrification. You do not have that if you have an equal number of positive and negative ions. You only get that when you have a difference in the number of ions. Poisson was not developing that with respect to ions. He did not know anything about ions, but it is simply a mathematical theory relating to a change in potential gradient with space density of electrification.

XQ. 55. You have the same kind of theory in gravitation?

A. Oh, yes, certainly you have the same thing. Indeed the equation may have been developed for application to gravitation.

XQ. 56. So that perhaps the history is this, that Poisson developed an equation by which, a very general equation, by which knowing the distribution of matter and force in space in particles, he could calculate the combined effect at a particular point which you called the potential of that matter or space, and then Thomson applied that to the case where the matter he was dealing with were charges of a single sign. Is that a rough but perhaps accurate expression?

A. Very roughly; I should like to modify it a little. The Poisson equation gives the potential gradient in terms of the space density of electricity, if it is electricity, or the matter, if it is the matter, that is the material particles that you are dealing with.

XQ. 57. And J. J. Thomson applied that to the case where the material producing the strain was electric charges of a given sign, is that it?

A. Yes, that is correct.

XQ. 58. The whole thing is purely a mathematical investigation?

A. The Poisson equation is a mathematical investigation.

XQ. 59. And Child simplified the thing by the assumption that the velocities at which the electrons escaped from the plate could be neglected?

A. Yes. What Child did was to take Thomson's analysis, which must not be confused with Poisson's equation, because Poisson's equation was merely used as a tool in Thomson's analysis and it is used in Child's and everybody else's analysis that has ever worked in that field. He introduced the simplifying assumption that you can neglect the initial velocity with which the electrons are projected into the space that you are considering.

XQ. 60. And got an equation which was based on considering a certain portion of the surface of two infinite parallel plates. That was Child.

A. It was everybody who worked or that has worked out a 3/2 power law.

XQ. 61. Began that way?

A. Began that way, yes.

XQ. 62. To avoid the difficulty of considering the boundary condition on the edges of the plate?

A. Certainly.

XQ. 63. You spoke this morning of a test of vacuum which you thought was very good, as I understood you?

A. Yes.

XQ. 64. Which consisted in still further increasing the vacuum to see if that changed the current?

A. Yes.

XQ. 65. I think you said it might be practically difficult to do it in a particular case, but where it could be done you regarded it as a good test?

A. Reasonably good test and under most conditions one of the very convenient ones in a laboratory where you are not dealing with a sealed-off tube.

XQ. 66. And where you had a sealed-off tube you mentioned duplicating it so as to perform that experiment on the duplicate?

A. I did not mention, I think, duplicating the tube with respect to this test, but with respect to what is called the three-electrode test.

XQ. 67. It could be done in either case, of course?

A. No, I do not know how it could be in the first case.

XQ. 68. You do not think it could be done in the first case?

A. No, because you have not got two things to compare. You are measuring pressure and current.

XQ. 69. It makes a difference what the voltage is?

A. It will make a difference what the voltage is provided you are under saturation of voltage.

XQ. 70. Suppose your voltage is high enough to saturate, will it make a difference what the voltage is?

A. When the vacuum is good enough you may become practically independent of voltage, at least up to large limits, until you begin to drive by your bombardment new gases out of your walls.

XQ. 71. Then the vacuum ceases to be good?

A. Yes.

XQ. 72. So that really when the vacuum is good and space good you are independent of voltages at and above the saturation voltage?

A. As a matter of fact, though, that is not quite a correct statement, because with any tubes you can drive them to a potential at which they break down.

XQ. 73. That is going beyond——

A. And then if you restore your low potential, you do not find that you have got a lot of gas in your tubes. You may have some. That is a point that I fancy is not important here.

XQ. 74. I think not. I was thinking more of working within the normal operation of the tubes. If you are on the portion of the curve which is above the ionization voltage and below saturation and pump a higher vacuum, your test would show either that there was or was not a change in the current?

A. Right.

XQ. 75. Suppose your test showed that as you pumped a higher vacuum there was a change. In what direction would that change be?

A. You wish me to compare a case where you have a high vacuum with one in which you do not have a high vacuum on the curve below saturation?

XQ. 76. Let us assume that you have a tube and you wish to apply this test which you said was a good test and you put a certain voltage through the tube. You think you have a good vacuum and now you pump some more. There either will or will not be a change in the current when you pump. If there is a change, in what direction will the change be?

A. If you are below saturation?

XQ. 77. Yes, sir.

A. In general, it will reduce the current as you increase the vacuum.

XQ. 78. If you are above the saturation under the same circumstances, in what direction will the change be?

A. In general, it also will reduce the current. You can have conditions under which it will go the other way, but in general it will reduce the current.

XQ. 79. If the gas was poisoning the cathode, for example, and you removed some of the gas that would increase the saturation point?

A. Under those circumstances, yes, if you mean by poisoning reducing the current coming from the cathode.

XQ. 80. It was using the term poisoning in the sense of some action of gas, which I profess I do not understand, which reduces the emission from the cathode.

A. It is rather obvious that if you take away that inhibition, you will increase it.

XQ. 81. So that in order to ascertain the meaning of this test or the results of this test which you spoke of, it would be desirable to know whether you were above or below the saturation point when you made it?

A. It might throw some additional light if you know that it will work in generally the same direction, whether you are above or below. Under some circumstances, as I said, and those were the circumstances which you were speaking of, you could have them work in the opposite sense.

XQ. 82. If you wish to use this test, would you prefer to use it above or below the point of saturation?

A. If you want to use it most sensitively you would use it below saturation. I have usually used it above saturation. In the early days it was always used above saturation and you would have to use it above saturation in all of these photo-electric experiments or in small current experiments, because you cannot really work there except in the field of saturation. You are so quickly saturated. So that my familiarity with the test is more where I worked above saturation. As a matter of fact, the test is a little more sensitive or perhaps a good deal more sensitive when you work below saturation if you are working with large current.

XQ. 83. These photo-electric tubes saturated practically at zero voltage?

A. Practically, yes. Very small voltage.

MR. DAVIS: I do not know whether your Honor wants any explanation of that.

THE COURT: I am not familiar with that, and you may explain it now or later if you like.

Mr. Davis: The term saturation?

The Court: There was one—will you please repeat that last question?

(XQ. 83 repeated by the stenographer.)

The Court: I understand that now.

XQ. 84. The reason being that the initial velocities are sufficient in general to send the electrons across the tube without much help from the battery, isn't that it?

A. I would not quite say that. It is because the electrons are not coming out in sufficient density so that their mutual repulsion gives you any appreciable space charge.

XQ. 85. Perhaps that is another way of looking at it.

A. Perhaps the other has to do with it, too.

XQ. 86. Space charge is not a factor which seriously interferes with it?

A. For very small currents, no.

XQ. 87. Such as are used here?

A. In most of my early photo-electric work.

XQ. 88. You spoke of the DeForest audion this morning. You are familiar with that?

A. Yes, I was from about 1912.

XQ. 89. Not back of that?

A. I think I saw the first DeForest audion at the Bureau of Standards in April, 1912. I may possibly be in error as to that date, but I think I saw them there in April, 1912. Certainly I saw the first one at the Bureau of Standards.

XQ. 90. Did you happen to notice the paper which Dr. DeForest wrote, describing the audion five or six years prior to the date you mention?

A. No, I did not. I may have seen it but it did not make any impression upon me and when I saw the first audion, which I am pretty sure was in April, 1912, I was very much interested and I studied it and made a little bit—I examined it carefully. It was at the Bureau of Standards.

XQ. 91. Do you know a man named Hollwecker?

A. I am afraid not.

XQ. 92. Hallwachs?

A. Oh, yes, I did know Hallwachs before he died very well.

XQ. 93. He was a physicist, was he?

A. Yes, he was a physicist.

XQ. 94. Of some standing?

A. Oh, yes, of considerable standing.

XQ. 95. He did good work in this same field of photo-electric work?

A. He did very good early work. He was one of the very first, in fact, the photo-electric effect is called the Hallwachs effect in Germany, and he was one of the very first who detected any effect of light emitting energy.

XQ. 96. This work of yours for which the Nobel prize was given, if I understood you correctly this morning, there were two branches of this work and the first was this very famous experiment of yours in connection with the oil drop and the determination of the mass of the electrons?

A. Yes.

XQ. 97. That was not vacuum work at all?

A. No, that was not vacuum work.

XQ. 98. And the other was photo-electric work?

A. Yes.

XQ. 99. And that was vacuum work?

A. Yes.

XQ. 100. Now, can you give us a list of the more important papers which you published on the photo-electric work?

A. I could not do that off-hand. I think Dr. Langmuir perhaps can assist with a list, but I see you have my little book there which contains probably most of them.

XQ. 101. I do not know whether it contains a list of the papers, Doctor, you probably remember approximately the more important ones, don't you?

A. I could give you those.

XQ. 102. Will you be kind enough just to do that?

A. The earliest photo-electric work was done from about 1902 or 1903 to 1907, and the publication was made, the first publication was made in 1906 or 1907, early in 1906 I think, and that was work in which I had spent a great deal of time in getting high vacua. You see I started into the photo-electric field for the very purpose of working in high vacuum, because there had been no photo-electric work when I started at all, in high vacuum, and I had to develop the whole technique from the start, and actually made one of the first vacuum determinations. Indeed, I was working at that time on the simple temperature effect because everybody supposed that the photo-electric effects varied rapidly with temperature, and one of my first discoveries and extraordinary surprises was to find they did not vary at all with temperature. That was due to the high vacuum work and due to the fact that I did get the gases out as the others did not. That was published simultaneously with similar work quite independent, and it was done in Germany.

XQ. 103. Do you remember where it was published?

A. Where?

XQ. 104. Where, yes?

A. In the *Philosophical Magazine*, I think it was published in abstract very briefly in the *Physical Review* of 1906, and in the *Philosophical Magazine in extenso* in 1907.

XQ. 105. And what was the next important paper that you remember?

A. Well, I published a series of small papers, which I do not remember. As a matter of fact, most of them had errors in them. I am glad to forget them —until 1913, when I began to get rid of the troubles, and get some results that I thought were important, and have since been regarded as somewhat important.

XQ. 106. And where was that published?

A. These were published——

XQ. 107. I do not mean the little ones containing your errors, but the 1913 one?

A. They do not all contain errors, but that was published in the *Physical Review,* beginning with 1914, 1915 and 1916, you will find a series of papers there, culminating in the paper of 1916, which is presumably the one that attracted the Nobel Prize Committee, which put together all the work that I had really been doing for the last ten years, just about ten years.

XQ. 108. Now, if I correctly understood you this morning, Dr. Millikan, there were four things that you said you always did in this work; first, you condensed out the mercury, which otherwise would have been introduced from the mercury pump?

A. Yes.

XQ. 109. I suppose that means that the lead from the tube to the pump passed through some very cold space?

A. Liquid air.

XQ. 110. Passed through a tube which was surrounded by liquid air?

A. Right.

XQ. 110a. And that kept the mercury in the pump from getting into the vessel to be exhausted?

A. Yes.

XQ. 111. And you always used that?

A. When we were working for high vacua, yes.

XQ. 112. And the second point was that you used charcoal and liquid air, which was explained this morning to the Court; that means a side tube, I suppose?

A. That is a second side tube, yes, underneath the bulb, usually.

XQ. 113. And you always used that, when you were working for high vacua?

A. Yes, always.

XQ. 114. And the third point that you mentioned was the use of the electric furnace, heated to 400 degrees C., to bake the bulbs of the glass pipes?

A. Yes.

XQ. 115. You always used that?

A. Where I could. I mean, in some instances you would have apparatus inside that you could not heat up to that temperature, but it was our regular practice where we could do so; if I was working, for example, with sodium inside, I could not heat up to 400 degrees C., because it melts too soon.

XQ. 116. And the fourth point was you clean up the electrodes, sparked the electrodes, I do not know what term you used, at a high potential, from 100,000 volts to a spark plug?

A. Yes.

XQ. 117. And you always did that?

A. In general we denuded our electrodes, too. I won't say always, because that depended on what your object was, but if you were trying to get as free from gas as possible, you employed that technique.

XQ. 118. Now, I understand that this paper in the *Philosophical Magazine*, which you think was published in 1907, was a paper in which you were trying to get high vacuum?

A. Yes.

XQ. 119. You did get a high vacuum?

A. Reasonably high, yes.

XQ. 120. And you used all four of these methods, and described those in the papers?

A. I do not know that. That was 1907. I am not sure of that for that tube, that was the early work of which I told you. The Dewar-bulbs came in about 1905 or 1906, but I was working on this from about 1902 or 1903, so that I did not use the liquid air and charcoal before I had learned of that technique. Obviously that was in 1905 or 1906.

XQ. 121. Did you use the others?

A. I used the others. Yes, I could tell exactly. The heating of the initial photo-electric tube to the high temperature, yes. The throwing of the high potential induction coil upon it, yes, certainly. The liquid air, probably not in the earliest, in fact, I think we got our liquid air plant for these researches. I think we got it about 1906, or that was at the very beginning of that work.

Mr. Davis: If your Honor please, Dr. Millikan, as I understand it, has engagements in the west and wants to leave tonight, and I simply want the privilege of studying these papers, and presenting evidence as to what is in them. I do not know what is in them, and have not read them; and normally if Dr. Millikan were here throughout this trial, as some of these other gentlemen are, we could call him back and question him on these papers later if there was anything in them. I suppose there will be no objection to our producing these papers at any time during the trial.

Mr. Haight: We think Dr. Millikan should be given an opportunity to explain them, if there is anything in there that should need explanation.

(Discussion.)

The Court: I can not pass upon the question in the abstract, Mr. Davis. If you deem it proper to present the papers in your rebuttal, that purport to have been published by Dr. Millikan, then, you may make your offer. I think I cannot make an anticipatory ruling as to their admissibility or not.

XQ. 122. This book which I hand you is a book which you wrote and published, is it, Doctor?

A. Yes, I recognize the outside of it—it is evidently that book.

XQ. 122a. Yes. There is no question about it?

A. Yes, this is my book.

MR. DAVIS: I ask to have the book marked for identification.

THE COURT: It may be identified by the title and publisher and the year of publication.

MR. DAVIS: "The Electron, Its Isolation and Measurement and the Determination and Some of Its Purposes," by "Robert Andrews Millikan, University of Chicago Press, Chicago, Ill." "Second Edition. Second Impression December, 1924."

THE COURT: You will probably find a part that will identify that particular copy.

MR. DAVIS: The last part, "541.2, Book M-62.1, accession 131.963." "Copy"—with a mark, which may be 2, I do not know.

XQ. 123. Is there any statement you care to make, Dr. Millikan?

A. I think that the only point that can be in the mind of counsel is that I stated that we regularly used those four processes. I was speaking of the period during which Dr. Arnold was at Chicago, which was from 1907 to 1911. I, of course, did not use any of those processes before they had been discovered. The liquid air and charcoal process was developed in 1905 or 1906, and in the first paper that you refer to, where I use what I called a high vacuum, it is probable that the liquid air and charcoal had not been used. I would not be quite certain about that, because I do not think I used liquid air and charcoal in it, but it would not make any difference for the purposes which we then had in mind, because the residual mercury would not affect the results we were concerned with at that time, so that the fact that the liquid air and charcoal would not appear in that paper, would not modify in any way the correctness of the statement which I have made. Whether it appears or not, I am not quite certain, but it is quite likely that it does not, that is, for the purposes of the case I should be willing to admit that it does not.

XQ. 124. You spoke of a paper of 1916, which was the one which I think you said attracted the attention of the Nobel Committee?

A. Presumably, yes.

XQ. 125. And you believe it was one of the things that led to the Nobel Prize?

A. Yes.

XQ. 126. In the work described in the paper you used these high vacuum methods, did you?

A. Oh, yes, we used high vacuum methods, but I was working there with the volatile metals, sodium, lithium and potassium and no claim was there made to clean up surfaces. You could not clean up those surfaces. I used the liquid air and charcoal of that vessel, and the Gaede molecular pumps, but there was no preparation of the surface of the lithium and potassium and sodium, and obviously could not be, by those methods for that; but there again, it was not important that there should be for our purposes.

XQ. 127. Why was it not important that you should have a high vacuum in that work?

A. It was not important to have a high vacuum in that work on the sodium, potassium and lithium, except high enough so that our photo effects that we should take from those surfaces should be completely independent of residual gases that were present?

XQ. 128. That the surfaces would stay clean?

A. As a matter of fact, the surfaces did not stay clean. We had in those experiments, gases evolving from the walls where I had the sodium, potassium and lithium that were continually contaminating the clean surfaces. This was an experiment in which I got cleanliness of surface temporarily by shaving in vacuum.

XQ. 129. You had a litle machine shop inside the tube?

A. A little device for continually shaving the surfaces, and as a matter of fact, I could not have got the results which attracted the Nobel Committee, if I had had clean surfaces at all, because the activity, the photo-electric activity of the sodium is very, very much greater when there is some action of gas upon it, than when there is not any action of gas upon it, so that that in particular research in it was not important at all, to denude the gases from the walls, and as a matter of fact, I could not do it in that thing, because of the nature of the metals that were inside.

XQ. 130. At that time you thought you had clean surfaces, though, when you wrote that paper?

A. Never, never claimed it; never thought it; never in the wide world.

XQ. 131. But you knew the vacuum was poor enough to oxidize those surfaces pretty rapidly?

A. I thought I did. I cut that surface and it was absolutely dead electrically, and I waited till it was sensitive because of the gases upon it, it was because of that that I could get the value so accurately that I made it.

XQ. 132. Is this the paper (handing paper)?

A. This is the 1916 paper, I think, the one that is most extensive—yes.

Mr. Davis: This paper, if your Honor please, appears as page 355 of the *Physical Review*, Volume VII, No. 3, Series II, published at Lancaster, Pennsylvania, and Ithaca, New York, 1916. It also belongs to the Wilmington Public Library—no, it belongs to the Delaware College, I am informed, "Accession No. 14,434," and for reasons which may be obvious, it is not offered in evidence.

THE COURT: I think your numbers sufficiently identify it.

XQ. 132a. You say in the paper, do you not, on page 361:

> "In all of this photo-electric work at the Ryerson Laboratory the same general method has been employed, namely, the substances to be studied or manipulated have been placed in the best obtainable vacuum on an electro-magnetically controlled wheel," and so on.

A. Yes.

MR. HAIGHT: I think you had better show the witness the book first. It is so long that there may be something there that you will want to know.

XQ. 133. Is there anything in the rest of the sentence there, Dr. Millikan, which will be helpful——

MR. DAVIS: Where was I reading? (XQ. 132a repeated by the stenographer as recorded.)

XQ. 134. The rest is not important in this connection?

A. No.

XQ. 135. There is a picture on page 362 of this same volume; is that a picture of the apparatus which you used in these experiments?

A. That is, yes.

XQ. 135a. What is the part marked H?

A. That is the device for changing the position of the electrode S, for raising and lowering it.

XQ. 136. There is a tubular opening there, the glass part extending to the inside of the tube which is a cylindrical glass rod with a handle on the end, which can be wound up from the outside, and wound up by this string—is it a string?

A. Yes, that is right.

XQ. 137. What was it, a silk thread?

A. We call it a silk thread.

XQ. 138. Now, there is what seems to be a tube extending from the thing marked "2 pumps." I suppose that is the pump connection of the tube through which the vacuum was made?

A. Yes.

XQ. 139. How long was that tube, if you remember?

A. Oh, several feet long.

XQ. 140. You had some difficulty, had not you, with vibrations, so that you had to carry the pump quite a distance from the apparatus?

A. No. No. The pump was right underneath it.

XQ. 141. There were several feet of tubing?

A. Yes.

XQ. 142. What is this thing marked O on the right?

A. That is a quartz plate through which the light entered the apparatus.

XQ. 143. How was that fastened to the glass?

A. With a high temperature cement.

XQ. 144. In preparing this tube which is shown on page 362, you used, did you, the liquid air trap for condensing out the mercury which came from the pump?

A. There was a liquid air trap on the tube, yes.

XQ. 145. The pump was a Gaede molecular pump, was it not?

A. Gaede molecular during part of those investigations, yes. There was a Gaede molecular pump which was put in parallel with a modified mercury pump, a Toepler pump. The two of them were both on.

XQ. 146. With some arrangement of stopcocks to throw either one or the other on?

A. Yes.

XQ. 147. There is no mention in the paper, is there, of liquid air being used?

Mr. Haight: I object.

A. I do not know whether it is mentioned in the paper or not, but it was used, as a matter of fact.

Mr. Haight: All right.

XQ. 148. I will read one paragraph, page 364:

> "The pressure in the apparatus, which was exhausted by the Gaede Molecular Pump, assisted by the chemical action of the sodium shavings, was carried on to a ten-millionth of a millimeter or less as measured by a McLeod gauge, sensitive enough to permit estimates as low as the value mentioned."

You have been improving your gauges since Dr. Arnold was there?

A. That was a very large bulb, a very special bulb for that purpose.

XQ. 149. And it goes on:

> "Such a gauge gives, of course, no indication as to the amount of mercury vapor present, but there appears to be no reason for thinking that this is not carried out by the molecular pump (which ran continuously throughout the observations unless otherwise stated) nearly as completely as are other gases. I have, however, made no tests upon this point and hence can make no positive assertions."

Have I read that correctly?

A. Yes.

XQ. 150. In using this special McLeod gauge, Doctor, at this pressure which you mention here, it is a ten-millionth of a millimeter, how much of a column would you have on the McLeod gauge, this special gauge?

A. This gauge is a modification of the Toepler pump which I had designed earlier, in which the bulb is about a liter, dependent on which pump I was using, a liter in capacity, and the gas in that liter was pushed over into a very small space. It is not an ordinary McLeod gauge at all. It was pushed over into a very small space, and the amount to which it was compressed could be read on the little bit of capillary chamber to which it was pushed, so that we could tell very minute traces of the permanent gases that were left in the pump.

Now, of course these quotations that have been read, apply to the precautions that were taken for exhausting this particular vessel for the particular purpose for which it was used. This has nothing to do with the technique which was used in our laboratory for the getting of high vacua under other conditions in which we were not dealing with these metals.

Furthermore, when I say in that vessel that I used the precautions, I do not remember the exact wording, for getting the best obtainable vacua at the time, I meant exactly what I said, that is, for removing the gases from the vessel. That does not apply in this case to the denuding of the walls, because the walls could not be denuded and were not denuded as is there indicated. The only reason for the high vacuum in this case was to get rid of any effects on the photocurrent that might be caused by the vacuum and let the readers know that you are not interfered with, with those things. As a matter of fact, I do not know that I indicated in this particular paper the fact that those experiments were made on a modified surface. That will appear in a subsequent paper to that. This whole matter has nothing whatever to do with the problem of what kind of precautions one would take or was taking in our laboratory for the preparation of tubes which did not contain alkaline metals of this sort.

Those figures are merely given to indicate the kind of apparatus with which we were getting our vacuum and the kind of pressures which could be measured if we had foreign gases left in our tubes.

MR. DAVIS: Thank you, Dr. Millikan. I think that is all.

RE-DIRECT EXAMINATION.

By MR. RICHMOND:

RDQ. 151. Referring to the piece of work in which Poisson's equation was used as presented in J. J. Thomson's book, and in your testimony, was the whole thing purely mathematical or was there some practical application?

A. I said that Poisson's equation was purely mathematical and I also said that the application of Poisson's equation to determine temperature gradients or to indicate the nature of the temperature gradient in the discharge tube was not at all mathematical. That is an explanation of the actually observed variation of the potential near the electrodes in a discharge tube where one type of ion predominates over the other and therefore, you have a space charge.

RDQ. 152. I think you said temperature gradient?

A. Potential gradient I should have said.

RDQ. 153. What kind of a cathode was considered in this piece of work?

A. In what piece of work?

RDQ. 154. In the application of Poisson's equation to the discharge in a vacuum tube?

A. Do you mean what shape?

RDQ. 155. I mean was it a thermionic cathode?

A. No, not a thermionic cathode. J. J. Thomson's treatment is for two parallel electrodes, cold electrodes. I do not remember now that he treats the case of one hot electrode. He may. I would not be certain about that now because it is so long since I read this.

RDQ. 156. I will ask you to refresh your recollection by referring to the book.

A. Thomson treats both cases, first case in Chapter 3 and he applies it to the thermionic case quite specifically in the chapter on the ionization of incandescent solids, it is Chapter 8.

RDQ. 157. Did the fact that you were using small currents in your photo-electric work have anything to do with the methods of procuring high vacua which you testified on your direct examination were used in your laboratory when Dr. Arnold was there?

A. Not at all. It is true that I developed my own knowledge of high vacuum technique for the purpose of applying it to the photo-electric problem and I did apply it first to the photo-electric problem, but I do not want it assumed or understood that it was only for photo-electric purposes that we were in our laboratory producing high vacua. I was working during all these years from 1906 on discharges, high potential discharges in the highest vacua that I could obtain in an endeavor to pull electrons out of metals by fields alone, the work that demanded the very best vacuum was with cold electrodes.

I published very little on that, nothing I think, although I was working on it from 1905 to 1906, published very little, nothing, until 1915 or 1916, but I spent several years of work on that field of getting high vacua for those purposes as well as building a large number of tubes for photo-electric purposes. This particular paper of 1916 was one in which the apparatus had been taken down and reput up a number of times with changes in the kinds of pumps that were used and changes of the liquid air traps in some cases. So that it is quite incorrect to assume that because there was no description in the particular paper of a vacuum technique that we were not using a vacuum technique.

RDQ. 158. It may be a little late to get it in, but would you tell us briefly what you mean by photo-electric effects?

A. Photo-electric effect is the discharge of electrons from a metal surface because of the incidence of ether waves of short enough wave length upon that surface, that is, because of the incidence of light in some cases, of X-rays in other cases, upon that surface. It is just like thermionic phenomena except that the agency that releases the electrons from the metal and puts it into the field, so that it can pass between the electrodes, is the effect of light instead of the effect of temperature, of heat.

MR. RICHOND: That is all.

MR. DAVIS: That is all, Doctor.

(Witness excused.)

EDWIN H. COLPITTS.

EDWIN H. COLPITTS, was called as a witness on behalf of the defendant, and having been duly sworn, testified as follows:

DIRECT EXAMINATION.

By MR. HAIGHT:

Q. 1. Mr. Colpitts, where do you reside?

A. I reside at 74 South Munn Avenue, East Orange, New Jersey.

Q. 2. And what is your occupation?

A. Electrical engineer.

Q. 3. What company are you at present connected with?

A. American Telephone & Telegraph Company.

Q. 4. And what is your position with the American Telephone & Telegraph Company?

A. Assistant vice-president.

Q. 5. What were your professional degrees?

A. I was graduated A. B. with honors in science at Mount Alison University, New Brunswick, in 1893. After two years' teaching as principal of a grammar school, I went to Harvard University. In 1895, I entered the senior class, graduating A. B. In 1896, I continued work in the graduate school of Harvard University, and received the degree of A. M. in 1897, and continued in graduate work in physics and mathematics and electrical engineering until February, 1899.

Q. 6. After your graduation, did you become connected with either the American Telephone & Telegraph Company or the Western Electric Company?

A. February 13, 1899, I entered the employ—to speak accurately, of the American Bell Telephone Company in the research laboratory of that company.

Q. 7. Where?

A. In Boston.

Q. 8-9. And how long did you remain?

A. I remained in that organization, or virtually that same organization, until September 1st, 1907.

Q. 10. And where did you go then?

A. At that time the research and development work of the Bell System, particularly the A. T. & T. Company, was reorganized to the end that the laboratory work of the system was unified in one place in New York, in the Engineering Department of the Western Electric Company. On September 1st, 1907, I transferred to the Engineering Department of the Western Electric Company.

Q. 11. And did you still remain in the research branch of that department?

A. The research work was carried on in the Engineering Department of that company, and I was for a number of years, beginning almost immediately after September 1st, 1907, the head or director of what was called the physical laboratory in the Engineering Department.

Q. 12. And how long did you remain in that position?

A. I remained as head of the physical laboratory until about the end of 1910, or the beginning of 1911.

Q. 13. And what position did you assume then?

A. I then became what was known as research engineer. That was coincident with the organization of the group of men to tackle and to undertake certain more fundamental lines of development and research, particularly the problems applicable to the job that immediately confronted us, namely, the transcontinental line.

Q. 14. Now, did you subsequently become the chief engineer of the Western Electric Company?

A. I did not. I became assistant chief engineer.

Q. 15. I should have said assistant chief engineer?

A. I became assistant chief engineer, as I remember it, after my return from France in 1917, the last of December, or early in 1918, but I am not sure of the exact date.

Q. 16. What were you doing in France?

A. I was on the staff of General Edgar Russell, chief Signal Corps A. E. F., in connection with the organization of the department or Division of Research and Inspection. This department or Division of Research and Inspection consisted of a group of scientists and engineers to study and handle technical problems connected with the operations of the A. E. F. General Russell was on the staff of General Pershing.

Q. 17. I suppose particularly to the telegraphic and telephonic problems?

A. Applied to signaling, signaling problems were their most important activity, and of course, in signaling, telegraph and telephone, wire and radio, was the major element.

Q. 18. Yes. Now, when did you become assistant vice-president of the Telephone Company?

A. As I remember it, it was in March of 1924.

Q. 19. And what are your particular duties there?

A. Under Dr. Jewett, I am responsible for the operations or activities of the Department of Development and Research, as it is known. I would explain to you that this Department of Development and Research which includes, very roughly, 250 or 300 engineers, with of course, assistants, clerical and accounting, is a staff organization which does not have any laboratories. Our laboratories—and when I say our laboratories, I mean the laboratories of the Bell System—are the Bell Telephone Laboratories, Inc., as they are now known, located at 463 West Street. This staff organization, the Department of Development and Research, works in very close touch with those laboratories, in the study of the problems relating to the activities of the Bell System.

Q. 20. Now, from 1911 to 1914, were you charged with any particular duty of development or research, or both?

A. I was charged with the definite responsibility for studying and providing the means to accomplish transcontinental telephony in the first place, and in the second place, with the development of apparatus and means for long distance telephony in general.

Q. 21. Were you working under any one at that time?

A. On the organization chart at the beginning of that time I was working under Mr. McQuarrie, Assistant Chief Engineer of the Western Electric Company, and Mr. Scribner, the Chief Engineer. I was also working in very close touch, and you might almost say under the direct direction of Dr. Jewett, Dr. F. P. Jewett, who was at the beginning of that time Transmission Engineer of the A. T. & T. Company.

Q. 22. Now, you recall when the Telephone Company committed itself to the opening of the transcontinental telephone line; I do not ask you to fix the date, but do you recall the circumstance?

A. I of course, or perhaps I should not say of course, but as a fact, I was not involved in the discussion which led Mr. Vail's undertaking to give transcontinental service. I learned very shortly after the discussion of the matter that such a project was to be undertaken.

Q. 23. And after it was undertaken and Dr. Jewett returned from San Francisco with Mr. Vail and General Carty, was any particular duty assigned to you?

A. Towards the end of 1910, the problem, perhaps I stated before, of developing apparatus and assistants and equipment to accomplish this result was assigned definitely to me.

Q. 24. Was the repeater problem one of the propositions with which you were connected?

A. It was.

Q. 25. Will you tell the Court the difficulties that presented themselves to the Telephone Company and the Telephone Company engineers in respect to the matter of repeaters?

A. To state the matter rather concisely, for a rather long period of years the repeater problem had been before the engineers of the Telephone Companies and devices had been made up by various engineers, notably by one of the engineers, Mr. Shreeve. This, sometimes called the Shreeve repeater, consisted merely of a telephone receiver, or an electro-magnet structure closely resembling a telephone receiver as the input element of the repeater. This magnet acted to operate the diaphragm of the transmitter, very similar to the transmitter unit of the ordinary telephone transmitter.

This device had been used to a very slight extent on non-loaded open wire circuits of the Telephone Company. Attempts had been made to use two of these elements on open wire circuits installed at points separated by, for example, distances of several hundred miles, but the results had not been at all satisfactory, the reason being that this repeater was of such a type or at least actually possessed such characteristics that while it was possible under favorable conditions to secure fairly good repetition with one instrument in the line, say at Pittsburgh, in a circuit from New York to Chicago, it was not possible to introduce another instrument in the line say at Chicago on a circuit from New York to Omaha or Denver. One reason for it not being possible to do so was that a single instrument distorted the quality, made the speech less intelligible. If you introduce two, the words, syllables and the fundamental sounds of speech were so distorted that while the volume was increased, it was not possible to understand—speech was not clear.

Also I might add that the fundamental theory and practice of operating repeaters in series, one at one point and another at another point on a line, had not been worked out so as to secure freedom from singing or howling or the production of continuous oscillations, whichever way you wish to define it.

Q. 26. So that one of the big problems that confronted you in carrying out this transcontinental line was the development of an adequate repeater?

A. Yes.

Q. 27. Had the Telephone Company or the engineers of the Telephone Company and the Western

Electric Company any thoughts along the lines of what kind of a repeater would eventually have to be developed in order to carry out this project?

A. Broadly speaking, of course, the fact was that a repeater element or repeater device would have to be developed, which would not only amplify efficiently under the conditions of telephone service, efficiently from a power point of view, energy point of view, but would also operate without the introduction of distortion or impairment of the speech quality.

Coming to details or more specifically the thought was that we would be more likely to find such a distortionless amplifier, or, as it has sometimes been called, an inertialess amplifier or repeater in the use of some form of vacuum tube apparatus.

Q. 28. Now, did you continue to carry on the development of the mechanical repeater?

A. We most certainly did.

Q. 29. And why?

A. One reason was that we desired to have more than what is sometimes called colloquially one string to our bow, and another reason was that while 90 per cent. of the seriousness of my problem was immediately tied up with the Transcontinental Line, the other 10 per cent. of the seriousness of my problem related to long distance telephone service in general and it was not at all clear to me at that time but what if a vacuum tube repeater of some form could be developed commercially, and could be a very beautiful piece of apparatus from a commercial and engineering standpoint for such service in a transcontinental line, it might not be applicable commercially to circuits, for instance, between New York and Washington.

Q. 30. Now, do you recall the coming of Dr. Arnold to the Western Electric Company?

A. I most certainly do.

Q. 31. And can you fix the date in your mind?

A. Either the very end of 1910 or I think it was the very beginning of 1911.

Q. 32. Was he put under you?

A. Yes.

Q. 33. Assigned to work under you?

A. He was assigned to work under my general direction.

Q. 34. What particular work was he assigned to perform?

A. After a very short period of introduction, becoming acquainted with the personnel and our problems, he was assigned—the word assigned seems rather arbitrary, as a man of Dr. Arnold's standing, who is undertaking work, would do so more or less after agreement and discussion on all of our parts, those of us who thought the problem he was going on would be promising—he was assigned, using the word in that sense, to the study of vacuum tube devices or phenomena which it was hoped would lead to the production of a telephone repeater.

Q. 35. What particular line did he pursue?

A. The particular line that he pursued related to mercury discharge devices.

Q. 36. Without attempting to describe the mercury arc devices in any detail, was that a device which employed or used a vacuum tube?

A. The mercury arc device employed a glass tube which was evacuated.

Q. 37. Were you familiar with the work that he was doing on this mercury arc repeater during 1911 and 1912?

A. I saw Dr. Arnold probably every day excepting for short periods when he or I might be absent from New York or when I might have been tied up in a conference at the A. T. & T. Company or something like that. In general terms, to give the Court an idea, I probably saw him on the average five days out of six, and we continually discussed the problem on which he was working.

Q. 38. Do you know whether in the development of this mercury arc repeater he was endeavoring to get clear of gas in the tube other than that represented by the mercury vapor?

A. I know that he endeavored to free the tube from gases other than the vapor of mercury.

Q. 39. Did you see any of the apparatus that he used in connection with the evacuation of the mercury arc devices before November 1, 1912?

A. Yes, indeed, because the laboratory in which Dr. Arnold worked and the glass-blowing room, and the room in which Dr. Arnold had his pumps set up was very close to my office and I would drop in as a matter of interest, perhaps much more than a matter of directing or attempting to order Dr. Arnold as to what he was to do, or to guide him, I dropped in there as a matter of interest in the room and the boss dropping in the room, the men would be interested in showing how things were going on and how they looked and I remember very clearly the general picture of things that were being employed.

Q. 40. Just let me digress for a moment. I take it that in view of the fact that Dr. Arnold had been brought to the Telephone Company or the Western Electric Company especially for the purpose of developing a repeater, that his work was not directed by you, because he was considered more of an expert on that than you?

A. I would not attempt to direct him in the specific sense to do this or that. I did, however, direct him in the sense of advising that it would be foolish for him to devise a vacuum tube device or a mercury arc device or any other device which involved the use in the telephone plant of 10,000 volts to certain parts. I very definitely told him that 120 volts is a very comfortable voltage to be employed in the telephone plant. Of course, if your device can be operated from the source of electrical power, which is available, it is so much the easier.

Q. 41. Why did you speak about using the lower voltages?

A. I used that as an example of specific directions that might be given him.

Q. 42. If you did give any such specific directions, why did you give those?

A. I do not remember now. That direction was given in the natural course of outlining the conditions.

Q. 43. You are simply using that as an illustration of the kind of directions that you gave him?

A. Right.

Q. 44. Because of your familiarity with the telephone art and so forth, is that it?

A. Right.

Q. 45. Do you know whether during the time that Dr. Arnold was working on this mercury device during the year 1911 and the first part of 1912, he baked his tubes?

A. I most certainly do know that.

Q. 46. Did he?

A. He certainly did.

Q. 47. How did he bake them?

A. He had set up in the room in which he would exhaust his tubes an asbestos chamber, cylindrical, 12 or 15 inches high and perhaps 3½ or 4 inches in diameter. This cylinder wall was made up of a sheet of asbestos bent around, and as I remember it a couple of iron wires were wrapped around this cylinder, one towards the lower end and one at the upper end to hold the cylindrical surface in place and the bottom of this cylinder was open except for a gauze, wire gauze on which the cylinder rested.

The top was pretty well closed up, excepting for small holes or openings where the leads could be brought out, the leads to the device could be brought out, and the lead-in tube, the glass tube, to the device which led to the pump.

To complete the set-up underneath this wire gauze, Dr. Arnold had a gas flame, Bunsen burner close up, the flame in contact with the wire gauze to heat the interior of this asbestos enclosed chamber. The wire gauze was I should say 12 to 16-mesh to the inch, rather fine gauze.

Q. 48. What was the purpose of the baking of these tubes, if you know?

A. The purpose of the baking of the tubes was to accomplish the freeing of the interior of the walls of the tube from gas.

Q. 49. Is that what has been spoken of here in this case as occluded gas?

A. Yes, as I understand it, that is correct.

Q. 50. At the same time that this baking process was carried on, I do not mean at the same moment, but during the same period of time, was any other procedure practiced by Dr. Arnold for removing the objectionable gases from the tube or tubes?

A. If by the tube you mean the parts inside the tube more particularly——

Q. 51. Yes, I had reference to the electrodes.

A. I remember very distinctly the arrangement that Dr. Arnold employed for what I believe is commonly called bombardment. At least, it was so referred to by us at that time. I remember this rather distinctly, your Honor, because of a circumstance. I went out into the laboratory one day in 1911 and found Dr. Arnold with a great lot of dry cells, something like, enough to give three or four hundred volts, arranged rather promiscuously on wooden shelves, and they were not protected so that employees could not come in contact with these dry cells and terminals, and so I told Dr. Arnold that he was carrying into our laboratories the practices of physical laboratories in colleges and universities and that we could not do that and I insisted on a very ship-shape set of iron shelves with wire lattice in front of them and the terminals brought out to properly fused switches and so on, and we had that set up in spite of the fact that Dr. Arnold had insisted that a college laboratory had never burned down and nobody had ever been killed in them.

I saw Dr. Arnold and his assistant employ this battery to heat the electrodes in his tube. In his tube he had two iron electrodes, located one on each side of the, as you might speak of it, of the arc stream, and I saw him use this with proper connection to bombard these electrodes and get them very hot and sometimes burn them up.

I might add perhaps more pertinently to my last question, but right here, that in this asbestos cylindrical chamber there was a mica window on the side of it, so that if you wished to see what was happening inside of this asbestos chamber other than by trying to look up through the wire gauze at the bottom, or down through these little holes around the lead-in wires at the top, you could look in through this mica window and see how hot the tube was or how hot the electrodes were in the sense of determining the heat of anything by visual inspection.

Q. 52. Do you know to what extent he baked the tubes?

A. The tubes were heated—of course this term is just a general term—to red heat.

Q. 53. You are speaking now of the electrodes?

A. No, I am speaking of the tube itself.

Q. 54. The walls of the tube?

A. The walls of the tube. This is what you would observe from the baking.

Q. 55. Did you see the condition of the electrodes while they were being bombarded?

A. Many times and after they had been bombarded.

Q. 56. How did they look, to what condition of heat had they been heated, to what temperature?

A. At different times when I went in there, sometimes they were rather dull red heat, if that is what was being done, and sometimes very hot, so hot that they were destroyed, that is, the facilities were sufficient under these conditions to destroy the electrodes completely.

Q. 57. Did these tubes that Dr. Arnold was working on contain more than one set of electrodes?

A. They contained actually five electrodes, if you include the starting electrode which was in a side tube.

Q. 58. And the electrodes were heated or bombarded, I should say.

A. What I have been referring to more particularly in my answer were these two side electrodes which in a great many of the tubes were of iron, but in the manufacture of mercury arc tubes where there is——

Q. 59. I am going to show you a drawing attached to the patent issued to Dr. Arnold on November 24, 1914, and known as No. 1,118,172, and ask you if you will point out to the Court by reference to numbers the electrodes that you refer to.

A. The two electrodes that I have referred to are also referred to in the patent as auxiliary cathodes 7 and 8.

Q. 60. How about the other electrodes?

A. The electrode 5 which is referred to as anode 5 of carbon or other suitable material was also bombarded in the course of manufacture of the tube, that bombardment being accomplished by pushing up or increasing the current between the mercury cathode 6 and the anode 5, some time during the process of manufacture.

Q. 61. Will you point out to the Court the other two electrodes that you spoke of?

A. When I spoke of the tube as possessing five electrodes, this patent device actually contains six, as I see.

Q. 62-63. Where are the others?

A. The two mercury electrodes 6 and 4, 4 being merely used in connection with starting and the other being an electrode, I think it is 9, it is referred to as auxiliary anode in line 88. So that in that partic[illegible] form there are six electrodes.

Mr. Haight: We are not clear whether this patent is in the record that was in the Patent Office or not; but in order that we may make certain, I am going to ask that that drawing be marked for identification, and if later we find that it is in the record, we will not—Mr. Davis says it was not—so that I think that in order to make the testimony intelligible, I will have to offer this patent, and that is the purpose of it at this time. It may serve some other purpose later.

(Received in evidence and marked "Defendant's Exhibit No. 43." *See Volume V, Defendant's Exhibits, page 610.*)

The Court: You are offering this, as I understand, for no purpose other than the drawing, to illustrate the devices that were worked on at this time by Dr. Arnold?

Mr. Haight: Yes, at this time.

The Court: Yes.

Mr. Howson: I should call attention to the fact that the witness did refer to the descriptive part.

Mr. Haight: Yes.

Q. 64. Now, to what extent had the work on the development of the mercury arc repeater gone, by the 30th of October, 1912?

A. By the 30th of October, 1912, Dr. Arnold had developed a device which in suitable repeater circuits, as they are termed in the telephone art, and properly located on suitable lines, would operate reasonably satisfactorily.

Q. 65. Now, do you recall the visit of Dr. DeForest to the engineers of the Western Electric Company?

A. I certainly do.

Q. 66. Can you at this time fix the date when you first saw him?

A. I assume that by your question you mean the date that I first saw Dr. DeForest in connection with his visit to the Western Electric?

Q. 67-68. That is what I mean, yes.

A. I can fix the date by reference to records.

Q. 69. What date was it that he first came, so far as your personal knowledge goes, to the offices or laboratories of the Western Electric Company?

A. I met Dr. DeForest in Dr. Jewett's or Mr. Scribner's office—they were adjacent offices—on the twelfth floor, and I think it was Dr. Jewett's offices, on October 30, 1912, the morning of October, 30, 1912.

Q. 70. Was he introduced to you by Dr. Jewett?

A. He was introduced to me by Dr. Jewett.

Q. 71. And were any arrangements made at that time for a demonstration to you of his audion?

A. The arrangements had been made previously for his coming to the Western Electric Company. On that morning, it was merely in effect a statement: "Mr. Colpitts, here is Dr. DeForest, who has come up here to disclose to us his idea of an amplifying device."

Q. 72. And did he have his device with him?

A. He had his device with him.

Q. 73. Were any arrangements made for a demonstration of the device to you?

A. I said to him in effect: "Well, now, if you are ready, Dr. DeForest, we will go downstairs to my office and we will have this demonstration or test of your apparatus;" and I had been told the day previously that Dr. DeForest was coming and had——

Q. 74. Without going into detail, was the apparatus set up in your office?

A. The apparatus was set up in my office that morning.

Q. 75. Was the demonstration that day or the following day?

A. Certain preliminary test demonstration was made that morning. Dr. DeForest then excused himself, because he had, as he stated, an engagement.

Q. 76. Was there a full demonstration the following day?

A. There was a full demonstration the following day.

Q. 77. And will you just describe the apparatus that he had there at that time?

A. Dr. DeForest's apparatus consisted of a three-element audion, two of them, as a matter of fact, mounted in a simple manner on a box which could be opened up, so that you could see the bulbs, and so on, and input coils, output coils, and a battery in a separate box, a B-battery, or plate battery in a separate box. We provided him with certain other apparatus.

Q. 78. Now then, who was present on the occasion when the simple tests that you have spoken of were made, on October 30th?

A. On October 30th, Mr. W. L. Richards and myself were present with Dr. DeForest.

Q. 79. And on October 31st?

A. During the early part of the day, the principal part of the tests, Mr. Richards and I were the only ones present.

Q. 80. Was Dr. Jewett present at all on the 31st?

A. Dr. Jewett came down to my office, it being understood that on account of the simplicity of the apparatus and tests not requiring laboratory facilities—this was set up in my office—Dr. Jewett came down more as a matter of courtesy, very shortly before DeForest left, and at that time certain simple tests were made.

Q. 81. Now, tell us the test, or what the demonstration revealed when they were made to you and Mr. Richards on October 31st.

A. The tests revealed this: That as far as could be determined by listening over a device which included only one amplifier in series, that with low input volumes——

THE COURT: With what?

A. (Continuing) —low input volumes of speech, the device operated, I might almost say, beautifully; it operated very, very well.

Q. 82. What did it do?

A. It amplified the weak speech currents, and it amplified them as far as you could tell, with just making qualitative tests, it amplified them accurately. There was no tendency to impairment of the quality or intelligibility of the speech.

Q. 83. Now, go ahead.

A. When, however—and Dr. DeForest was entirely frank and brought this out himself—when, however, the speech was loud, the volume of the speech current was increased, the quality was impaired. The speech was not reproduced accurately, and it also, as you could tell from this qualitative test and roughly quantitative test, it was not amplified to anything like the extent that weak speech currents were amplified.

Q. 84. Now then, did you notice any visible manifestation or change taking place in the tube when the speech currents were increased?

A. Well, sometimes that happened, yes, at times.

Q. 85. And what was it?

A. At times a condition occurred in the tube which visually made itself manifest by blue haze.

Q. 86. Did you know what blue haze indicated?

A. Oh, of course. I knew it indicated ionization, the condition of the gaseous vapor in the tube.

Q. 87. Now, did you conduct any test at that time in the matter of increasing the voltage on the plate?

A. Dr. DeForest demonstrated that the effect of increasing the voltage on the plate beyond a certain point, was to introduce a permanent condition manifesting itself as blue haze.

Q. 88. You mean he demonstrated that. Did he show it or what?

A. He showed it.

Q. 89. Or stated it?

A. He showed it and stated it. Dr. DeForest, I want you to understand, was very frank in saying that these things occurred.

Q. 90. Now, was anything said by him as to the life of the filaments, which he was using?

A. I asked Dr. DeForest as to the life of the filaments which he told me were tantalum, and which made me suspicious on this point of life, and he told me that the tubes gave—some of the good ones, went up to 100 hours, and I got the impression that fifty-hour life was perhaps normal.

Q. 91. Now, did you make any arrangements, or did you make arrangements to have the apparatus left with you for further experimentation?

A. The understanding at the time that Dr. DeForest came, was that he was to leave the apparatus.

Q. 92. Was that done?

A. And it was done.

Q. 92a. Now, what happened on the following day in reference to a further examination of the apparatus?

A. By the following day, I assume you mean November 1st?

Q. 93. November 1, 1912.

A. On November 1st, I had Dr. Arnold come in to my office where the apparatus had been left over night, and we sat down, and I told Dr. Arnold in general terms, what I had observed regarding the apparatus, and what Dr. DeForest had told me, and Dr. Arnold and I then repeated certain of the tests, which Dr. DeForest, Mr. Richards and I performed the day previously.

Q. 94. Now, let me digress just a moment. Why did you call in Dr. Arnold?

A. I called him in because he was the one man pre-eminent in our organization who knew about such types of devices in a general way, and could appreciate the device, and he was the man that we would assign the further study of the work to.

Q. 95. Well now, you conducted some tests, did you, or did you and Dr. Arnold conduct some tests, put it that way?

A. We did.

Q. 96. And just tell the Court, please, what the tests were, in a general way, that you conducted?

A. The tests were virtually a repetition of the tests that had been made when Dr. DeForest was there, talking in a weak tone of voice; talking in a loud tone of voice, and observing the results, and increasing the B-battery, that is the potential between the plate and the cathode to a point where something occurred in the tube which was manifested by blue haze.

Q. 97. Now, when you did increase the voltage in the B-battery, the blue haze was manifested; that is to say, when you increased it to a certain point?

A. It certainly was.

Q. 98. And the same condition happened when one spoke in loud tones?

A. If the B-battery was put up and increased to a certain point, and then at that point you spoke very loudly, then you would introduce blue haze, or a condition manifested by blue haze, either intermittently or continuously, and bring it about, so that it lasted.

Q. 99. Now, what happened to the amplifying qualities of the audion, when one spoke loudly in the apparatus, or when the voltage was increased, as you have spoken of?

A. Well, I will have to separate my answer into two parts. When the B-battery was low enough so that there was no interference from the conditions that rather made themselves manifest as blue haze, and one spoke loudly into the amplifier, the result was simply that there was very little, if any, amplification of the transmitted speech, and it was distorted. If, however, the device was used, or attempted to be used as an amplifier, when blue haze was present, superimposed on any distorted repeated current that came through the device, was a lot of noise.

Q. 100. When, however, you spoke in low tones, and there was no increase in the battery voltage, did it amplify on November first, as it had in the previous tests?

A. Most certainly.

Q. 101. Now, was Dr. Jewett present during the tests of November first?

A. Dr. Jewett was not present during the first tests that Dr. Arnold and I made; but after we had made certain tests and talked the whole matter over, I called Dr. Jewett on the telephone and said that Dr. Arnold and I were together down in my office and would he not like to come down and discuss this matter with us.

Q. 102. And did he come down?

A. He did.

Q. 103. And did you conduct tests in his presence?

A. We repeated tests with Dr. Jewett, we demonstrated to him both the virtues of the device and also its serious limitations.

Q. 104. Now, did the fact that this device would not amplify, and would distort voices, and manifest the other defects which you have spoken of when the voltage was increased, or one spoke in loud tones, affect its usefulness as a telephone repeater?

A. Most certainly.

Q. 105. Just state briefly why, will you? I think it is quite manifest, but we might as well have the record clear.

A. Under the conditions on which the device operated well, the input energy was so small. It was much smaller than the input energy involved under the conditions of actual telephone service. Therefore, to make it a device which would be useful in the telephone art, its energy-handling capacity would have to be increased manifold.

Q. 106. Now, did Dr. Arnold state to you and Dr. Jewett, whether or not these conditions which you have described—these conditions and defects which you have described—could be cured?

A. He most certainly did.

Q. 107. And just tell us, please, in your own way, exactly what he said?

A. Dr. Arnold said that the condition which manifested itself by blue haze, was due to ionization of the gas present in the device; gaseous vapor present in the device, and that the only thing that was necessary to do would be to secure a better vacuum, that is, a higher vacuum.

Q. 108. Now, did he make any statement at that time that you recall as to how a higher vacuum could be procured or secured?

A. I can not recall that it was at that particular time that Dr. Arnold made the statement or whether it was within a few days afterwards, but either at that time or very shortly afterwards, Dr. Arnold said that a sufficiently high vacuum could be procured by the methods well known to the art.

Q. 109. Did he tell you what they were?

A. He mentioned several things.

Q. 110. For instance?

A. He mentioned the use of charcoal tubes with liquid air. He also mentioned the fact that his present apparatus supplemented by charcoal and liquid air, could be used to secure a fairly satisfactory degree of vacuum.

Q. 111. That apparatus as I understand it, was designed, however, to leave some mercury vapor in the tube?

A. His apparatus?

Q. 112. Yes.

A. Of course, it operated by virtue of the mercury vapor which was present in the tube.

Q. 113. And was it his purpose to remove from the DeForest audion—did he state whether he was going to remove from the DeForest audion all vapors?

A. His statement was that it would be desirable, or his aim was to remove all gases and vapors from the DeForest audion.

Mr. Davis: If your Honor please, I think the statement should be as to the conversation and not as to the unexpressed aim.

Mr. Haight: He said "his statement."

The Court: The witness changed it, as I understand it, he changed it. Am I right? Read it, Mr. Smart. (Answer repeated as recorded.)

Q. 114. Which was it, Mr. Colpitts, a statement or an aim that you just gathered from his statements?

A. His statement was that it was his aim to remove all gases.

Q. 115. After Dr. Arnold made that statement that you have referred to, namely, that the defects could be cured by increasing the vacuum, was there a discussion between you and Dr. Arnold and Dr. Jewett, regarding the cure which he had suggested; I mean, did you discuss the matter?

A. We discussed in general terms, yes.

Q. 115a. Do you recall any particular question that you asked Dr. Arnold in regard to the effect on the emission feature of the tube, if the gas were removed?

A. I do. I asked Dr. Arnold this question. I said: "You say you want to get all of the gas out of this tube; if you do that, will not the electron emission fall down to very small values so that you will defeat the purpose that you have in mind, namely, to secure a device which has in the discharge between cathode and anode, a considerable energy?"

Q. 116. Well, now, what did he reply to that?

A. Dr. Arnold said to me that he believed that the emission of electrons from a filament was due to the action of heat, a boiling out process; a vaporizing process, as he described it at the time, of the electrons contained in the filament or cathode; that this kinetic theory was the correct theory. He then went on to say that he was aware that certain others, notably chemists, held to a chemical theory; that according to this chemical theory, it was necessary that there should be a small, perhaps a very small amount of gas present, not so much in the tube as on the surface or in intimate contact with the cathode in order that the electrons would be emitted.

Q. 117. Did he say anything as to whether or not he subscribed to that theory?

A. He certainly said that he did not subscribe to that theory, and I thought at the time, he was a little bit contemptuous, in referring to it as the theory held by chemists.

Q. 118. What induced you to ask the question?

A. Well, I always like to find fault with suggestions and I had that reason, that I wanted to be sure that Dr. Arnold was right, that when he proposed to take all the gas out, that the tube would work, and I also had another thing in mind, and that was in connection with the other devices, which we were interested in.

Q. 119. Well, had you attended any lecture or heard any discussion of these two theories?

A. No, I had not attended any lecture in which there was so much discussion of the two theories, I have, however, to modify the last sentence. I attended a meeting of the American Institute of Electrical Engineers, any way it was a meeting in Boston in June of that year in which Dr. Whitney had referred to this matter and as I interpreted it had inclined to the belief in his statement that small amounts of gas were necessary to emission. I interpreted his statement that way.

Q. 120. When you speak of Dr. Whitney you mean Dr. Whitney——

A. Dr. W. R. Whitney.

Q. 121. The head of the Research Laboratories of the General Electric Company?

A. Yes.

Q. 122. Did you have any discussion with Dr. Arnold at that time in reference to what has been spoken of in this case as the space charge effect?

A. I cannot be sure that it was that day. If not that day it was very soon thereafter. And I asked Dr. Arnold rather a foolish question, at least the answer when he gave it to me was so obvious that it seemed to me a foolish question, and that was whether if the gas was——

Q. 123. Before you go to the question, does the fact that it was a foolish question now tend to fix it in your memory?

A. Yes, it does. I asked Dr. Arnold whether if the gas was all removed from the tube the electrons would not be swept across from the filament to the plate with a very low voltage. I had in mind at that time having not very expertly reread the literature, certain statements which were true in respect to some devices, the statement that electrons were swept across from the cathode to anode at low voltage, it was true I presume with respect to these devices, because there were only a few electrons there.

Q. 124. What did he tell you?

A. Dr. Arnold said no, that this was quite different from the discharge path space between the electrodes, for instance, in the mercury arc, where you had two kinds of carriers present, negatives and positives; that in this case we were dealing with a rather dense cloud of electrons and that there was mutual repulsion between the electrons, so that you would require—he stated, with high vacuum you would require substantial voltages, large voltages to drive the electrons across.

Q. 125. Of what practical importance from the telephone engineering standpoint was the question as to whether or not the electrons would flow over without increased voltage?

A. The practical point was, stating it in general terms, this, that if all of the electrons were swept across we will say by the application of one volt, then a space current of ten milliamperes at one volt would represent a very small amount of energy on which to impress an incoming telephone current. You would not have any energy to work with to modulate it. In other words, the energy-carrying capacity of an amplifier is roughly measured by the energy in the space represented by the space current times the plate voltage.

Q. 126. Did he subsequently show you any quantitative measurements that he had made to demonstrate the correctness of the statements that he had advanced to you in respect to this space charge effect?

A. A few days later Dr. Arnold said to me, "You remember the question that you asked the other day regarding the mode of driving the electrons across from the filament to the plate?" He said, "I am working on that and I think I will have something to show you."

A few days later still—oh, I just cannot fix the exact date from memory, but around perhaps the 20th of November, he showed me a curve and some data, and I did not look at the data particularly, but I remember the curve, it showed that the space current was related to the voltage applied between the plate and the filament by approximately the law or rule that the current equalled the constant times the voltage to approximately the 1.6 power. It might have been a little below or a little higher, but 1.6 is accurate enough. This was experimental data. He also stated at that time that he was also working on it theoretically as it was an interesting problem. By theoretically, I mean he was attempting to derive a formula or a statement as to the law from fundamental consideration.

Q. 127. Do you know whether he did so or not, whether he formulated a law?

A. He did.

Q. 128. And did he show the formula to you?

A. He derived a law for an ideal condition, not a law which would be rigidly applicable, theoretically rigidly applicable to a vacuum tube structure such as we were employing. He showed me his formulation of it some time early in 1913.

Q. 129. You speak of an ideal condition. What do you mean by that?

A. I mean the actuaul condition was parallel plates in effect, that is, where the cathode was a parallel plate and the anode was another plate, plane surfaces parallel to each other.

Q. 130. And what about the gas pressure, if anything?

A. The computations were for the condition of one kind of carrier, that is, pure electron discharge.

Q. 131. Just tell us what this computation was.

A. You refer to his mathematical——

Q. 132. The mathematical formula.

A. I did not cross-question Dr. Arnold on that as to his mathematical formula.

Q. 133. I do not mean as to exactly how he worked it out. But what was the result that he arrived at?

A. The result that Dr. Arnold announced to me was that his computation gave approximately the same result as his experimental results that he had shown to me, namely, that it came out that the current was related to the space voltage by the 3/2 power law.

Q. 134. Had you heard of the 3/2 power law before that?

A. I had not.

Q. 135. Now, let us go back to November 1, 1912, again. You have spoken of the defects that were discussed for which Dr. Arnold offered a cure. Were there any other defects in the audion noted or discussed at that time? I mean for its use as a telephone repeater?

A. Noted in this sense, that we considered, for instance, that the use of the filament with relatively short life and also the use of the filament, whether rightly or wrongly, which I understood at the time slowly evaporated, and changed its condition, would not be satisfactory in a telephone repeater.

Q. 136. Which of the defects that you have discussed was the most important one?

A. The most important physical defect in the device was the condition which manifested itself as blue haze.

Q. 137. Did the audion present itself to you as a possibility for a telephone repeater?

A. Most certainly so. I just want to make that clear that "possibility" is perhaps too weak a word. I should say it was rather a probability.

Q. 138. When this conference between you and Dr. Jewett and Dr. Arnold was over or during the course of it, were any instructions given to Dr. Arnold in respect to further work on the audion?

A. Conference is rather a formidable word and instructions the same, but the mutual understanding was that Dr. Arnold would proceed to make a study of the audion in such a way and along lines which in his wisdom or sapiency would be most effective.

Q. 139. Do you know what was done in order to enable him to conduct his further examination of the audion or further work on it?

A. Such things for instance, there were a few tubes left with us by Dr. DeForest, and Mr. Richards had been told how he could get some more and some of these tubes were turned over to Dr. Arnold. In addition to that, almost immediately after November first, I assigned to Dr. Arnold a younger engineer, a man of some experience with us, as an assistant, P. H. Pierce, and a young man whom I had employed the previous fall came to the laboratories November first or thereabouts, it may have been a few days before or a few days later, A. M. Nicolson, who had been a student at Harvard, and he was assigned to work with Dr. Arnold. Then I told Dr. Arnold that he ought to get more help, and he came to me around some time probably in December and he said there is a man by the name——

Q. 140. Without going into detail, was another man assigned to him at that time?

A. Two men assigned at that time, E. W. Kendall and I authorized his employment and that was about the beginning of 1913.

Mr. Haight: Does your Honor wish to adjourn at this point?

The Court: 2.15.

After Recess.

Q. 141. Just before recess we reached the point where you had referred to the additional assistants that had been given to Dr. Arnold after he had been instructed to begin work on the DeForest audion. What happened, if anything, so far as instructions were concerned in respect to his work on the mercury arc repeater?

A. Dr. Arnold continued his work on the mercury arc repeater after November first to some extent. Along about the end of November I arrived at a definite understanding with my superiors particularly Dr. Jewett, that the mercury arc repeater work of Dr. Arnold could be relaxed so that he could devote the major part of his time to the audion.

Q. 142. And what was actually done in practice in that respect after the latter part of November?

A. Dr. Arnold devoted a relatively small fraction of his time to the mercury arc repeater, or the Arnold arc repeater, as we generally referred to it, after that time.

Q. 143. Suppose you had had a high vacuum audion on November first, one that withstood high voltages on the plate without ionization and one which would have withstood large input currents, could that have been used in a telephone circuit?

A. By telephone circuit I assume you mean to be used as efficiently, readily——

Q. 144. In a commercial line, I mean.

A. Yes. The answer to that question is that if you handed me a number, 8 or 10, of the present day commercial high vacuum audions and gave me their characteristics in addition to giving me merely the device and allowing me to determine that it would operate as a high vacuum audion, that out of that 8 or 10, none of them might be or could be employed readily commercially or practically as a telephone repeater for this reason:

Or to make the point clear, we speak of high vacuum audions, some of them as current amplifiers. We generally speak, for instance, of the audion that is used in large numbers, in the telephone circuits, as current amplifiers. Whereas, we speak of other audions as voltage amplifiers. We have used a few of them, I think, in telephone circuits.

They are both high vacuum audions, well designed, long life and the other characteristics. Some of this number of high vacuum audions that you gave me, perhaps some of them are very useful devices commercially, but are not capable of handling the amounts of energy that are involved in telephone service. That is, there is beyond meeting the requirements for a high grade tube that you spoke of in your question, there are other requirements which would not likely to be met unless the instrument, the audion, was designed by one knowing all the conditions which it was to meet in service.

Q. 145. Was any work required to be done in order to fit an audion into a telephone circuit? Do you understand what I mean by the word "fit"? I mean to make it applicable or adaptable as a repeater in a telephone circuit.

A. Even if we could imagine the development of a suitable current amplifying audion had been completed, there is a large amount of work to be done to fit it into a telephone circuit.

Q. 146. Will you just explain generally that to the Court without too much detail?

A. Briefly this, all of the devices previously considered, such as the mechanical repeaters, the Arnold mercury arc repeater, had very different electrical characteristics from a high vacuum audion. This means that the apparatus associated with the audion has to be made the subject of special consideration. The circuits have to be made the subject of special consideration. And of course there is always give and take, in order to get a proper balance, and what is feasible to do with the circuit and apparatus, and what is feasible to do with the audion itself.

Q. 147. Now, you spoke of these things requiring careful consideration. Were you familiar with the work that Dr. Arnold was doing in respect to the audion after November 1, 1912?

A. I was familiar with it.

Q. 148. What particular lines was he working on, say, during the month of November and December of 1912?

A. In the months of November and December, 1912, he was studying the audion, using as the basis of his study the devices which DeForest had left with us or that we purchased from McCandless, the manufacturer in New York of the DeForest audion, to determine their electrical constants under various conditions.

Q. 149. And for what purpose was that?

A. For the purpose of establishing certain broad fundamental principles that would enable him to design the ultimate telephone audion.

Q. 150. Did it have anything to do with the inside internal characteristics of the audion?

A. Most certainly. The dimensions, the mechanical dimensions of the various parts inside of the audion affect the electrical constants, and its electrical performance and variations of these mechanical constants had to be studied intimately.

Q. 151. Now, during that period of time, did he do any work in respect to filaments?

A. Dr. Arnold had the matter of filament on his mind and spoke to me concerning it. As far as I know there was no actual experimental work begun during the two months that I presume that you refer to.

Q. 152. Now, do you know whether he made any tests with audions, one or more, that had been left by DeForest?

A. I do. Dr. Arnold made tests with audions left by DeForest or purchased promptly thereafter from the manufacturer.

Q. 153. What was the nature of those tests, from your own knowledge?

A. The nature of those tests was at the beginning, Dr. Arnold made tests using alternating currents. He then proceeded with a series of tests, using direct currents in order to determine for one thing the relation between the current and voltage in the filament plate circuit. These tests were made in such a way as to give him the amplification factor of the audions. Also to give the impedence to the plate circuit of the audion under various conditions.

Q. 154. Now, what did he do, if anything, in the way of getting a high vacuum; that is, during these two months that I am speaking of?

A. During those two months——

Q. 155. And I am confining my question to your own personal knowledge?

A. My own personal knowledge relates principally to the steps or consideration which Dr. Arnold gave to the procurement of the Gaede Molecular Pump, and which at that time had recently been described in technical literature.

Q. 156. Now, what did he do in that respect?

A. At least, as early as about November 23d, we talked the matter of this Gaede Molecular Pump over. I remember, for instance, that it came up in connection with a trip which I proposed to Princeton, to what was then the new Palmer Physical Laboratory. I told Dr. Arnold that I thought I would like to go down to see the laboratories, and would not he like to go along with me, and he said: "That comes in very conveniently; I would like to do it very much, because I want to talk with Professor Trowbridge at Princeton, regarding this pump, because I understand he is ordering one."

Q. 157. Did you go to Princeton?

A. We went to Princeton. At Princeton, I listened in on a conversation between Dr. Arnold and Professor Trowbridge regarding the pump which was not at Princeton at that time. I wish you to understand that Professor Trowbridge I understood had ordered one.

Q. 158. Well, now, how do you fix that date as November 23d; I say, how do you fix the date?

A. By the records. I think by reference to a notebook that I kept at that time.

Q. 159. Now, as the result of the conversation that Dr. Arnold had had with you with reference to this pump, and the conference with Professor Trowbridge at Princeton, do you know whether you gave any authorization for the ordering of a Gaede Molecular Pump?

A. I told Dr. Arnold that it was satisfactory to me for him to proceed to get one.

Q. 160. Now, did you make any recommendation to Dr. Jewett in reference to the telephone company procuring a license under the DeForest audion patent or patents?

A. I advised Dr. Jewett that the audion gave such promise of being a satisfactory solution to our repeater problem, that everything within reason ought to be done in the way of securing rights under the DeForest patents.

Q. 161. When did you so advise Dr. Jewett?

A. Very early in November.

Q. 162. 1912?

A. 1912. Dr. Jewett and I discussed this whole problem, this whole matter, very frequently, or various phases of it very frequently.

Q. 163. Now, let me turn for just a moment to another subject. Was there brought to the attention of the telephone company during the year 1912, another apparatus which was claimed could be used as a telephone repeater?

A. There was.

Q. 164. Please tell us when and what that apparatus was. I mean by that, who had devised the apparatus?

A. During the later summer of 1912, before Dr. DeForest—before I knew anything at least of Dr. DeForest having approached the Telephone Company with respect to his device, we had a letter from our European engineer, calling our attention to a repeater which was known, as I remember it, as the Von Lieben, Reiz and Strauss repeater. We generally referred to it as the Von Lieben repeater. Our first information was rather vague and we wrote back and asked for further information. At the same time approximately we looked up what very small amount we could find in the literature regarding this device.

To state the matter briefly, arrangements were finally made by the Telephone Company or the Western Electric Company, representing the Telephone Company, and the inventors of this device, for them to bring their apparatus to the United States, or in connection with their bringing it to the United States for other purposes, I cannot now say which, that we should have an opportunity to consider it.

Q. 165. Do you know whether this device was patented in Germany?

A. This device was patented, as I remember it, in Germany. I remember quite distinctly that about the only literature, if not the only literature that we found in New York on this device were some sort of patent abstracts of German patents. That referred to and gave us a clue to its structure. By the end of the year we had, I think—it is a matter that I have not looked up for a long time—we had the German patents referring to this device in New York.

Q. 166. When did the inventors or their representatives bring the device to the Western Electric Company for demonstration?

A. They brought the device to the Western Electric Company's laboratories about the 1st of March, 1913.

Q. 167. Did you witness the demonstration of it?

A. I witnessed it and was in very close touch with the tests and demonstration, in fact, I perhaps had almost as much to do if not more to do with the tests and demonstration than any of the other engineers of the Western Electric Company.

Q. 168. Can you tell us the result of those demonstrations on your opinion as to the effectiveness of this apparatus as a telephone repeater?

MR. DAVIS: I suppose the relevancy of this will be shown later.

MR. HAIGHT: Yes, I would rather not state it to the witness now.

MR. DAVIS: Certainly.

(Q. 168 was repeated by the stenographer.)

A. I just do not understand that question.

Q. 169. I did not make that clear to you?

A. No.

Q. 170. After the demonstrations had taken place, what was your opinion as to whether or not this could be made a satisfactory telephone repeater?

A. The tests demonstrated that while the device operated under certain conditions, operated very well under certain conditions, that it was very far from being a practical telephone repeater device.

Q. 171. Did you do anything further with it?

A. No, not after—well, the tests lasted off and on because the inventor kept coming back with certain suggestions. They lasted off and on for three weeks or thereabouts. After I had had a very short time to sit down and think the matter over we decided that it was not worth while to do any development or carry on any development or research work with the device.

Q. 172. Why?

A. Because the high vacuum audion was a much more promising device and we were not interested in the Von Lieben device in comparison.

Q. 173. Do you recall the circumstances of the arrival of the Gaede molecular pump from Germany?

A. No, I have no definite remembrance of the arrival. I remember that the Gaede molecular pump did arrive sometime in the later winter of 1913 and that it was set up and operated.

Q. 174. Did you witness any demonstration of the use of an audion that had been pumped by the Gaede molecular pump in the spring of 1913?

A. I was shown an audion that had been pumped by the Gaede molecular pump and listened to telephone amplification tests made over it.

Q. 175. When was it that you witnessed that demonstration? Can you fix the time?

A. No, I cannot fix the time. It was in the late winter or early spring, perhaps early spring of 1913.

Q. 176. Can you fix the month?

A. I think it was in April, but I cannot state definitely.

Q. 177. You cannot state definitely?

A. No.

Q. 178. You witnessed the demonstration, as I understand it, of the use of that apparatus in a telephone circuit, is that correct?

A. Yes, by telephone circuit meaning a simple amplifying set up.

Q. 179-80. Just tell us how this audion acted and compare it as you go along, please, if you will, with the audion that DeForest brought in, and which was tested on November 1, 1912?

A. The principal difference between the performance of this audion and the audion that DeForest brought in, consisted in its ability to handle magnitudes of energy which are involved in commercial telephone service. It was not subject to the defect that it amplified only weak currents. As demonstrated it gave no sign or indication of conditions arising in the tube such as were manifested by blue haze.

Q. 181. Do you know what voltages were applied to the plate during the test that you have referred to?

A. I do not know. I cannot now state definitely what voltages were applied. It was my understanding at the time that under tests——

Q. 182. I do not want anything except what you know yourself.

A. I did not make tests or observe them.

Q. 183. Did you speak in loud tones in the transmitter?

A. The person who talked to me spoke in loud tones.

Q. 184. And what effect did that have on the audion, first, in respect to its amplifying qualities; second, in respect to the reproduction of the voice, and so forth?

A. As I remember it, the audion amplified normal volumes of speech current. No tests were, I think, made, in connection with my observations for my information, showing a difference between weak and loud tones. I wish it clearly understood that the tests that I made were under normal conditions of talking.

Q. 185. Well, how did those conditions compare with the conditions that were employed on November 1st, 1912?

A. Well, the conditions of this test were that the input energy to the tube was much larger than in the case of the tests made on the DeForest audion in 1912, meaning the tests on the DeForest audion where it amplified reasonably satisfactorily.

The Court: I have not gotten that.

Mr. Haight: I am afraid I have not either.

Q. 186. Let me state it this way: You say that the tests that you witnessed in the spring of 1913 were conducted at an ordinary tone of voice?

A. Yes.

Q. 187. Now, when that was done, how did the audion work?

A. It worked satisfactorily.

Q. 188. Well, did it blue haze?

A. No blue haze.

Q. 189. Did it amplify?

A. It did.

Q. 190. Was there any distortion?

A. No noticeable distortion.

Q. 191. Now, then, do you know whether during the tests which were conducted on November 1st, 1912, an attempt was made to talk over the audion in an ordinary tone of voice?

A. There was.

Q. 192. What happened?

A. In an ordinary tone of voice, coupled with the use of the ordinary telephone transmitter, of course, or under similar conditions of test, that is, similar conditions of input volume to the tests made in April, the DeForest audion failed to amplify and distorted the quality.

Q. 193. How about the blue haze?

A. The blue haze in November depended altogether, or depended on the plate voltage that you were using at the time, and on how near the condition of blue haze you were, when you talked in a loud tone of voice.

Q. 194. Did the blue haze come in November when you spoke in a loud tone?

A. Not necessarily.

Q. 195. Did it at all?

A. It did sometimes.

Q. 196. Yes, that is what I wanted to get at.

A. When you were right on the ragged edge of the condition, you had blue haze.

Q. 197. Now, do you know what work was done on the audion?

THE COURT: Before you go into that, Judge Haight, will you tell me what you understand to be the situation of this last part; I still have not got it?

MR. HAIGHT: I understand the situation to be this: I simply wanted to bring out the improvement that had been made between November and April. I should probably have added this——

Q. 198. Let me ask you this question—maybe I had it in the preceding question, but do you know whether the audion in the demonstration which you witnessed in the spring of 1913, and which you have just testified to, had been pumped by the Gaede molecular pump?

A. I do not know that in the sense that I did not actually see Dr. Arnold or any of his assistants pump that glass tube. I did not witness the operation. I know this, that when I went into the laboratory, I was told by Dr. Arnold that this was a tube that was pumped by the Gaede molecular pump, and I believed it.

Q. 199. And do you know whether or not the pump had arrived before the date of this demonstration?

A. I know that.

Mr. Haight: Now, the purport of the testimony is this, as I understand it: In November, when they talked even in an ordinary tone of voice in the DeForest audion, it failed to amplify, and the speech became distorted. It would only work when one spoke at a very low tone in the audion and under certain conditions of louder tones of voice, it blue-hazed. It always blue-hazed when they put an increased amount of voltage on the plate; that is, the B-battery.

The Court: Then I understand it. My misunderstanding was what happened in the DeForest tube unchanged on the 1st of November. I now understand.

Mr. Haight: Now, then, in April, Mr. Colpitts only witnessed a test when there was an ordinary tone of voice carried on, I presume, because that was the only thing he was concerned in.

The Court: I was confused as to the testimony touching the experiment on the first day of November. I thought that the ordinary tone of voice was reproduced and amplified with a blue haze and he got into the blue haze whenever there was an unusually loud tone, and the plate circuit voltage was just below the blue haze; that is how I understand the testimony.

Q. 200. You understand the remarks that his Honor just made; were they correct?

A. Well——

THE COURT: You had better not say yes or no unless you find them correct.

THE WITNESS: I can not say yes or no.

Q. 201. Under what conditions did you get blue haze during the November 1st, 1912, test?

A. The simplest condition to obtain blue haze was this: Without any conversation on the transmitter connected to the intake, simply increase the plate battery up to a certain voltage and the tube would blue haze. If you reduced the plate battery by a certain amount, so that to the eye, at least, the blue haze vanished so far as you could tell, to the eye, if you then talked into the transmitter, which was included in the input circuit in the audion, at times, I do not say all the time, you would, at times, get blue haze to appear in the tube.

THE COURT: Whatever the tone of voice?

THE WITNESS: With any moderate tone of voice, yes.

Q. 202. But how about when you spoke in a low tone?

A. I do not remember that we reduced the test to the microscopic limits.

Q. 203. When you spoke in a loud tone of voice, did you always get blue haze or only at times?

A. When the plate voltage was reduced well below what can roughly be called the blue haze limit, then whether you talked in a low or talked in a loud tone of voice, the blue haze would not appear.

Q. 204. How about the distortion feature and the amplification feature when you spoke loud?

A. When you spoke loud under these conditions of no blue haze, the device did not amplify to any appreciable extent and the reproduced speech was distorted.

By The Court:

Q. 205. Where your plate circuit was blue haze or near the blue haze limit?

A. If it was near the blue haze limit loud speech would not be reproduced with amplification or with good quality.

By Mr. Haight:

Q. 206. After April, what was the character of the work that was done with respect to the audion?

A. In general terms after April the emphasis was put on obtaining a satisfactory form of—April, 1913?

Q. 207. Yes, April, 1913, I mean.

A. —a satisfactory form of filament.

Q. 208. And do you know whether that condition was solved?

A. Gradual advances were made in the filament art, using for the most part the so-called Wehnelt cathode, that is a platinum alloy ribbon coated with oxide of calcium or strontium or a mixture of one and another.

Q. 209. Was such satisfactory filament evolved?

A. Almost from the beginning we got promising results so that by the fall of 1913, we considered we had the problem pretty well solved in the way of producing a satisfactory filament.

Q. 210. Now, do you know of your own knowledge whether work was done on this filament by one or more of Dr. Arnold's assistants during the winter of 1913?

A. I know of my own knowledge that the literature was being looked up during the winter of 1912-13, but I do not know of my own knowledge as to any experimental work that may or may not have been carried out. I know of course that to a certain extent the tests on the Von Lieben tube, represented to me at least the test of the Wehnelt type of filament. The Wehnelt type of filament was included in that tube.

Q. 211. Did Dr. Arnold take part in any further work on the audion in the late spring and summer of 1913?

A. Dr. Arnold, during the late spring of 1913 and the summer of 1913, continued work on the audion. I point out, however, now, that during the early part of the summer of 1913, Dr. Arnold began to have trouble from what later turned out to be appendicitis, and was absent during a substantial portion of the period covered by your question, as I remember the question. Without looking up the records, I cannot say the exact date, but Dr. Arnold, as I remember it, was absent for two months during the summer of 1913.

Q. 212. When was the first audion installed as a repeater in a commercial telephone line, and where and on what line?

A. As I remember it, the first installation which involved a commercial circuit was made at Philadelphia, in the fall of 1913. I may say that at Philadelphia for some time we had a room in one of the Telephone Company buildings which we used more or less as a laboratory or as an extension of our New York laboratory for putting in repeaters and elements if we wished to try such a test, or for measurement of the characteristic of lines and so on, and this room was in one of the Telephone Company buildings at Philadelphia and was practically a part of our laboratory.

In the summer or early fall of 1913, Mr. Kendall, one of Dr. Arnold's assistants, took certain repeater elements and other apparatus to Philadelphia and used this room and set the apparatus in it and after what might be called laboratory testing and adjustment, a repeater set-up was left in commercial service.

Q. 213. Did you see that set-up?

A. I saw the set-up.

Q. 214. And what was the repeater element?

A. The repeater element that I am speaking of as being used in the circuit was an audion.

Q. 215. Now, then, did you subsequently talk and listen over that line?

A. I at least listened but to be mathematically accurate, I do not know that I ever talked over the line. Yes, I talked over the line. I was thinking then of certain other tests. I was thinking of some first steps. I talked over the lines made up first by circuits from Philadelphia to New York, back to Philadelphia on one side of repeater, and from Philadelphia to Baltimore and back to Philadelphia on the other side of the repeater. I also talked from New York to Baltimore on the repeater after it was left in service.

Q. 216. How did the audion act at the time you talked and listened to conversations over it as you have described, as compared with the way that it acted on November 1, 1912?

Mr. Davis: I assume you mean, Judge Haight, although you have not brought it out with the witness, that the witness could see the audion act?

Mr. Haight: He did say that he did see it. I asked him if he saw the set-up.

Mr. Davis: Does he know of his own knowledge how it acted?

Mr. Haight: He said he saw the set-up himself in Philadelphia and that he talked over it. I suppose he cannot possibly say himself that the audion he talked over was the same one that he saw, but so far as he knows that is a fact.

Q. 217. Is that the fact, Mr. Colpitts?

A. Yes.

(Q. 216 was repeated by the stenographer.)

A. The test as made included many factors, many elements under consideration other than the audion element itself. The overall performance of the circuit from New York to Baltimore was entirely satisfactory as a commercial telephone circuit; that is, one could talk in a normal or loud tone of voice in New York and speech was satisfactorily repeated by the apparatus set up at Philadelphia and to me listening at New York, the speech was repeated or reproduced entirely satisfactory from the person talking in Baltimore.

Q. 218. Subsequent to that time the transcontinental line was opened, was it not?

A. Yes, the transcontinental line was opened, as I remember it, on July 29, 1914, in the sense that that was the first day on which Mr. Vail and other important officials of the telephone company talked from New York to San Francisco with certain people there.

Q. 219. And the audion was used as an amplifier?

A. The audion was used as an amplifier on that date.

Q. 220. And what has been the amplifying element that you have used since the time the audion was tried out on a commercial line in the fall of 1913, as you have testified? Is that question a little too involved?

A. No, the question is all right, if the stenographer will read it.

(Q. 220 was repeated by the stenographer.)

Mr. Haight: Change the word "amplifier" to "repeater."

The Court: Read it once more.

Mr. Haight: Suppose I strike it out.

Q. 221. Since the time when you used the audion in a commercial line as you have testified in the fall of 1913, what has been the form of repeater used in commercial service by the telephone company?

A. The form of repeating element used in commercial service by the telephone company has been the high vacuum audion.

THE COURT: Since when?

THE WITNESS: Since July 1914.

Q. 222. Since July 1914. Did you give up all of the mechanical repeaters that you had installed at that time?

A. Fixing a definite date, say January 1st, 1914, there had been very few perhaps half a dozen mechanical repeaters installed at various points in the telephone plant. Gradually, the use of these was discontinued or replaced——

Q. 223. Now, let me ask you one other question—I thought you had finished.

A. In connection with the transcontinental line, there were mechanical repeaters installed at the various repeating points. These were not used except for demonstration or test on the transcontinental line.

Q. 224. Were any improvements made in the mechanical repeater between 1912 and July, 1914?

A. Very little, if any; between November 1st, 1912, did you say?

Q. 225. Yes.

A. Between November 1st, 1912 and 1914, very little, if any, improvements were made in the mechanical repeater.

Q. 226. Take the period from the latter part of 1910 up to November first, 1912.

A. During that period, very substantial improvements were made in the mechanical repeater. To give the Court a picture of the improvement, or to describe it, I may say that in 1910, the introduction of a single repeater in a telephone circuit reduced the intelligibility, distorted the quality by a certain amount. It was noticeable, substantially noticeable, in fact, in

1910 the mechanical repeater introduced so much distortion that it was not possible, commercially possible, to have two repetitions, put one say at Pittsburgh, another at Chicago, on a New York-Omaha line, the distortion in quality was to be made. The improvements made between 1910 and 1912 permitted us to put three mechanical repeaters in on a long circuit and have no more distortion than in 1910, with one repeater on the circuit. The change I may add was due largely to making the mechanical repeater more nearly a commercialized device.

MR. HAIGHT: That is all.

CROSS-EXAMINATION.

By MR. DAVIS:

XQ. 227. I understood Dr. Jewett to testify that only one mechanical repeater could be used, and if you used two, you would destroy the quality and make the speech unintelligible; that was not correct in 1912, was it?

A. I do not remember Dr. Jewett's testimony.

XQ. 228. Regardless of what Dr. Jewett said—the facts are——

A. Regardless of what Dr. Jewett said, the facts are that by, very roughly, 1912, we had carried the development of the mechanical repeater to the point where it was possible to talk through about three of them on a line.

XQ. 229. Do you recognize the drawing which I show you, Mr. Colpitts, page 2339 of the Interference record in the Arnold-Langmuir case in the Court of Appeals, being copy of drawing in patent No. 1,128,292?

THE COURT: Whose patent was that?

XQ. 230. That is one of your own patents, is it not?

A. Yes.

XQ. 231. Taken out February 16, 1915, on an application filed January 3, 1914; is that right?

A. That is right.

XQ. 232. Now, this patent relates to a combination by which two tubes are used, one operating on the positive side and the other on the negative part of the wave; is that correct?

A. That is correct.

XQ. 233. And the tubes are three-electrode tubes, are they?

A. They are.

XQ. 234. And you say in the specification, do you not, on line 24 of page 1:

> "The principal parts of an audion element or structure are a heated filament or other source of ionization, an anode usually called a plate, and an intermediate electrode usually called a grid"?

A. Yes.

XQ. 235. It goes on, does it not:

> "These are preferably enclosed in an evacuated glass vessel, the characteristic features of the audion are that a current can flow in one direction only in the ionized stream, and that the strength of current in the stream flowing from its source to the plate is modified by electro-static rather than by electro-magnetic force as in some other types of gaseous repeaters"?

A. That is right.

XQ. 236. And the first claim reads:

> "An electric wave repeating apparatus comprising divided input and divided output circuits, means for producing two ionized streams, said streams being oppositely included in said output circuit,"

and so on?

A. That is correct.

XQ. 237. This application was filed, that is, the application for which this patent was issued, was filed some months after its use on this Philadelphia-New York-Baltimore circuit began, was it not, the filing date being January 3, 1914?

A. It was.

XQ. 238. This use, by the way, you would hardly properly call it a commercial use, would you?

A. No.

XQ. 239. How would you describe it?

A. The apparatus was set up in an extension of our laboratory. We called it our Philadelphia Laboratory, sometimes. It was simply left in under an engineer's observation during some time after late in 1913 or early 1914.

XQ. 240. You were really treating your wires from New York to Philadelphia and so on, as part of your laboratory equipment to that extent?

A. To a certain extent so, yes.

XQ. 241. But by the middle of the year 1914, you opened the transcontinental line, and there you had a real commercial use of this device?

A. I want to make that clear; perhaps I did not. The transcontinental line was cut through July 29, 1914, and Mr. Vail—I have forgotten who was at the other end—spoke the first words over that circuit. We had made loop tests up to a certain point, up to Denver and back, but they spoke first words and conversation was carried on over the circuit which was not opened until during the winter of 1915.

XQ. 242. Opened to the public?

A. Opened to the public, the reasons were commercial, and policy, rather than physical.

XQ. 243. So that the beginning of the commercial use of these tubes was in the early part of 1915?

A. That is right, as I remember it. I do not think that any were put in for commercial service before that.

XQ. 244. My memory happens to coincide with your own as having used them the date the "Lusitania" was sunk; is that about right?

A. That is right.

XQ. 245. That was rather early in the use of that line, was it not?

A. I think so.

XQ. 246. Now, what sort of a tube are you disclosing in this—you did not say much about the tube—what sort of a tube are you talking about in this patent?

Mr. Haight: I object, if your Honor please. I do not see the relevancy of this patent. The witness is called as a fact witness to relate circumstances, and Dr. Arnold's connection, and his, with the development of the audion, and we have brought him up to the first of July, 1914, and no further. Now, if we are going into some of the patents, we are going very far afield, I think, and quite beyond the scope of direct examination.

Mr. Davis: If your Honor please, the witness has testified to what he evidently regards, and my brother also regards, as a perfectly continuous story of effort and development, culminating in the production of satisfactory tubes in May or some such time, in May, 1913, and the experimental installation of these tubes on the commercial circuits in August, September or October, 1913, and in the transcontinental line. Now, here he files on January 3, 1914, an application for a patent, in which he discloses a use——

The Court: When?

Mr. Davis: On January 3, 1914—at a time when, according to the statements which have been made here today, the invention, the tube had been a completely developed, finished thing, in which he would naturally use that tube, and he does not disclose the tube. He discloses, as I understand it, the audion, although he has testified the audion was barely operative for the purpose, but he described it as having a source of ionization and current flowing in the ionization stream, and compares it with other types of gas repeaters, and I want to know how that happened.

(Discussion.)

. . . .

Mr. Davis: The evidence is contradictory. I will not assume that a man of Mr. Colpitt's standing has filed a patent application for a thing which he knows is not good.

. . . .

The Court: I have that. Judge Haight, as I understand it, it is this: Mr. Davis is by necessary implication indicating that this patent is a circumstance which is humanly irreconcilable with the facts testified to. Mr. Davis cannot put that patent in evidence now and according to the plan we outlined a day or two ago that comes in in his rebuttal. You do not have to meet that now, but you have to meet that in your sur-rebuttal.

. . . .

A. Talking about the kind of tube that on January 3d, or the date of the application, had been developed by the Western Electric Company——

XQ. 247. That is, you are talking about this Arnold tube?

A. I am talking about the Arnold tube.

XQ. 248. And about that tube you say that one of its characteristic features is that current can flow in one direction only in the ionized stream?

The Court: Now, I am wondering whether

you are not going under our Delaware State practice, you are now going beyond your cross-examination. You may call attention to it and put it in.

Mr. Davis: I withdraw the question, if your Honor please.

Mr. Haight: Now, do I understand that it is offered? If it is, I want to have an opportunity to explain it.

The Court: It is really now marked for identification, that is all, in effect.

Mr. Haight: But it will be in the evidence.

The Court: Yes, but you may meet that patent after the rebuttal.

Mr. Haight: And not by the examination of Dr. Colpitts now?

The Court: No. He has identified that as his patent and if there is anything in there inconsistent with his testimony, it becomes effective against his testimony when the plaintiff puts in his rebuttal testimony. Then you can come in with sur-rebuttal and attack it. I see no other way of keeping the issues in mind.

Mr. Davis: If your Honor please, as this is bound in this Court of Appeals record, I assume it is not necessary to mark it, to identify it.

The Court: The patent referred to is identified by its number.

Mr. Davis: And by its page in the Arnold-Langmuir case.

By **Mr. Davis**:

XQ. 249. Do you know Mr. Bancroft Gherardi?

A. Very well. He is now vice-president of the A. T. & T. Company, in charge of the department of operation and engineering.

XQ. 250. And has been in a prominent position with the company for a long time?

A. He has.

XQ. 251. By the way, you mentioned Mr. Vail in your answers. Will you tell us who he is?

A. The Mr. Vail to whom I referred was Mr. Theodore N. Vail, who was president of the A. T. & T. Company.

XQ. 252. A very prominent and a very distinguished man?

A. Very prominent man in the line of business.

XQ. 253. He was the great business man in the telephone art for a generation, isn't that so?

A. Yes.

XQ. 254. This is the transcript or what purports to be the transcript in the suit which Dr. Hewitt brought against your company for royalties?

A. I remember it by hearsay.

XQ. 255. Would you mind looking over this table that Mr. Gherardi seems to have put in in evidence in his testimony on page 281, and see if it is correct?

A. I assume that it is correct.

XQ. 256. That is you have read this question 12 on page 281 and this table down at the bottom of page 281, and assume it is correct. Will you also on page 290 read that question on the fourth line and the table and see if you think that is correct?

A. I would say it is correct.

Mr. Davis: May I have this transcript marked for identification.

The Court: If you will identify it by page it will be sufficient.

Mr. Davis: I have mentioned the pages.

The Court: Very well.

XQ. 257. These tables show the use of the mechanical repeaters in considerable quantity as late as 1918?

A. I think these tables—considerable in one sense of the word, yes, but not compared with the number of repeaters that are used now in a plant. In round figures it is twenty or thirty thousand repeaters, but the use was very limited.

XQ. 258. This table shows that in December, 1904, there were two mechanical repeaters, and in December, 1913, there were thirty-two repeaters and in December 31, 1918, there are 236 mechanical repeaters, but by that time there were 973 audion repeaters, is that correct?

A. That is correct.

XQ. 259. And now I assume that the mechanical repeater has disappeared entirely?

A. I would not want to state entirely. The use is practically nil. There may be one or two left in at certain points but it is practically nil, that is, in very round numbers we have a thousand to one any way.

XQ. 260. You spoke of Mr. Richards having been told where he could get some more audion tubes?

A. Yes, sir.

XQ. 261. Who told him?

A. Dr. DeForest.

XQ. 262. And that place was McCandless?

A. Yes, it was McCandless, I do not remember his initials. As I remember it was somewhere downtown New York.

XQ. 263. When Dr. Arnold dropped this mercury repeater work, who continued it?

A. Dr. Arnold never completely dropped it. He dropped it say nine-tenths of his time, but never did entirely, for the next year and a half.

XQ. 264. Part of the time of his assistants would be given to it as well?

A. I cannot tell you now definitely, but I think it more was likely that whatever work was done was done practically on the whole time of one assistant or two assistants, rather than part time of certain assistants. The assistants would be less likely to divide their time between the audion and the mercury arc.

XQ. 265. On this question of mechanical repeaters again, is there any limit to the number of repeaters you can now use on a line?

A. As far as I know the limit to the number of repeaters that you can use on a line, that is the vacuum tube repeaters, is not due to the element itself, but is due to the apparatus associated with the repeater and to the lines.

XQ. 266. And as a practical matter, this is true, is it not, that you now have commercial circuit, beginning some place in Cuba, quite remote from Havana, to Havana, by cable to Florida, to New York by wire across the continent and to San Francisco and say down to Los Angeles?

A. Such connections have been put up and can be put up.

XQ. 267. If I happen to be in Matanzas, Cuba, and called a friend in Los Angeles and was willing to pay for it I would get the connection?

A. You would either get that connection or a slightly more direct connection across the southern part of the country.

XQ. 268. That would involve a great number of repeaters?

A. That involves a great number of repeaters.

XQ. 269. And the quality of the conversation would be satisfactory?

A. Very satisfactory.

XQ. 270. You said or implied one or the other that you knew Dr. DeForest before this date in November or October, 1912?

A. No, I do not think I implied it. I did not wish to imply it, although I do not wish to state that I had not met him before.

XQ. 271. You do not remember whether you met him before?

A. I do not remember one way or the other. It is quite possible that I met him.

XQ. 272. I noticed that you put it a little oddly.

A. No, I have no remembrance of having met Dr. DeForest before that time.

XQ. 273. You were a member of the American Institute of Electrical Engineers?

A. I think I was a member at that time.

XQ. 274. I think you have spoken of having heard Dr. Whitney's paper?

A. I heard Dr. Whitney's paper. Of course, persons who are not members can attend those meetings, but I think I was a member at that time.

XQ. 275. Did you hear Dr. DeForest's paper describing the audion?

A. I did not.

XQ. 276. Did you read it about the time it came out?

A. I did not as far as I now remember. I think that was—no, I did not, as far as I remember.

XQ. 277. When did your company to your knowledge first take an option or acquire any right under the DeForest patents?

A. I do not know except by hearsay. In fact, I do not know that any option was taken. I think just by hearsay that there was a final agreement in July, 1913.

XQ. 278. Now, you spoke of a tube which you saw in the spring of 1913, as having been pumped on a Gaede pump and actually, what you said, I think, or what you meant to say, was that you went into the room and here was a tube and the people said, "This tube was pumped on a Gaede pump"?

A. That is right.

XQ. 279. You believed what they said?

A. I did.

XQ. 280. You did not mention in the statement which you made in the Interference, this occurrence of seeing a tube operate in the spring. Do you remember that?

A. I do not remember that.

XQ. 281. You do not remember then why you did not mention it in the statement?

A. No.

XQ. 282. Mr. Colpitts, those statements which were filed in that Interference were prepared with very great care?

A. They were prepared, I assume, with great care.

XQ. 283. There was a good deal of discussion and conversation about it?

A. There was considerable conversation.

XQ. 284. And a good deal of pain was taken to have them accurate and complete and right, is that so?

A. It was as far as the material that went in was concerned.

XQ. 285. And of course that was a good many years nearer to the time of the event than we are now?

A. I do not remember the date, but just the general impression is that it was eleven years or fourteen years.

XQ. 286, I think the statements were made in 1921 and the events took place in 1912 and 1913 and we are now in 1926?

A. Yes.

XQ. 287. In spite of that fact, you have a positive and definite recollection of that test that it was in the spring?

A. I do.

XQ. 288. Mr. Kendall made some reports. I think you mentioned Mr. Kendall in your testimony?

A. Yes.

XQ. 289. As having had to do with this installation on the lines in Philadelphia?

A. Yes.

XQ. 290. His report seems to show that the audion repeater as there set up gave a gain considerably less than that of the mechanical repeater. Is that in accordance with your recollection?

A. I do not recollect that under the final adjustment that that was the case. It may have been.

XQ. 291. Do you recognize the report (showing the witness what was Arnold Priority Exhibit 22). Have you seen that before?

A. I assume I saw it. It is a fact that those probably are my initials. They look like mine.

XQ. 292. That is, after the word "section"?

A. Yes. I have no special remembrance of the report or the occasion.

XQ. 293. And he says: "In general, possibly because of poorer balancing of circuits, it was necessary to use one more cell in each grid circuit than had been used in the preceding tests on artificial line; this cut down the efficiency by about four or five miles."

Before that he said it gained five miles each way.

A. Yes, sir.

XQ. 294. And he speaks of the mechanical repeaters giving twelve miles gain?

A. Yes.

XQ. 295. And then he says at the end of the report: "With audions as good as N-26.1 which can probably be made by using oxid filaments, it is thought that somewhat more satisfactory results can be obtained, say eight miles each way;" is that correct?

A. That is what he says.

Mr. Haight: What are you asking the witness, to tell what is in the paper or something about his opinion? If the former, I ask to strike it out.

Mr. Davis: I am asking him whether or not, having seen this report, whether the audion gave as much gain as the mechanical repeater did at that time.

The Witness: I did not understand that you asked that question.

XQ. 296. I will ask that question.

A. The report states, and I do not question Mr. Kendall's results, that under the particular conditions of use the mechanical repeater gave as I remember several more miles gain than the audion.

XQ. 297. In the testimony you gave this morning, you spoke of work which Dr. Arnold did prior to this interview with Dr. DeForest, which resulted in a patent, which was brought to your attention in the experimental production of mercury amplifiers or mercury repeaters, is that right?

A. That is right.

XQ. 298. You spoke of his heating the glass to prepare those tubes in connection with the preparation of the exhaustion of those tubes?

A. Yes, sir.

XQ. 299. Was that done before or during the exhaust?

A. The point I referred to was the heating that was carried on during the exhaust.

XQ. 300. The heating of the glass itself?

A. The heating of the glass.

XQ. 301. You did not have the glass red hot during the exhaust, did you?

A. I do not think I said red hot without a qualification. Dr. Arnold was using at that time, as I remember it, because of the way he used to worry about getting supplies of glass, and worry me about it, a hard glass. I am not much of an expert on glass and I will have to trust my memory, but I think he called it soda glass. It was a hard glass which can be heated to a higher temperature than ordinary glass and it was a dull red heat, very dull.

XQ. 302. The expression red is what attracted my attention. I did not know that any glass at that time could be heated red hot without melting.

A. I have a positive remembrance of this use of hard glass in the dull red.

XQ. 303. While it was being pumped?

A. Yes.

XQ. 304. Of course, you do not know the temperature?

A. I do not know the temperature.

XQ. 305. The mercury was in it at the time.

A. The mercury was in it at the time.

XQ. 306. How long would this condition continue?

A. Do you mean how long did he apply the heat?

XQ. 307. Yes.

A. I cannot say.

XQ. 308. The whole tube was in this hood?

A. The whole tube was in this hood.

XQ. 309. And being heated?

A. Being heated.

XQ. 310. Then, of course, the tube was not in any sense a vacuum under those conditions. There must have been very high mercury pressure?

A. I cannot speak as an expert on that subject, but it is my understanding that inside of the mercury stream there is a high pressure, but I do not think there was a high pressure outside of the mercury stream.

XQ. 311. Now, coming to the exhaust, you spoke of bombardment.

(After a short recess.)

XQ. 312. In the preparation of these mercury tubes, you spoke of something taking place in the nature of bombardment?

A. I did.

XQ. 313. Now——

The Court: If you want to make a general statement at some time about a mercury tube as distinguished from the DeForest tube, for example, I should be glad to have it.

Mr. Davis: If your Honor please, I will make a statement and ask the witness if I am right.

Dr. Peter Hewitt about the time of the Spanish War, or in that neighborhood, did a great deal of work on mercury arc lamps. That is that long green tube, full of green light which your Honor may have seen. It is used in printing offices and in some photographic places. The tube is three or four feet long.

The Court: Jewelry stores, in the showcases?

Mr. Davis: I think possibly. It is often used for blue-printing photographs. The Government printing office in Washington has used it.

Mr. Haight: I would suggest to your Honor that that will all come out in Dr. Arnold's examination. He will explain the whole thing.

The Court: Very well. I thought nobody had told me about the mercury tube, and that we were getting information before I had an opening about it.

XQ. 314. The mercury arc lamp, as it was called, was actually an arc, was it not, Mr. Colpitts?

A. This——

XQ. 315. The mercury arc lamp was a low pressure arc, is that right?

A. That is my understanding.

XQ. 316. This device that we are looking at is also an arc from a mercury cathode, is that right?

A. That is my understanding.

XQ. 317. And this electrode 4 at the bottom is a pool—have you got the patent there, Mr. Colpitts?

A. No, I have not.

Mr. Howson: Here is one (handing).

XQ. 318. The electrode 4 at the bottom is a pool of mercury, liquid mercury in the tube, is that right; that is referred to in the patent as a "mercury cathode 4," lines 7 and 9 first page?

A. That is right.

XQ. 319. And the cylinder at the top of the left-hand tube marked 5 in the drawing, is what?

A. Yes. Well, it is a long time since I have studied this, but I believe that is the anode.

XQ. 320. That is described as the anode 5 of "carbon or other suitable material," line 80. The starting mercury anode 6, is that other pool of mercury at the bottom, is it?

A. That is my understanding.

XQ. 321. And in the normal operation of the tube so far as we have been talking about it, you would put a direct current between the terminal 4, and the terminal 5, making the terminal 4 the negative; is that right? That is making the mercury the negative?

A. I believe so, yes.

XQ. 322. And if you could start an arc, an arc discharge, it would play across between those two points; is that correct?

A. That is right.

XQ. 323. Now, this starting electrode, what is the function of that, do you remember?

A. It is my understanding of a mercury arc, of the normal mercury arc, that you can not start the arc—I am not of course talking as an expert on the subject, but as an engineer—you can not start an arc between the normal anode and cathode in a mercury arc tube, but you have to have some auxiliary device or tube, the tube in somewhere so as to get some vapor in the tube.

7

XQ. 324. So that you start an arc between 6 and 7 and then the arc jumped up to 5; is that right?

A. I assume that is the arc direction.

XQ. 325. When they bombarded 5, how did they do it?

A. When they bombarded it at 5, they did it by cutting down the resistance in the arc circuit so as to increase the arc current, that raised the anode 5 to a higher temperature than normal operation.

XQ. 326. That is, they simply ran a higher current than normal through the tube?

A. That is my understanding.

XQ. 327. And that heated this anode 5, which was "carbon or other suitable material" to a high temperature?

A. That is true.

XQ. 328. And the voltage of that discharge across that, do you know what it was? I mean in the order of magnitude of it?

A. As I remember it was thirty volts or thereabouts.

XQ. 329. It had to be low?

A. It had to be low.

XQ. 330. Because that is the nature of the mercury arc?

A. As I remember, it was thirty volts.

Mr. Davis: Now when they came to bombard —let me ask your Honor if that is clear?

The Court: Yes.

XQ. 331. When they came to bombard those auxiliary cathodes 7 and 8 which appear about halfway up the left-hand tube, how did they do that?

A. They did that by connecting this large higher potential battery that I spoke of, the negative pole of the battery, to these auixliary cathodes in parallel and the positive pole to the mercury cathode.

XQ. 332. No. 4?

A. Mercury cathode 4, yes.

XQ. 333. To the mercury cathode 4?

A. Yes, sir.

XQ. 334. Was the main current flowing through the tube or not at the time that was done?

A. The main current was flowing through the tube.

XQ. 335. And then they had, I suppose, some resistance, or something in the circuit of this battery to regulate the current?

A. I do not remember the exact set-up.

XQ. 336. Have you any idea of the order of magnitude of the current that flowed out of that dry battery?

A. I do not remember any figures. No. I do not remember any figures.

XQ. 337. Do you know what the main current was, the current in the main circuit?

A. I do not remember now anything definite. My remembrance—I would not want to be held to it, is in the order of the ampere.

XQ. 338. In the order of an ampere?

A. Yes.

XQ. 339. You mean the normal current——

A. Through this main arc circuit.

XQ. 340. And higher than that when they were bombarded?

A. Higher than that when they were bombarded.

XQ. 341. Now, this other cathode 9, which is described in the patent as an auxiliary anode, how was that cleaned up, if at all?

A. I do not remember what treatment was given to 9.

XQ. 342. Or whether any treatment was given to 9?

A. Or whether any treatment was given to 9.

XQ. 343. Now, going back to what you said about the work which was laid out between you and Dr. Arnold in conversations, and so forth, you spoke of the necessity of certain changes in the audion itself, to adapt it to the telephone circuits; is that correct?

A. We did.

XQ. 344. What was in a very general way—what were the reasons why it was necessary to change the audion to adapt it to telephone circuits; what kind of changes did you need to make in it?

A. The principal change and the major change was to first, looking at it as an engineer, with something in a box, not knowing how it operated, and what was there, that if we considered the audion when it was operating properly with low energies, as a device, then from the standpoint of the telephone engineer, the change that had to be made was to get a device which would handle very much greater amounts of energy. Now, on considering the opening of the box, and looking at the device, we found that when we modified conditions to tend in the direction of making a device or securing a device which would handle these larger amounts of energy, we immediately ran into the condition that I have described as blue glow.

XQ. 345. Now, Mr. Colpitts, if I may interrupt you, I quite understand that and I am trying to direct my questions to something else than that.

A. Yes.

XQ. 346. Just leave that to one side, because you have already fully discussed that, and what else did you have to do to it besides getting it so that it would not blue-glow, for instance, you speak of impedence; would you mind telling the Court what impedence is, unless his Honor knows the term—what is impedence?

A. Well, impedence, perhaps—if we have a source of electromotive force E, then the current I, which flows, is equal to E divided by the impedence.

XQ. 347. Now, just to interrupt you, his Honor has heard that statement made in the form of E is equal to I, divided by the resistance; why do we introduce the term "impedence" instead of "resistance"?

A. The term "impedence" is a very general term, more so than the term "resistance." It takes account of effects like capacity or inductance.

XQ. 348. So that when you are dealing with the direct current, you use the simple form or expression, and speak of "resistance" and when you are talking of alternating current, you deal with "impedence"; is that right?

A. That is right?

XQ. 349. And that is a more complex quantity than resistance?

A. Yes.

XQ. 350. And it has about the same bearing in the equations?

A. Yes.

XQ. 351. So that when you speak of the impedence of the tube, you mean the resistance of the tube, using the term "resistance" in a very broad and general way; is that right?

A. That is right.

XQ. 352. Now, then, did you have to make any changes in the impedence in these tubes?

A. Here are the facts: The DeForest audion as submitted, and under the conditions where it could be used satisfactorily, using it satisfactorily in the physical sense, not in the engineering sense, that is, the output of the plate filament resistance or impedence, or, as I remember it, in the general order of say 200 or 300,000 ohms, I would not want to be held to them within 25 or 30 per cent. either side, that corresponds to certain commercial tubes today, I think, in a very, very rough way. That is, there are commercial tubes today where the impedence is up ten or even tens or hundreds of thousands of ohms, the tube that we use for general telephone circuits has an impedence or resistance in the plate circuit of in the order of five thousand or six thousand or seven thousand ohms. I do not want to be held to that figure within two or three thousand ohms, though it is somewhere in that order. Now, the input impedence is another factor which depends largely on the capacity that is in high vacuum tubes, largely on the capacity of other factors, as I understand it.

XQ. 353. Then, one of the things that you did to these tubes, was to re-arrange the parts inside of the tube, either their size or their relation to each other, in order to reduce the impedence of the tube; is that right?

A. There are other factors, of course, than——

XQ. 354. I am trying to get the other factors one at a time.

A. Than the term "impedence," as I understand the operation of these tubes, I would not set up to be an expert, but as I understand it, the amount of electron emission, for instance——

XQ. 355. Take that, you changed that, did not you?

A. We increased that.

XQ. 356. By using the Wehnelt cathode?

A. By using the Wehnelt cathode with larger surfaces and so on.

XQ. 357. And you also, I understand, were dissatisfied, I think perhaps Dr. Jewett spoke of that, with the mechanical ruggedness of the tube?

A. Very much so.

XQ. 358. And you wanted to make it mechanically more rugged and better?

A. Yes.

XQ. 359. And that you did that in those tubes of May, 1913?

A. We carried that to a certain extent, yes.

XQ. 360. I did not mean you made it perfect. I do not assume you have it perfect yet.

A. No, we do not have them perfect yet.

XQ. 361. But you are improving them all the time?

A. And spending a large sum of money.

XQ. 362. But during that period from November 1st, until May, there was considerable progress made in all these directions?

A. There was.

XQ. 363. Perhaps you may tell us, Mr. Colpitts, as well as anybody, as somebody must, what this word "gain" means, that was used?

THE COURT: What is the word?

XQ. 364. "Gain."

MR. HAIGHT: Gain.

XQ. 365. It is telephone slang, is it not?

A. It is a telephone slang. The term means this, if the "gain" represents the increase in length of the telephone line, which is made possible for a certain condition, if we set out to obtain a certain condition, the increase in length which is made possible by the use of the telephone repeater, is known as the "gain." It is commonly expressed in miles of a certain kind of cable.

XQ. 366. And it is true, is it not, or am I wrong, that of that standard cable that you used at that time three miles gain was about the same thing as doubling the signal?

A. Three miles gain would be very roughly, well, let us say, the attenuation of the cable was about one-tenth per mile. That is——

XQ. 367. You need not calculate it. We can calculate that. The attenuation is about one-tenth per mile?

A. One-tenth per mile.

Mr. Davis: Thank you very much.

Re-Direct Examination.

By Mr. Haight:

RDQ. 368. You spoke of the improvement of the audion continuously; will you give the Court some idea of the annual expenditure that the Western Electric Company and the American Telephone and Telegraph Company have made in the way of improving the audion since it was inserted in the transcontinental line in 1914?

A. I only carry those figures roughly.

RDQ. 369. I want just your approximation.

A. I have to get them each year, but I think the expenditures now are running at about the rate of three hundred thousand dollars a year for the laboratory work in the Bell Telephone repeaters.

The Court: I do not know whether the witness is confining that to the audion?

The Witness: That is for the audion element itself, and underlying physical phenomena.

RDQ. 370. Mr. Davis spoke about the use of the audion, the great number of them as repeaters in telephoning. For instance, from Cuba or Porto Rico, I think he said to San Francisco?

A. Yes.

RDQ. 371. Would it have been possible to do that with the audions of 1914?

A. It would not—in 1914, did you say, excuse me?

RDQ. 372. Yes.

A. With the audion of 1914, it would have been perfectly possible.

RDQ. 373. I want to submit to you these statements referred to. I notice that on page 290 of the Hewitt record, that is to say, the table that is there, shows that on December 31, 1904, you had two mechanical two-way repeaters?

A. Yes.

RDQ. 374. And by 1916, when apparently, according to this table, the peak of the use of mechanical repeaters had been reached, you had ninety inserts?

A. So it states. I do not know just how the tables were made up, what was included.

RDQ. 375. And in 1917 they dropped to eighty-six, and in 1918 to seventy?

A. That is right, according to the table.

RDQ. 376. Now then, it appears that on December 31—I am taking two-way repeaters only—now on December 31, 1913, that was the first time according to this table that there were any audions installed—two-way repeaters?

A. Yes.

RDQ. 377. And at that time you had two in service?

A. That is what the table says.

RDQ. 378. Now, does that indicate to you that your statement that you made on cross-examination to the effect that you did not have any in commercial service until 1915, may have been an error?

A. It all depends on what you mean by "commercial service." It may be that my statement was in error, that my definition of commercial service, that is what it indicates to me, and is no doubt correct, that people were actually paying for telephone calls over repeaters in service. Now then, when I spoke of at least one installation, namely, that of Philadelphia, which was made in this laboratory room of ours, I did not mean that was commercial service in this sense of the word.

RDQ. 379. Let me understand on that——

A. I think it is very probable that the repeater or continuation of that repeater stayed in continuously in the sense of paid service.

RDQ. 380. Was that repeater in Philadelphia in a commercial line?

A. It was in a commercial line, yes.

RDQ. 381. And was it put to commercial use?

A. It was.

RDQ. 382. Now, then, I find in this table that in the period from 1913 to the peak of what I have spoken of as the peak of the mechanical repeater, the audions had grown in the period of four years from 2 to 150?

A. So it says; I have no reason to doubt it.

RDQ. 383. And up to 1918 to 973?

A. I have no reason to doubt it.

XQ. 384. Now, how do you account for the growth of the use of repeaters from 1904 to 1916, say?

A. I cannot explain, not knowing definitely where those were made, I cannot explain.

RDQ. 385. What I want to get at is whether telephone service and telephone lines were developed and increased and extended during that period of time?

A. They were.

RDQ. 386. To what extent? I do not mean in figures; just give me a general statement.

A. There was a large increase in telephone plant and numbers of telephones during the years up to 1907, and then there was a little slump, no decrease, but a slow rate of increase, and then a steady increase with a very big peak of course, after the war.

RDQ. 387. Did the increase and the extension of telephone lines and whatnot require an increase in the number of repeaters?

A. I would not say that you could explain that unless you knew the facts.

RDQ. 388. I am asking you for the facts.

A. There was an increased number of repeaters which was directly related to a general increase, and I would not be surprised that a large number of these mechanical repeaters went in at one fell swoop at a point like perhaps Providence or New Haven or somewhere, and that explains it.

RDQ. 389. You mentioned something about this repeater in Philadelphia and you spoke of the conditions under which Kendall had the audion set-up. What did you mean by that?

A. Conditions?

RDQ. 390. Yes.

A. What I mean, as I remember the question and answer, is this: You take the most perfect repeater that anybody in the Western Electric or anywhere else can design, the number of miles of gain, to use that term, that you can get out of it is not determined by the tube, but it is determined by the repeater circuit and the condition of the lines. As a matter of fact, you might very well, not necessarily, get a condition where a poor repeater would show up better in miles gain than a good one.

RDQ. 391. When you used the word repeater there, did you mean that?

A. I mean tube or element, repeater element.

Mr. Haight: That is all.

Mr. Davis: That is all.

(Witness excused.)

Mr. Haight: Does your Honor prefer that we call another witness or adjourn?

The Court: If you want to go on until five minutes to five, we will go on.

Mr. Haight: We were rather concerned about you.

The Court: Oh, no.

HAROLD D. ARNOLD.

Harold D. Arnold, called as a witness on behalf of the defendant, having been duly sworn, testified as follows:

Direct Examination.

By Mr. Richmond:

Q. 1. Please state your name, age, residence and occupation?

A. Harold D. Arnold, forty-three, Maplewood, New Jersey, Director of Research of the Bell Telephone Laboratories, Incorporated.

Q. 2. How long have you been connected with that organization?

A. With that organization since its inception, two years ago, but the work which that laboratory is now carrying on was previously carried on under the name of the Western Electric Company, Engineering Department, and I was employed by them in January of 1911, and have been with them since.

Q. 3. Will you please give us a little better idea of the succession between those two organizations?

A. Yes. I think in December of 1923—I am not positive of that date, but I think it is right—the Bell Telephone Laboratories was incorporated in New York for the purpose of taking over the engineering laboratory operations that had previously been carried on by the Western Electric Company and which included the engineering services of the Western Electric Company as a manufacturing organization plus the laboratory services which the Western Electric Company had previously carried on as a service for the American Telephone & Telegraph Company.

Those two services had existed under the title of the Engineering Department of the Western Electric Company, and all that occurred was simply a transfer.

of name of organization; the work remained identically the same.

Q. 4. Will you tell us of your first contact with the DeForest audion, when and where?

A. The first time that I saw the DeForest audion was when Mr. Colpitts called me into his office on November 1, 1912, and showed me there the audions which Mr. DeForest had left with him.

Q. 5. Was any one else present with you at that time aside from Mr. Colpitts?

A. No, not to my recollection.

Q. 6. Did anyone else join you at that time?

A. Oh, yes. After we had talked for a little while on that day, Mr. Colpitts called up Mr. Jewett and suggested that he come down and talk it over and he did, and we three discussed the matter together.

Q. 7. Please state very briefly what was the structure of the audion as you saw it then?

A. Perhaps I can show his Honor one of the audions that was left by Mr. DeForest.

There is the identical audion that Dr. DeForest left and by good fortune it is preserved in our museum. As you will see the audion is somewhat like our present-day audions. It has two plates, the solid nickel parts, and two grids, rather peculiar looking structures, too, and the filament is a very small loop in there. That is a tantalum filament.

I might explain to you that this tube as left with us by Dr. DeForest had two filaments. It was so arranged that if one of the filaments should burn out then this wire which you see coiled around here could be soldered on to this place and then the other filament could be lighted and its use still go on. That was for the purpose of doubling the life of the tube if that were possible.

I would like to call particular attention, since the mechanical fragility of the tube has been mentioned, to the very irregular construction of this tube and mechanically one cannot duplicate it and have a device which could be replaced time after time in a telephone plant with any decent service.

It has then a thermionic filament, in this case tantalum, a pair of grids and a pair of plates all enclosed in a bulb about two and a half inches in diameter. It is sealed off and evacuated.

I might for purposes of comparison show your Honor the type of bulb that we now make. That is the type of bulb that is used by the thousands in the telephone repeater service of the country. Fundamentally it is the same thing. There is only one filament, but that filament runs up and down. The reason we do not have to have two filaments is because the life of this filament is remarkably long.

You will notice the principal change in structure is that the cross sectional area of the device is multiplied by perhaps six. The grids are firmly made and firmly supported and the plates are firmly supported and the whole thing is a very rigid piece of machinery. It is really a piece of machinery. Perhaps the principal difference between these in structure is in the filament itself, and I will speak about that later on.

Q. 8. When you saw this DeForest audion on November 1, 1912, please tell very briefly what operations were undertaken with it and how it performed.

A. What we did was to use a circuit that Dr. DeForest had left with us and in that circuit was a provision for talking into a transmitter and for listening to the current which had been sent through the audion, listening at a telephone receiver, and we talked over it, and when you spoke in a very soft tone of voice—if I dropped my voice to the softness of tone that I mean the stenographer would not be able to hear me from this distance, it was a very soft gentle tone of voice, then this DeForest audion repeated and amplified very, very well indeed, providing the voltage on the plate was not too high. If, however, the voice was raised to that commonly used in telephone conversations, which is perhaps considerably less than the way I am speaking now, and particularly if the voice were raised to the tone which I am now using in talking in a natural manner here, then the tube would not amplify, or if it did amplify, the sounds you got from it were distressing and not intelligible.

The noise was the sort of thing that your Honor may have heard on poorly regulated wireless receiving sets which, at times, as you know, become a mass of cracklings and noises. Do not misunderstand, there was no static in this case; it was just irregular operation of the tube.

Q. 9. What impression did the DeForest audion make on you at that time? What did you think of it?

A. I was amazed. I had made a study of repeaters and I thought that I had pretty well sized up all the repeater possibilities in the world at that time and I had invented and developed a repeater of my own, and when I went into the room and saw this thing and saw how it worked I was very much astonished and somewhat chagrined because I had overlooked the wonderful possibilities of that third electrode operation, the grid operation in the audion.

I was familiar with the Fleming valve—when I say familiar with it, I never used it as a practical device, but I was familiar with it in the literature and I was familiar with the long series of conversations in the *London Electrician* carried on between Fleming and DeForest as to who was prior in that matter—and so I knew about the DeForest audion in print, but I was wrong in my impression of what the DeForest audion might do because I had not realized what the grid would do in such a device.

So when I saw this thing and saw it work my first feeling was one of some chagrin that I had not recognized its possibilities before, but I saw at once how the thing worked and I realized at once as did Mr. Colpitts and Mr. Jewett, who were trained telephone experts, that in this principle of the control of conduction of electricity between electrodes by the interposition of the grid there lay a device of marvelous usefulness in the telephone industry.

Q. 10. You have spoken of its apparent limitations. Did you make any suggestions for improvement at that time and if so what were the principal ones?

A. I suggested that we make the thing larger, increase the area of the plate with the corresponding increases in sizes of the grid, but particularly at that time, I suggested that we were not getting enough electrons from the filament in the DeForest audion.

There were two ways we could get more. One was to put in more tantalum filament and the other way was to run the tantalum filament in there hotter, but if you ran it hotter it would not last any appreciable length of time. As I recall it, DeForest told us about the length of life of these tubes that with the normal current he expected it to have about thirty-five hours' life.

So therefore we could not run the filament hotter in any reasonable way and I was very much afraid of tantalum filaments and I did not want to put in a larger tantalum filament, but I did know of Wehnelt's work and I knew that a Wehnelt oxid emitted its electrons copiously and at a very low temperature, surprisingly low temperature, and I assumed, and it turned out that I was right, that a filament could be made of the Wehnelt oxid type which would have a long life and emit large numbers of electrons. So that the suggestions that I made as to the structure of the audion were to increase its size, make it more rugged, and put in a filament which would give more electrons, specifically the Wehnelt oxid filament.

The Court: We will continue this case ten o'clock Monday morning.

(Whereupon at 4.55 P. M., an adjournment was taken to Monday, October 25, 1926, at 10 A. M.)

U. S. District Court,
Wilmington, Delaware,
Monday, October 25, 1926.

EIGHTH DAY.

Before:
Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Richmond: Your Honor, I will mention that this audion bears the mark 7-A and was referred to by Dr. Arnold on Friday, as one of the original DeForest audions brought in November, 1912.

The Court: Do you want to give it a marking here?

Mr. Richmond: That is already an exhibit in the District of Columbia case, so that I thought I would have it marked here for identification, and let the matter be taken care of when the record in the District of Columbia case is offered.

Mr. Richmond: I will mention that it was Exhibit No. 39 on the motions in the District of Columbia case, and again Exhibit No. 2 on priority in that same case. Then this other audion that the witness Arnold referred to is an example of a telephone repeater, which was Exhibit No. 104 on the motions (indicating).

HAROLD D. ARNOLD, resumes the stand.

DIRECT EXAMINATION (Continued).

By MR. RICHMOND:

Q. 11. You have mentioned some suggestions that you made on November 1st, 1912, for improvement in the structure of the DeForest audion. Will you proceed with the mention of any other suggestions for improvement at that time?

A. On Friday I talked about the improvements in structure, which I think were rather plainly visible to your Honor when I showed you the tubes. Now, those were not the most important changes that were necessary in order to go from the DeForest as presented to us, to a satisfactory telephone repeater.

The most important defect in the DeForest audion was the erratic behavior and the poorness in quality of the repeated speech, under certain conditions of operation, those conditions of operation being those normally met with in telephone service, namely, reasonable loudness of speech impressed upon a telephone transmitter. It was entirely apparent to the three of us who were together on November 1st, and to me particularly, that unless that erratic behavior could be in some way obviated, the audion, in spite of the value of the third electrode control, would not be a satisfactory device for the telephone plant. I was asked by either Mr. Colpitts or Mr. Jewett—I do not remember now which—if that erratic behavior could be obviated and I said—yes, it could be obviated; and they asked me how it could be obviated; and I told them that it could be obviated if the vacuum in the tube was made such that positive ionization did not interfere with the functioning of the tube.

Perhaps I should explain that it was clear to me at the time that when the DeForest audion was operating with low voltages and with a small speech input, it was not affected in its operation deleteriously by the presence of positive ions, but that when the voltage was increased or the speech made too loud that the unsatisfactory results which were then obtained were due to positive ionization. There were various other qustions which were asked me at that time as to the way in which I would propose to secure such a vacuum, but the suggestions that I made, the principal suggestion that I made was to get a vacuum so good that positive ionization would not interfere with the operation of the audion.

Q. 12. Did you make any suggestion as to how to get this vacuum at that time?

A. Yes, I did. I had quite a considerable amount of experience with the evacuation of various devices and particularly I had been working at that time with a device which, in the process of its construction, required careful evacuation but which itself operated in the presence of positive ions. I was therefore familiar with the technique of evacuation and Mr. Colpitts and Mr. Jewett had frequently visited the laboratory where I was working and they had seen what I was doing.

The degree of vacuum that was necessary to make from the DeForest audion satisfactory telephone repeaters was, however, a different degree of vacuum than that that I had been using and in response to questions as to how I could get that vacuum I replied that in addition to the technique that I was then employing I proposed to use liquid air and charcoal to remove the last troublesome traces of gas.

Q. 13. I am not sure whether you have testified before, but to be sure of it, will you please tell briefly just what this erratic behavior was that you referred to this morning?

THE COURT: And may I make this suggestion, Mr. Richmond? I seem to have a particularly bad blind spot with regard to why the loudness of the tone of voice seemed to increase the ionization in the tube, as I gather that it did, that when you spoke in a whisper you got amplification, but if you increased the tone of voice, that that increased the current, as I gather from Mr. Colpitts, for some reason, and I know nothing of the electrical art, except what I gathered in the various cases and what I read on the subject. I shall be glad if you will have Mr. Arnold give me such information.

Q. 14. You have heard his Honor's remarks. Will you give the explanation as indicated?

A. Yes, I will try to make that clear and if I go into too much or too little detail I hope you will instruct me.

THE COURT: You cannot do that so that you may go into all the detail that you want, because that furnishes background which enables me to get the idea.

Q. 15. Tell about the erratic behavior first and then go on.

A. The facts were these. With the DeForest audion, as DeForest left it with us, if for example one put his watch near the transmitter, then the tick of the watch was very loudly amplified and sounds of that general magnitude were loudly and well amplified, but if one spoke in a normal tone of voice in the transmitter the sounds either were not amplified or if they were amplified were clouded by the concomitant presence of erratic cracklings and noises which made the intelligibility practically nil. Those are the facts with regard to the loudness of the sound impressed upon the transmitter. Quite apart from that, if one adjusted the B-battery to increasingly large voltages, there would enter a condition in the audion which made the reproduction noisy and which might destroy the amplification even for the faintest of sounds. Those two are quite separately controlled phenomena. As to why a similar result may be obtained by those two quite dissimilar adjustments, the fact is that the adjustments are not really as dissimilar as they appear to be. I can put it briefly but perhaps not quite clearly in this way. The function of the audion repeater is to amplify. What it amplifies is the voltage which is impressed on the grid. That amplified voltage becomes apparent in the plate or B-circuit. Therefore, effectively applying a voltage on the grid is—I can hardly say equivalent—but for the moment let me say analogous to applying that same voltage in the plate circuit multiplied by the amplifying factor, of the element itself.

Now, that is a statement of fact, but I may not have made it reasonably clear to your Honor.

The Court: You made that entirely clear. But have you told me this one fact, which is one that I should know about but I do not, and I can only find out now—why does the increased volume of sound put into the transmitter increase the voltage on the grid?

A. Yes. When one speaks into a transmitter the resistance of the carbon granules in the transmitter is varied by the motion of the diaphragm which is moved by the voice. That variation in the resistance of the carbon granules correspondingly varies the current. That current passes through one of the windings of the transformer, and when you vary the current in one winding of the transformer, if the other winding is open-circuited, or essentially open-circuited, you vary the voltage on the other winding, the winding attached to the grid of the audion.

THE COURT: I have it.

THE WITNESS: Lest I have not made myself quite clear, I fear that perhaps I have not, I said this action was analogous, but I did not say that it was entirely equivalent, but if you will allow me to speak of the matter in a slightly different way, referring to what actually does take place, with the currents and voltages in the tube, when an increasing positive voltage—when I say positive voltage, I mean a voltage positive with respect to the filament—is applied to the grid, then the number of electrons that are allowed to pass from the filament across the space to the plate is increased, and the ionization in the tube is proportional to the number of those electrons which pass through the tube; and if, therefore, the grid is made more positive, the current will increase, and the ionization will increase, which is the same thing that happens when the voltage on the plate is increased.

Now, let me say one other thing further, in order that this matter may be quite clear; the telephone currents and telephone voltages are alternating currents and alternating voltages; so that if they become large in the positive sense, a thousandth of a second later, they are large in the negative sense, since they are alternating voltages; is that quite clear?

THE COURT: Yes, I understand.

THE WITNESS: So that corresponding to the times when the grid is caused to assume a comparatively high positive potential by the louder speech, are times when the grid is made to assume comparatively large negative potentials by the speech; and thereby may come about another quite different cause of erratic behavior, which I think I ought to explain.

When an audion is working as a repeater, there is a certain current flowing in the plate circuit. As these alternating positive and negative voltages are applied to the grid, it is required that the current in the plate circuit shall increase, corresponding to the positive voltages as applied and decrease corresponding to the positive voltages applied.

The Court: I do not follow that.

The Witness: Your Honor is quite clear that normally there is a definite current flowing in a plate circuit?

The Court: Yes.

The Witness: And when speech is impressed upon the grid, the grid alternatingly becomes positive and negative. When the grid becomes positive, as I have explained, a larger current flows in the plate circuit. When the grid is made negative, a smaller current flows in the plate circuit. Now, that plate current passes through a transformer, and there is impressed upon the line only the alternating components of the plate current, that is, the amounts by which it increases and the amounts by which it decreases; and in order that speech may be clearly reproduced, those currents must vary positively and negatively, proportionately to the currents which were impressed upon the audion in their positive and negative variation; otherwise——

The Court: Are you using "audion" for the grid there?

A. Yes, that is quite true. Therefore, the device itself, the audion itself, must be capable of having its current increased by an amount sufficient to respond to the positive increases of grid potential; and it must have a current, a fixed current, large enough so that when the grid becomes negative, that current can be reduced *pari passu* without becoming zero, because the current itself cannot reverse, for the electrons will only go in one direction. Therefore, if we have flowing through an audion—now to come to actual numbers which makes it easier—a current of one milliampere, then when loud speech is impressed upon the grid, it may be necessary for that current to increase to two milliamperes, corresponding to a certain large alternating voltage impressed upon the grid. If that is so, it must also reduce to zero on the corresponding negative voltage impressed on the grid, and such an audion will operate perhaps satisfactorily for impressed voltages which demand such a numerical variation; but if we impress upon the grid of the audion a voltage which requires that it increase positively to three milliamperes—an increase of two milliamperes, when the corresponding negative charge is impressed upon the grid, it cannot decrease by two milliamperes because there was only one milliampere flowing, and the only way to make such a decrease occur would be to make it have a current of one milliampere in the opposite direction, which is an impossibility; so I have tried to make clear two causes of erratic behavior. One is the incidence of ionization corresponding to increased current and increased voltage and the other is imperfect reproduction, quite apart from ionization, because of the inadequate electron emission or inadequate arrangement within the tube of its parts, so that the current cannot increase and diminish correspondingly.

There is still a third thing that causes erratic behavior and it was quite apparent in this DeForest audion. If in a highly evacuated device you have negative electrons present—well, let us be specific, let us consider this audion 7-A, which we are looking at. Electrons were coming out from the filament and going across to the plate and the grid was interposed between the filament and the plate. If the grid were made positive with respect to the filament, then some of the electrons would flow to the grid and lie upon its surface.

Now, as DeForest demonstrated that audion to us there was a condenser on the grid lead. It is a very common affair nowadays to have condensers in the grid leads of audions used as wireless detectors but not with those used in telephone repeaters. When the grid became positive in the DeForest audion the electrons collected on the grid. What could become of them? You see, they could not go anywhere. They could not get through the condenser because the condenser is made with a sheet of paper between its plates or with air between its plates so that the electrons cannot get through there and they could not get off the grid because the grid was not hot and the electrons only get off voluntarily from the surface of hot things. So the grid having become positive and having collected a lot of electrons, if then the potential in the grid circuit were reduced to zero all those electrons collected on the grid gave it a negative charge and charged the condenser and the condenser being negative prevented the flow of electrons through the tube just as if it had been charged negatively through an exterior source.

That phenomenon, the stopping of the electric current, was well known to DeForest. At any rate, he showed it to us. He did not know why it happened, but I saw right away why that happened, because I was familiar with that sort of thing. We called that action paralysis or blocking and what would happen physically would be this, that you would speak in a loud tone of voice into the audion and there would not be any blue haze, there would not be any positive ionization but the current which had been flowing from the filament to the plate would stop and would stay stopped perhaps for a minute or two minutes. Of course, during that time the audion would not repeat at all. That condition could be cured by touching one's finger to the grid or the grid wire. The reason it was cured was that the electrons which had collected on the grid were thereby let to escape through the conductivity of your body.

Now I want to make this quite clear. That phenomenon could not occur in the presence of positive ions, I mean of any considerable number of positive ions, for had there been any considerable number of positive ions they would have been attracted to the grid by its negative charge and would have discharged it. So that phenomenon was not coincident with blue haze. It was at the other end of the gamut. This erratic behavior which I spoke of rather hastily is really quite a complicated physical phenomenon when one dissects it in detail.

By The Court:

Q. 16. That is the purpose of the grid leak, to carry off those electrons on the grid?

A. Exactly, sir.

The Court: I think my blind spot has entirely disappeared.

By Mr. Richmond:

Q. 17. I want to bring out your educational training, previous to this disclosure that you made on November 1, 1912. Will you tell us what was your training and experience in the line of these phenomena before you came with the Western Electric Company, as you have said, on the first of January, 1911?

A. I received the degree of Bachelor of Philosophy at Wesleyan University in 1906, with special honors in physics and during the next year I remained at Wesleyan University, studying with Professor Cady and acting as his assistant in certain experiments which he was carrying on, relating to the behavior of an arc between iron electrodes in partial vacua. As a result of that year's work I received the degree of Master of Science.

I might say in connection with this work with Professor Cady, one of the first things that he instructed me to do was to take a large and complicated gas apparatus which he had had made by Eimer & Amend at New York City and prepare it for these experiments by building an asbestos oven electrically heated around this glass apparatus to bake it out during the process of evacuation. That was my very first experience with glass apparatus and my very first experience with the problems of evacuation. We were not at that time working for a remarkably high vacuum.

I might also say in passing that at Wesleyan University Professor Bradley, who was my professor in chemistry, had installed one of the first liquid air plants in an American college, and during my under-graduate work I helped Professor Bradley's assistant in the cryogenic laboratory, as it was called, as a sort of handy man, and so I was brought up in an atmosphere of liquid air and it was very familiar to me.

From Wesleyan in 1907, I went to the University of Chicago, where I had been given a fellowship and stayed there for four years with a short intermission while I went out on a teaching job. At the University of Chicago the problem that I was given was the problem of effect of various degrees of vacuum upon the width of the alpha line of hydrogen. That is a rather technical matter that I need not go into here but which involved the construction of apparatus in which was very pure hydrogen, and experimentation with that apparatus under various electrical and temperature conditions.

In the process of that experimental work I was taught by Professor Millikan the technique of the laboratory which was much in addition to the technique that Professor Cady had taught me at Wesleyan and under his direction—under Professor Millikan's direction—I prepared a considerable number of vacuum devices. I will leave those for the moment and speak to you about the other work I did at Chicago.

I studied of course the regular courses given in the Physics Department and particularly I specialized with Professor Millikan in modern electron theory.

When I was studying at Wesleyan I had been required to read and report upon in detail the work of J. J. Thomson as set out in his "Conduction of Electricity through Gases." At the University of Chicago, I found that Professor Millikan was using the same textbook as a basis for his courses, but was giving most of his work as a consideration of the current technical literature, basing his lectures upon the detail[illegible] reports of experimental procedure and experimental results obtained by scientists in this country and abroad in their laboratory.

I continued to take these courses in electron theory all the time that I was at the University of Chicago and they constituted a very thorough course in the literature of the time.

Returning to the experimental part of the work that I did there, I found that they had very recently installed a liquid air plant in the laboratory and were performing most of the high vacuum experiments that they performed, and there were very many such experiments, with liquid air and charcoal as the means of absorbing gases. The pumps which were being used were not very different from pumps that I had been familiar with, pumps capable of securing a fairly good vacuum, but always involving the presence of mercury vapor. The liquid air and charcoal assured that mercury vapor was removed and no traces of it were left from the apparatus to which the liquid air and charcoal was attached.

I also found that the technique that Professor Cady had taught me of building electrically heated asbestos oven around the glass apparatus was commonly followed at Ryerson Laboratory at Chicago, and Professor Millikan had me use that technique in preparing the glassware both for my own experiments and in the work that I did for him as his assistant.

Finally in the preparation of the sort of tubes that I was using it was very essential that there should be only one kind of gas present. Spectroscopic phenomena are very sensitive, particularly under certain conditions, to the presence of impurities and in the preparation of the apparatus that I used the glass was thoroughly baked and the tube was thoroughly evacuated to get out the last traces of gas that we could get out from the glass walls and in addition the electrodes and the tube which were customarily of aluminum were heated very high, frequently so hot that the glass tube broke because of the heat conducted to the glass. This heating was done by a large induction coil. The heating took place, it is true, in the presence of a very small residue of gas, because the voltages which we used, perhaps of the order of 50,000 volts, required the presence of a very small residue of gas in order to pass such a current through a tube. Nevertheless, the gas residue at the time the discharge passed was so small that the amount of gas removed from the electrodes amounted to practically all the gas that could be removed from the electrodes.

Q. 18. At what stage were those tubes sealed off?

A. After the walls had been denuded out, and after the electrodes had been freed of gas, and a very high vacuum had been secured in the tubes, the gas it was desired to investigate spectroscopically was admitted from a small side tube to the required pressure, and then the tube was sealed off from the pump and the liquid air and charcoal.

The Court: I do not understand whether the electrodes were heated and the glass tube heated while it was being pumped, or prior to that.

The Witness: Shall I answer that?

Q. 19. Yes.

A. Yes. The heating of the glass walls and the heating of the electrodes were both carried out while the pump was running and while the liquid air and charcoal were attached to the tube. That was necessary because in the heating of the electrodes, large amounts of gas are liberated. Really it is surprising how much gas is liberated from a piece of metal under these conditions and this had to be continually removed while the electrodes were heated. That was the purpose of heating the electrodes.

Q. 20. Please tell the circumstances of your going with the Western Electric Company at the first of the year 1911.

A. In the autumn of 1910, Dr. Jewett came to my room in the Ryerson Laboratory, and talked with me about employment in the telephone industry. He was introduced to me by Professor Millikan, and told me that the telephone industry required an inertialess repeater, and that he felt certain there must be a solution of the problem attainable by a proper use of the electron phenomena which were at that time the subject of the most intense study of perhaps any phenomena in physical laboratories. Dr. Jewett asked me if I would accept employment in the telephone industry, and I was very glad to accept the offer, and as soon as I had completed the experimental work which I was then doing, I left for New York and reported to work at the Western Electric Company on the second day of January, 1911.

Q. 21. And what was your first work there?

A. In an organization as large as ours it usually requires as much as three months for a man to become adjusted to the surroundings and to the general types of problems, and so during the first three months I was getting acquainted with the telephone industry and with the personnel and with the laboratory. Beginning about April, I undertook after consultation with Dr. Jewett and Mr. Colpitts the development of a telephone repeater, using the mercury arc. The suggestion to use the mercury arc as a telephone repeater was an old suggestion which had been advanced among others by Peter Cooper Hewitt but it had never proven to be a feasible suggestion in a practical way. I had the good fortune to discover a rather peculiar phenomenon in connection with mercury arcs which made it possible to make a fairly good telephone repeater, using the mercury arc, and I was later granted a patent on this device. This device differs from the ordinary mercury arc in appearance, by the inclusion within the last chamber of several different electrodes, and I think I need not go into the theory or mode of operation of the device at present; but I will speak of the preparation, the method of preparation of the device which I used. It had long been recognized that mercury arc devices were only steady in their operation when there was practically no other gas other than mercury vapor present. Peter Cooper Hewitt had made a great point of this in his patents. I studied his patents very carefully before I undertook the work, because my starting point was really where his work had left off. In order to get pure mercury vapor in an arc tube, it is necessary not only to get out the gas that was in space of the tube, but it is necessary to get the gas which was occluded on the inside of the glass walls out, with great care.

One reason why this is so essential is that a mercury arc by its very nature runs at a high temperature, and so the glass walls of the arc are during normal operation just about as hot as they will comfortably stand without softening. The very nature of the mercury arc is such as to automatically produce a good vacuum inside the container in the process of manufacture because there is a mass of mercury in the arc tube, the arc stream is hot, the mercury evaporates and passes up in a cloud of vapor rapidly through the tube to the pump and washes out whatever gases may have been left in the tube. So the mercury arc is quite a good pump. However, in the process of manufacture, that I employed, I used a Gaede mercury pump, which was at that time and still is, the best commercial mercury pump of its type.

Now, Peter Cooper Hewitt had also advised and pointed out the necessity of removing gases from the electrodes in the tube, and I followed essentially his technique, as far as positive and negative arc electrodes were concerned. That technique consisted in passing a large current through the arc, thereby heating the electrodes very hot, getting the gas out of them and continuing the pumping until that gas had been entirely removed from the tube. Thereafter, when the arc was operated at its normal value, that is, at a lower current value than that used in the existing process, the vacuum would remain good because the electrodes would not be heated so hot as they had been in the pumping process. Perhaps I might refer to the patents that disclosed what I have been talking of. There is a patent by Peter Cooper Hewitt entitled "Vapor Electric Apparatus," patented May 7, 1912, No. 1,025,464. On page 1, beginning on line 17, he says:

> "Devices of the same general character are described in certain patents issued to me on Sep-

> tember 17, 1901, and reference may be had thereto for details as to the general plan of exhausting the enclosing chamber and securing the proper conditions of the enclosed gas or vapor."

On the same page beginning with line 55:

> "In the original experiments with this class of devices, difficulty was encountered in obtaining a solid conductor which could be freed from gases and foreign materials within a practical time while on the pump. Such lamps after having apparently been suitably exhausted would become inoperative within a comparatively short time which was attributed to the giving off of deleterious gases from the extension of the negative electrode, thus rendering the lamps difficult to make practically and impairing their durability when made. I have devised various ways of overcoming this difficulty among which may be mentioned, constructing the extension from the negative electrode of very thin material and heating it by reason of the ohmic resistance offered to the passage of current through it while on the pump. . . . The material forming this extension may also be treated externally from the lamp, before putting on the pump, thus obviating the major part of the difficulty of removing the gases while the final pumping is in progress. The material may be of soft iron, carbon, graphite, or other suitable material."

And two of the patents to which he refers which issued to him September 17, 1901, have certain extracts which I wish to read. Patent No. 682,699, dated September 17, 1901, entitled "Method of Manufacturing Vapor or Gas Lamps." Page 1, line 36:

> "In the manufacture of my lamp it is essential that the containing-chamber shall be freed from deleterious gases and substances and caused when finished to have a suitable quantity of gas or gases at the proper densities. These results I accomplish by manufacturing the lamp in a

manner which will be more particularly described in connection with the accompanying drawing, which illustrates diagrammatically the lamp and the circuits and the apparatus for manufacturing it."

Now, I will skip the reference to the numbers on the drawing. Beginning on line 55:

> "The lamp is during the process of manufacturing connected with a suitable exhaust-pump 10 by means of a pipe 11. The lamp structure is exhausted by means of the pump 10, and I usually heat it during the process of exhaustion—as, for instance, by the flame of a Bunsen burner 12 or in any other convenient manner."

Has your Honor one of these copies of these patents?

The Court: Yes, I have it.

The Witness: You see the Bunsen burner?

The Court: Yes.

The Witness (Reading):

> "Previous to placing the lamp upon the pump it may be thoroughly washed with alkalies and acids to remove the impurities. When the atmosphere has been pumped out from the structure, a quantity of gas of the same kind as that which it is desired to use in the completed lamp may be let into the lamp either through exhaust-tube 11, or, if more convenient, through a tube 14, which is here shown as connected with the lower end of the lamp and as leading from a suitable reservoir 15, containing the gas. The exhaust-pump 10 is operated to pump out the gas thus admitted, and the washing by means of this gas is continued as long as may be necessary.
>
> "In order to heat the electrodes within the lamp as well as the whole lamp structure, it may be connected with a suitable source of electric currents 16, 17, and for the purpose of applying a higher difference of potential to the lamp

> than that with which it is intended to ultimately operate it a transformer 18 may be employed, having its primary coil 19 suitably connected with the source 16 and 17, and, if desired, through an interrupter 20 of any convenient character, while the secondary coil 21 is connected in the circuit leading to the lamp."

I think I need not go any further in that quotation, but I would like to point out that these last sentences refer to the same sort of technique that Professor Millikan and I employed at Chicago for denuding electrodes or tubes of gas by a passage of an induction coil discharge.

Now, turning to the last of these three patents, Patent No. 682,692, dated September 17, 1901, the title is "Method of Manufacturing Electric Lamps," page 5, beginning with line 18:

> "The lamp is then sealed onto a suitable exhaust-pump 60, of any suitable character, through an exhausting-tube 61, and the process of exhaustion is commenced. Meanwhile artificial heat is applied to the tube—as, for instance, by a Bunsen burner 62, or an electric heater, or in some other convenient manner. After the free gases and air have been exhausted an electric current of higher potential is applied to the terminals of the lamp—as, for instance, by a system of circuits and apparatus—as shown diagrammatically in Fig. 2 and consisting of a transformer 40, the primary coil 41 of which is connected between the main conductors 14 and 15 and through any suitable form of circuit-interrupter 42. The secondary coil 43 has one terminal connected with the main conductor 14 and the other terminal through a suitable adjustable resistance 44ª with the leading-in wire 7. In this manner induced high-potential currents may be applied to the terminals of the lamp and the passage of this current through the lamp produces an effect somewhat similar to that noticeable in Geissler tubes. The operation of the

exhaust-pump is continued, and a difference of potential approximately equal to that under which the lamp is intended to be operated is applied to the terminals of the lamp."

This passage again repeats the technique that I was accustomed to in Chicago.

Now, I was quite familiar with these patents of Peter Cooper Hewitt for two reasons. One was that I had made a thorough study of them when I undertook to develop the mercury arc repeater, they being the best evidence of the art as it existed that I could get hold of. The second being, that somewhat to my surprise, after I had developed what I thought was quite a different type of repeater from that that Peter Cooper Hewitt had made, I was informed that very possibly his patents were fundamental to the work that I had done and that we might have to get a license from him in order to use my invention, and I was instructed to go very carefully over all of his patents, and I did, and I read every patent he had issued at the time, and that was probably in July or August, 1912, at a time when all these patents were issued and available.

Now, I was speaking of the technique that I employed in making this mercury arc repeater that I developed. I pursued these procedures that were disclosed by Peter Cooper Hewitt and that I was familiar with in my previous work.

In addition to that I had a different problem with the repeater that I used, because I had some metal parts in that repeater that were not readily heated to a high temperature by the plans that Peter Cooper Hewitt and others had explained. There were two electrodes in my repeater adjacent to the arc stream and I had to get them hot to get the gas out of them. The way I got them hot was to apply a potential of from 150 to 300 or 400, sometimes higher, volts to those electrodes and bombard them to white heat.

That bombardment was by positively charged mercury molecules, and I think I ought to state that physically there is no difference at all between the behavior of positive ions and of negative ions except as their weight differs. Negative ions have during the last few years come to be called almost universally electrons, although when I was in school they were still called negative ions. And positive ions are not as familiar to the ordinary non-technical man nowadays because they are not much referred to in the non-technical literature, but the positive ions are simply the atoms, in this case of mercury, from which the negative electron has been removed which have a positive charge and which behave exactly as negative electrons would behave, except for the fact that they are perhaps ten thousand times as heavy more or less. So I bombarded these side electrodes in my repeater with positive ions at potentials of about 200 to 400 volts, got them white hot while the tubes were being pumped for the purpose of getting the gas out of the electrodes. I think that covers the method of preparation.

By The Court:

Q. 22. I would like to get some further information about the bombardment. If I understand, that is for the purpose of increasing——

A. Yes.

Q. 23. My lack of information is on this point, why cannot that same degree of heat be obtained by the current without the bombardment?

A. I think I can perhaps explain that in a comparatively few words and it is a very interesting and a very important point. The only way that electricity can get from an electrode into an evacuated space or any space where there is ionization present is by the emission of electrons from that electrode, Electricity can be conveyed to the electrode by the approach of positive ions to the electrode, but the electrode itself does not to any considerable extent give off positive ions. What I want to make quite clear is that when an electrode is in a gaseous discharge of any sort that the phenomenon that is happening right at the surface of the electrode is either the emission from the electrode of electrons under the influence of heat or light or the approach to the electrode of positives. I have been speaking so far of the cathode.

At the other end of the discharge, the anode can only take part in the current flow in one way, and that is by the approach of electrons to it. So as the current flows there is always the impinging on to the cathode of positive ions and also always the impinging of negative ions on the anode and that is what the current flow is, so that your Honor is quite right that there is no difference between the flow of the current and the process of the bombardment.

The two things are absolutely coincident and cannot be separated at all. However, under certain circumstances the voltage drop directly at the electrode may be large, and if the voltage drop is large then the ions, be they negative or positive, which hit the electrode, hit it very hard and as they hit it harder and harder, and more and more of them hit it, the electrode gets hotter, and that is what heating by bombardment is. Have I made that clear?

THE COURT: Yes. May I ask for some more information on one more source and then my curiosity will be satisfied? I understand the A-battery is purely for heating purposes and that is to create the Edison effect between the anode and the cathode. I think I have that. This blind spot is there. Is that the sole function and effect of the A-battery? Let me connect it up with the other difficulty because they may be related. They may not at all have anything to do with this. I have run into them and they will not get out of my mind.

The B-battery is a pump, and I think I understand that, it charges the plate positively and being positive it has the tendency to attract the electrons from the cathode and causes the stream across the path. How about the negative side of the B-battery? What is it doing all that time and what effect does it have—suppose it had no connection at all with the filament. I assume I am getting outside the field. If I am getting too far out, all you have to do is to say so.

Mr. Richmond: As long as we have Dr. Arnold here he can supply that information.

The Court: I just wanted to know these things, although perhaps they are not part of the case here. I do not know whether you are going to touch on them.

By Mr. Richmond:

Q. 24. If Dr. Arnold followed your Honor, I will aske him to make the statement.

A. If the negative terminal of the B-battery is not connected with the filament in any conductive way then there is no way in which the electrons can flow through the B-battery and through the tube. The circuit would be open as it would be if you pulled the plug out of the socket in an electric lamp and nothing will happen.

By The Court:

Q. 25. May I get just a little closer then? Somewhere I have read that under the electron theory all matter is composed of electrons or something to that effect. If sometimes in your radio you get sounds with the A-battery connected, but with the B-battery turned off, there is volume enough to hear on a clear night. Whether that means there is current from the B-battery there notwithstanding, or whether I am getting the flow of electrons from the filament through the B-battery, I do not know. I am not trying to find out about that, but I am interested in the theory which comes in here. Consequently I have wondered as to whether that A-battery is supplying both heat and the flow of electrons and then I wonder where the electrons come from, whether they come from the filament itself or whether they are supplied by a battery? If they are outside of the field here, do not bother with them.

A. I think I can explain that very briefly. As you say the B-battery is essentially a pump, it pumps electrons. Electrons exist in everything. They exist in a movable condition, particularly in metals, so that if we attach to this pump metals in which the electrons can move, the pump will cause a flow of electrons through the metals, provided a complete path, a complete circuital path is furnished in which the electrons can circulate. In the case of the vacuum tube, the electron leaving the B-battery goes to the negative terminal of the B-battery which is joined to the filament of the audion. The filament is hot and hot filaments have the property of spontaneously allowing electrons to escape from them into space. This electron starting from the battery journeys through the wire to the filament out into the space, crosses the space without hindrance, except electrostatic forces, arrives at the plate, actually hits on the plate, goes into the plate and goes along the wire from there to the positive terminal of the B-battery.

If the metallic circuit, or the conducting circuit of the B-battery is open at any place, then there will not be any current flowing and if ever there are evidences of current flow of ordinary frequencies, it is probably due to irregular construction of the equipment. The current is leaking around the place that you think you have the circuit interrupted at. May I just say this word more? The sole purpose of the A-battery is to heat the filament hot enough so that the electrons will spontaneously come out. It does have another and very, very minor effect, and that is this, you cannot send the current through the filament without having a potential difference across its terminals and when that potential difference exists in the tube then it itself varies the electrostatic field in the tube and allows a certain electron flow from one terminal of the filament to the other terminal of the filament; one terminal of the filament will be positive with respect to the other and electrons will there flow from the negative to the positive terminal. That takes no part in the operation of the tube.

Q. 26. Then may I ask this last question? The A-battery current passing through the filament does not, as I understand your answer, create a potential difference between the cathode and the anode?

A. I want to make that quite clear to you, and it is a matter of some importance in this connection, too. If the wire which you have brought from the plate to the filament is connected to the negative terminal of the filament, then all the rest of the filament except that one spot is less negative than the spot of your connection, because I said it is connected to the most negative spot in the filament. Therefore, the potential of the A-battery is not assisting the flow of electrons at all, from the filament to the plate. If, however, you attach this wire from the plate to the positive terminal of the filament, then the remainder of the filament is more negative than the spot you have attached it to, because by assumption you have attached it to the most positive spot. That greater negativeness of the remainder of the filament is caused by the A-battery and to that extent the A-battery is at that time an extension of the B-battery and does assist in the creation of potential difference, but if your Honor remembers ordinarily the voltage as used on B-batteries run from forty volts to perhaps 120 volts and the battery in the A-circuit is at most five volts and frequently very much less. You see that that plays a minor part in the operation of the tube.

Q. 27. Yes. It was plain curiosity on my part as to whether the A-battery could create a potential difference between the cathode and the anode, wholly apart from the B-battery.

A. Suppose you take the B-battery out and leave the circuit closed with just a wire from the filament to the plate. Then there may be a current flowing in the B-battery circuit due to the A-battery, and I may have misunderstood your original question because I thought your question referred to opening the B-battery circuit.

Q. 28. No, it did not.

A. If it referred to the moving of the B-battery and leaving the wires connected——

Q. 29. That is what I meant.

A. Then the answer is yes, a small current will flow.

Q. 30. Of course, in the other case you have a broken circuit?

A. I am sorry I misunderstood that.

THE COURT: I have no more questions left and suppose we take our recess.

(After a short recess.)

MR. RICHMOND: I wish to offer in evidence the three Hewitt patents referred to by the witness, Nos. 1,025,464, 683,699, and 682,692.

(Received in evidence and marked respectively "Defendant's Exhibits Nos. 44, 45 and 46." *See Volume V, Defendant's Exhibits, pages 614, 619 and 622.*)

By MR. RICHMOND:

Q. 31. I understood you to mention that the mercury arc tubes with which you worked before November 1, 1912, involved a different degree of vacuum from the audion. Will you please explain that particularly with reference to particular gases?

A. The mercury arc tubes operated with hot mercury inside of the tubes and therefore there was a considerable pressure of mercury gas present. However, the presence of any other gas than mercury was practically fatal to the satisfactory operation and life of the mercury arc tubes. Therefore, the vacuum as regards everything but mercury vapor was at as high a vacuum as that secured in the present-day audion in my judgment.

Q. 32. I understood you to say something like this, that the nature of the mercury arc was such as to automatically produce a good vacuum or a degree of vacuum. Will you please tell me whether I understood correctly and explain?

A. Certainly I did not mean to say just that. What I wanted to say and what I think I did say was that the mercury vapor boiling out through the tube carried with it gases that were in the tube, flushing them out as we commonly say. However, the vacuum was only produced when the tube was attached to a suitable pump.

Q. 33. Did you bake these mercury arc tubes that you worked with in the Western Electric Company laboratory before November 1, 1912?

A. Yes, indeed. I baked them during the process of exhaust and while they were being pumped and the process was to insert them into an asbestos oven, the asbestos oven was heated with a group of Bunsen burners whose flame was kept from striking directly upon the glass of the tubes by the interposition of a wire mesh as is common in chemical laboratories in heating beakers over Bunsen burners.

Q. 34. Could you look into this oven?

A. Yes, there was a mica window provided for looking into the oven and while the tube was being evacuated the oven was kept at a high temperature and the arc discharge was caused to pass through the tube with a larger current value than that normally to be used in its commercial service. As a result of the heating of the oven and the heating of the arc stream, the anode of the arc tube would become white hot or yellow hot and was very plainly visible when the arc current was temporarily discontinued. I might say also that the bombarding of the auxiliary or side electrodes was carried on while the tube was being exhausted and while it was in the oven.

Q. 35. You have spoken of the desire that Dr. Jewett expressed for an improved telephone repeater when he met you at Chicago in the latter part of the year 1910. Was there any special object involved in this wish for a better repeater?

A. Yes, he told me about his engaging or his having engaged to provide facilities for transcontinental telephone lines and that for such a service the mechanical repeaters which were then available were entirely unsuited. He wanted to get a different sort of a repeater whose moving parts would be so light that they of themselves would not distort the speech which they were attempting to repeat.

Q. 36. What was the repeater situation just prior to November 1, 1912?

A. There were three kinds of repeaters just prior to November 1, 1912, that we had in mind as possibilities for transcontinental lines. First was the mechanical repeater which was an old device in the telephone art, but which had been very much improved during the year 1912, and had been so improved that whereas previously only one repetition through a mechanical repeater was commercially feasible, by the end of 1912, I am not sure by November 1st, but by about that time, three mechanical repeaters could be used in series and still the speech be maintained of a commercial nature.

These mechanical repeaters were being developed in the laboratory adjacent to mine and I was personally very familiar with the work that was being done with them.

Secondly, there was a repeater that I had developed which was commonly called the Arnold arc repeater. I thought it was a very good repeater, but still it had its very definite limitations. Under certain conditions it was noisy and I had found it very difficult to get the tubes made in such a way that they would not break in service, and when they broke they spilled mercury all over the rest of the apparatus and that was a very unpleasant thing.

In brief, the mercury arc repeater was a workable device which had not been developed to a commercial state, where it was suitable to be put into a commercial plant, on November 1st, although it was so developed shortly thereafter.

These were the things we knew about. The third thing was the Von Lieben, Reisz & Strauss repeater, about which we knew through correspondence, and which was rumored to be a good repeater and to have been used in Germany, but I knew nothing of my own observation about that repeater on November 1st, indeed not until three months afterwards.

Q. 37. Now, coming back to November 1st, 1912, after you had stated that the defects in the audion for telephone repeater purposes due to gaseous ionization could be cured by procuring a high vacuum, did either Dr. Jewett or Mr. Colpitts ask you any questions as to how the vacuum would affect the operation of the audion?

A. Yes. As I recall the events, Dr. Jewett was not with us very long on that day, perhaps half an hour, and during the time that he was with us, I had expressed myself with absolute confidence that this device could be made to work as a satisfactory telephone repeater, by getting entirely rid of the ill effects of positive ionization, and after Mr. Jewett had left us, Mr. Colpitts said that he was not quite clear on one or two points. In the first place, he had heard and read that some people thought if the gas were all taken out of a thermionic device, electrons would no longer come out of the filament. I told him that there were two things he ought to get clearly in mind about that; the first was the effect, if any, of the gas that might exist between the filament and the plate. As far as that was concerned, it would not have any effect at all on the electrons coming out of the filament, because whether they came out or not was a matter of the filament itself. However, the second thing he ought to have clearly in mind was the phenomenon of emission from the filament; that I had been taught, and that I believed completely that the electrons came out of the filament solely as the result of heat. That was the theory of Richardson that Millikan had taught me, and that I had studied and understood and believed for years. That, however, it was a known fact that impurities upon the surface of a cathode, did change the amount of electron emission, and to that extent if there were gas deposited upon the filament, there might be an effect upon the emission of electrons from the filament. I made that quite clear to him. It was a matter that he was not familiar with at the time. However, I was very familiar with it, because I had looked up some time before, the literature of the Wehnelt oxide, and there, to a casual glance, at any rate, the depositing of a film of oxide upon a piece of platinum does change its electron-emitting power very enormously. So that that was the first question that Mr. Colpitts asked me, and I answered that there was no fear at all that the electron current would stop, if you got the gas out of the tube.

The second question that he asked me was if there were no gas left in the tube to interfere with the passage of the electrons across it, then, why would not all the electrons just hop across, and that, I think, is a very natural sort of question for one to ask; but I explained to him that the free electricity in the space was exactly the thing that was covered by Poisson's equation, and that although I did not know just what the law would be relating to the flow of current to the voltage, I could assure him that it would take a large voltage to get many electrons across the space.

Q. 38. Who were present when you discussed this matter of the voltage necessary to get the electrons across a perfect vacuum, I mean a practically perfect vacuum?

A. My recollection is not completely clear on that matter. I know Mr. Colpitts was present, and it is my present recollection that Mr. Jewett had left the room, but of that I cannot be certain. At any rate, perhaps I should explain that these matters were discussed between us three very freely and very frequently at that time; and it is for that reason that I cannot remember more accurately the exact occurrence at that moment.

Q. 39. You may have already answered this question, but to be sure, I will ask you: What was the life of the tantalum filament of the DeForest audions at that time, in November, 1912?

A. It is my recollection that Mr. Richards was informed and told me that DeForest expected a life of thirty-five hours of the tantalum filaments.

Q. 40. Did you have any experience at about that time so that you could speak of your own knowledge as to the life of the tantalum filaments?

A. Well, of course these tubes DeForest left with us were the subject of further investigation by us. I would hesitate very much to base any opinion as to the life of the filaments or the probable life of the filaments on my experience with those tubes, because I do not know what they had been subjected to before we got them. I might say this, however, that in the audion 7-A, which he left with us, was a filament which had to my knowledge not been used, and we used that filament, and I cannot recall just how long it did last. But I should say something of the order of less than one hundred hours.

Q. 41. Did you have any further discussion with Mr. Colpitts within the month of November in regard to this limitation on the current flow in a vacuum, due to the repulsion of the electrons that you have mentioned?

A. Yes, I did. Perhaps two weeks or about two weeks after my talk with him, I had secured the current voltage relation experimentally in the DeForest audion, when the DeForest audion was operating in the absence of appreciable positive ionization. I found that the relationship in the particular device that I had, was given by the equation I equals E, to the exponent 1.59. That was a purely experimental result.

Q. 42. There should be a factor of proportionality in there?

A. Yes, if you write it in the form of an equation write it i equals A times e to the exponent 1.59.

Q. 43. What was the interest of this result at that time?

A. My principal interest in the result was that I wanted to know just what the numerical relationship between current and voltage is, because upon that numerical relationship would have to be based the design of all the apparatus we were to use around and associate with the audion; but my reason for showing it to

Mr. Colpitts was merely to show him that I was right when I told him that there would be a considerable voltage to draw the electrons across.

Q. 44. My understanding of this result, expressed by the equation you have just given, is that it was purely experimental. Were you interested in the thing from a theoretical aspect?

A. Yes. I was very much interested in that from the theoretical aspect, and as soon as I could, within a matter of two or three weeks thereafter, I took time to work it out mathematically. I remember that I worked it out prior to Christmas, because, as a matter of fact, I went out to Cleveland at Christmas time and I recall distinctly that I had worked it out before I went to Cleveland, because I worked on a certain other case all the way back from Cleveland. What I did was to assume a very ideal case, namely, that I had a plate one square centimeter in area, which was a part of a very large plate, the whole thing being uniformly hot and emitting an enormous number of electrons, and at a distance from this large plate I had another plate cold, which was the anode. I concerned myself with the flow of electrons from the square centimeter which I had chosen on the heated plate to the opposite square centimeter on the cold plate. That makes a very simple mathematical problem, and I worked that out, and found there was a certain algebraic equation relating the current to the voltage. I worked that out before Christmas. Coming back from Cleveland, I worked out the case of the flow from the wire to the cylinder, that is a more complicated matter, and I showed this mathematical work to my assistants in the early part of 1913. I showed it to Professor Millikan in the early part of 1913, and he was not very much excited about it, because he said: "Well, that is practically the same thing that has been worked out in J. J. Thomson's book, is it not?" I said that I had looked in the book, and I did not see it there. Later on, I had occasion to review Child's article in the *Physical Review*, not because of this phenomenon, but because Child's article dealt with the emission from Wehnelt oxides, in which I was interested, and I found that Child had worked the thing out exactly as I had, and I wrote to Professor Millikan to that effect. So that in perhaps the middle of November, 1912, I had obtained experimentally the 3/2 power law with as good a degree of approximation as is obtained in the majority of present-day high vacuum devices; but that was not anything new because Lilienfeld had worked the thing out and published it a year before. And furthermore in 1913 I had worked the matter out theoretically, and arrived at the 3/2 power law, but that was not anything new, as I found that Child had worked that out.

Q. 45. To whom did you disclose it? You said to one of your assistants, I think.

A. To Mr. Nicolson and to Mr. Kendall. Mr. Nicolson had been working for me beginning November 1st, on the general problem of electron emission, and Mr. Kendall, who had been an instructor at Columbia University, came with me at the close of the winter term in Columbia, about the first of February, and the first thing that I gave him to do was to check over these figures of mine and become familiar with them.

Q. 46. Now, going back to November 1st, you have mentioned that you suggested the use of the Wehnelt oxides for the filaments instead of the tantalum filaments that were used in the audions as produced by DeForest. What were the first steps taken along this line, if any?

A. First of all perhaps I ought to speak again about the situation with regard to the tantalum filament. I was very much afraid of the tantalum filament as a filament for practical use in a telephone plant, not because I knew about it, because as a matter of fact I was quite unfamiliar with it, but because the literature indicated that people who used tantalum filaments had a great deal of difficulty with them, because of short and erratic lives. It was essential that a telephone repeater should not burn out during the telephone conversation. I knew from my studies at Chicago, that if one coated a filament with Bank of England sealing wax, or some other material which might have barium or calcium in it, that then the platinum so coated became an efficient emitter of electrons at low temperatures, and it was on that information of mine that I based the statement to Mr. Colpitts and Mr. Jewett that we ought to consider at once the use of Wehnelt oxide cathodes.

Now, at just that time Mr. Nicolson who had been a graduate student at Harvard reported for work at the laboratory, and Mr. Colpitts assigned him to me to work on the general audion problem, and as was true when I first went with the company, and as is true when any new man goes with the company, there ensued a period of perhaps two or three months, in which Mr. Nicolson was familiarizing himself with the place and the people and the job. However, his job during that time, as I had outlined it to him, was to become familiar with all the literature on thermionic emission, and he made such a study and discussed his results with me. I do not know just when I told Nicolson that he ought to make up Wehnelt oxide filaments, but it must have been some time in December. These things took some little time to start, and I think before he had made any Wehnelt oxide filaments himself, we were certain through our arrangements with the Germans that the Von Lieben, Reisz and Strauss repeater using Wehnelt oxides was going to be brought to our laboratory. and so Nicolson was told to wait that part of his work until we saw what the results were to be gotten with the Von Lieben, Reisz and Strauss repeater. I might say that to my knowledge, that repeater was the first commercial use of the Wehnelt oxides to any large extent, and we thought that by studying it we might get very practical information as to the desirability of such a construction.

The work that Mr. Nicolson did on Wehnelt oxides, the actual laboratory work, started under my direct supervision immediately after the conclusion of our tests of the Von Lieben, Reisz and Strauss repeater, and that work continued with growing success through 1913, and probably by the summer of 1913, we had a pretty good Wehnelt oxide cathode of our own.

Q. 47. Let us get a brief outline of the history of this Von Lieben, Reisz and Strauss repeater as it came to your knowledge?

A. It was in October that this matter was up for consideration. During December, as I now recall it, definite arrangements were made for a display of this repeater. The gentlemen who were to display it, came to our laboratory—I suspect in February—I have not a clear recollection of that date, but I imagine our records will show that quite clearly. They spoke English very poorly and Mr. Nicolson who had spent some five years in Germany, was assigned to them as a sort of personal guide during the work, and he devoted himself to that work during the two or three weeks that the work of testing and demonstrating their device continued in our laboratory. At the conclusion of that time, we had convinced ourselves very thoroughly that there was nothing in the Von Lieben, Reisz and Strauss repeater that compared with the audion repeater when the audion repeater was used in the absence of positive ionization, and so our negotiations with those people were stopped almost immediately thereafter.

Q. 48. Briefly, what was the further history of the Arnold arc repeater after November 1st, 1912?

A. As I indicated, on November 1st the device was not in a very good mechanical shape, and the circuits associated with it were not very well worked out; so, during the remainder of 1912 and the early part of 1913, work was continued to the extent necessary to prepare an arc repeater, so that it could actually be used in the commercial plant. It was actually used in the commerical plant at Philadelphia in 1913, and it was actually used on the transcontinental line in 1914; but it had very great disadvantages, and there never were more than eight or ten of the installations put in, and they were all abandoned, I think by 1915, or shortly thereafter.

Q. 49. How many assistants had you had before November 1, 1912?

A. I had three, as I recall it. I had Mr. Trimble, who was a rather well-educated mechanic, and Mr. Banta who was a sort of a glass blower and an office boy. I might say that the work which I had done up to that time on the mercury arc repeater, was done largely with my own hands. I spent most of my time in the laboratory at the work bench, with Mr. Trimble and Mr. Banta, conducting the electrical experiments on the apparatus, with my own hands.

Q. 50. As compared with this, what was the character of your work after November 1st, 1912?

A. The nature of my work changed completely on that date. Up to that date, I was a one-job man, and as of that date my responsibilities changed, and I became the co-ordinator on several lines of work; on the first of November, Mr. Nicolson was assigned to me and just about the same time Mr. Pierce, who was another man with some experience in the place was assigned to me, and shortly after, Mr. Weinhardt and Mr. Kendall about the first of the year, and numerous others, whose names I do not recall at the moment, were assigned to me, and my work from then on was largely the work of sitting at the desk and directing the laboratory experimentation of my assistants.

Q. 51. Just what was the reason for this change in your work?

A. The reason for this change in my work was that Mr. Jewett, Mr. Colpitts and I were all positively convinced on the 1st of November that we must go after the use of the high vacuum audion in the telephone plant just as hard as we could go. It is a little difficult, very difficult for a person who is not familiar with the telephone plant and telephone technique to appreciate what that sort of a job is and was. We think of this little bulb that I have shown here as the repeater element in the telephone plant, and so it is. But the circuits, which must be associated with it, in order to make it useful, are perhaps fifty times as expensive as the element itself and are far more complicated than the element itself.

In the case of the mechanical repeater the driving element of the repeater is much the same thing as the telephone receiver, and we knew quite a lot about that. The repeating element in the carbon repeater was a microphone much like our ordinary transmitter and we knew its characteristics quite well. Moreover, our entire telephone plant had been engineered from the start to fit those exact devices. When we came to the high vacuum audion we were confronted with a very different situation. The impedences involved were quite out of the range of those found in any telephone apparatus and new circuits, new transformers, new balancing net-works, and altogether a whole line of new technical apparatus had to be designed to fit this new device. By designed I do not mean merely designing in the mechanical sense. What I mean is that their electrical constants had to be determined in such a way that they would fit properly with the audion. As just an indication of how large a job that is, I might say that books have been published upon circuits to be used with the audion and our present every-day literature is just filled with the varieties of circuits and pieces of apparatus that are to be used with the audion.

In a telephone plant we had to find the best sort of apparatus to be used. In order to find that apparatus we had to know just what the electrical characteristics of the audion were and that I set myself to find out. It was the most important thing to do at that time.

Q. 52. Please go on and tell us about this work of finding out about the electrical characteristics of the audion, and the study of the audion that was made.

A. I was only interested in the audion as it behaved, without any positive ionization and so I took the best audion from that point of view that DeForest had left with us and it happens to be this same audion 7-A that I have already referred to. I had certain experiments made with it from which I might deduce the characteristics of the device and from which I might compute mathematically what apparatus, what sort of apparatus were needed to have associated with such a device to make it a usable part of the telephone plant.

This audion 7-A was numbered audion 7 when we got it and as I explained Friday the only difference in 7 and 7-A is that when the filament that was being used in the audion under its No. 7 chanced to be burned out we soldered the wire connection that Dr. DeForest had provided on at the base, which allowed us to light the other filaments and went ahead, but in order that we might not be confused in our records, we thereafter referred to the audion as 7-A.

There was quite a lot of work done with that audion. I was interested only in the part of that work that was concerned with its operation in the absence of positive ionization and I told Mr. Pierce, who was doing experimental work, to conduct his experiments in such a way that he was continually coming up to the blue haze region, and I knew that by doing so I would be improving the vacuum in this device, not improving the vacuum condition of the electrodes particularly, but cleaning up the gas that might exist in the space. I was quite familiar at that time with the fact that X-ray tubes and all other sorts of electrical discharge devices cleaned up the gas in them when they are being run. I wanted to get this No. 7 audion into condition so that I could get its electrical characteristics in the absence of positive ionization throughout just as large a range of voltage as possible. About the end of November—do you want the exact date there?

Q. 53. That is sufficient for the present.

A. About the latter part of November, I decided the time had come to make a complete test of that adion in the region below ionization and such a test was made and it is a part of the record in this case and it is in the exhibit book.

Mr. Richmond: Your Honor, I will explain that this volume which I hand you is the complete set of the Arnold documentary priority exhibits in the case in the District of Columbia. That is a copy that was filed in the tribunals there. The offer of that will be taken care of when we introduce the record in that case.

A. (Continued.) The work to which I am referring right now is found in the part of the exhibit book in Mr. Pierce's notebook under date of November 29th.

Q. 54. Dr. Arnold, will you give the page number to which you are referring?

A. The notebook page is 34 and 35 under date of November 29th. Perhaps I do not need at the moment to go into great detail about this page of data, but I will indicate that the record shows the current to the grid, as indicated in the upper left-hand corner, the current to the plate for various voltages applied to the grid and for various voltages applied to the plate. The voltages applied to the plate run vertically up and down the left-hand margin of the page, running on this page from minus 51 volts to plus 64. That record is continued curiously enough on the previous page of the notebook at the very bottom in some space which was left in the previous day's work and there the readings are given for 64 volts and for either 80 or 81 volts at the bottom of the page.

The voltages applied to the grid run along the top margin of the book and cover essentially the same range. The currents both to the grid and to the plate are inserted in the squares in which the records are found, the current at the top of the square being the current to the grid and the current at the bottom of the square being the current to the plate.

So we have here a complete record of the behavior of that particular DeForest audion of that date with the filament current of four amperes and with these voltages up to the place where ionization began to evidence itself.

Now, the best evidence of positive ionization that I know of is being able to get some of the positive ions to go through an electrical meter and measure them and in this record——

Q. 55. May I interrupt you, Dr. Arnold? Do you mean that the positive ions go through the meter?

A. That is an inexact expression. I do not know whether you want me to explain that in great detail.

Q. 56. I had in mind that you were rather careful to explain to his Honor a little while ago that the positive ions did not travel in the conductor?

A. That is quite true, they do not travel in the conductor, but if you are able to pick up out of the vacuous space positive ions upon the grid, then those positive ions create at the surface of the grid a positive charge, whose neutralization demands that electrons flow through the wire and the meter associated with it in the proper direction to neutralize that positive charge. I used a sort of technical slang which I think would not be misunderstood by technical people when I spoke of the positive ions going through the meter.

If you look down the column of grid current which are the top values in the little squares on the left-hand page, you will see a succession of zeroes. This means that the grid was not picking up any positive ions on that page. If you turn to the page that continues those observations, page 32 of the notebook, you will observe that on the left-hand page we have values, very small values, but yet definite values indicating current flowing because of the picking up of positive ions.

My observation stopped at the time that those currents became really appreciable. That was before very much ionization was present in the tube and before the operation of the tube was to any considerable extent effected by positive ions.

Now, the meaning of this rather formidable array of data could be got in a good many ways. One could plot grid current versus plate voltage for a given grid voltage and so on and so on. A considerable number of such plots were made. I know that I personally was most interested in finding out from this information how I should have to design the apparatus to work with the audion.

Therefore, I was particularly interested in what the input impedence of the device was, that is a function related to the voltage and current in the grid circuit; what the output impedence of the tube was, and that is a function related to the plate current and voltage; and what the amplifying factor of the tube was, that is, the number by which the incoming voltage or current would be magnified in passing through the device.

All those things were essential in order to properly design apparatus to be associated with the audion. Some days later as I had time to do it, I worked out these things and turned over the papers on which I had worked them out to Mr. Pierce who was my assistant. Will you please turn to Exhibit 10? Mr. Pierce was not very familiar with this sort of work himself and after I had turned over to him my papers he worked the whole thing out in order to familiarize himself with it. It happens that his papers are preserved and mine are not.

So there is beginning on this sheet of handwritten paper, of Arnold's priority Exhibit No. 10, a record of the algebraic work which I did and Mr. Pierce reproduced, from which we computed the input and output impedence of the tube and its amplifying factor.

After those calculations were made, I asked Mr. Pierce to check their accuracy by an actual experiment on the amount of amplification secured from the audion 7-A under certain conditions and so we have designated as E. S. 158,300 the values that I had computed for amplification to be expected from this device as a function of the grid voltage.

In this curve the grid voltage runs along the lower horizontal line and the amplification runs vertical and it is given here as miles gained and I think that matter has been clearly enough explained so I need not spend much time on it.

On the next page is a curve which is very nearly like this one. This is on E. S. 158,301 and is the results obtained by actually talking through the audion in circuit. It shows that the calculation that I had made was actually very nearly right as to the magnitude and the effect to be expected. I want to point out that the entire calculation that I made was based upon the presence of no positive ions. Had there been positive ions in that tube, my calculations would have been quite different, but I assumed that when the grid was made negative, there being no positive ions there, there would be no current flow, and when the grid was made positive the current that would flow would be entirely that of electrons.

As a result of this work many things were apparent to us. One was that the input impedence of the tube was a function of the grid voltage and it required a certain amount of skill to engineer the input device, and input transformers which would work satisfactorily with it and it was apparent that the input impedence was very high, of the order of hundreds of thousands of ohms and under certain circumstances millions of ohms.

It was also apparent that the output impedence of the audion was quite high. In this particular case considerably higher than the audions that we use at present. We had no transformers suitable for use either on the input side or the output side of that device. It indicated further that the amplification obtained was of sufficient magnitude to work satisfactorily in the telephone plant and it indicated how that amplification was modified by the various voltage factors involved. I do not know that I need to go further with the work of that time unless you want me to.

Q. 57. When was it that you began work on the audion?

A. I think I can truthfully answer that on November 1st. That was the first day, November 1, 1912, that I ever personally, with my own hands, experimented with the audion. The first constructive work I think is the work that was done under my direction by Pierce about a week thereafter, as soon as he quite got to it, in which he used this audion 7 in such a way as to improve its vacuum and prepare it for these tests that I have just described.

Q. 58. And how is that improvement effected?

A. That improvement was effected by operating the audion 7 with voltages which repeatedly introduced blue haze.

Q. 59. And the principle involved was what?

A. The principle involved was the clean-up of evacuated space by the passage of an electric discharge. I might add that, of course, the vacuum was improved by the mere act of burning the filament as we say, that is, it is known and was known at that time that in an incandescent lamp if the filament is brightly lighted for a considerable time, the vacuum improves, because of the consumption of some of the gas in the space and its deposition in some form or other on the walls of the container.

Q. 60. Can you point out a comparison that was made between this same audion and some example of a much later high vacuum tube?

A. Yes. That is a rather interesting matter. I had occasion to have made some time, some years later, as a matter of fact, a comparison between this device as I used it then and one of the high vacuum audions made by the General Electric Company as a commercial product, and that record is Exhibit 9, the blueprint. The circles in this exhibit are the results obtained with audion 7-A and you will see them extend from the very left-hand corner of the plot very closely to the upper right-hand corner of the plot. The crosses are the points obtained with the General Electric type G pliatron, otherwise known as the VT13, and those crosses also extend from the left-hand lower corner to the upper right-hand corner of the plot.

The dotted line is shown following the trend of these points, and your Honor will observe that both the crosses and the circles follow this line with reasonable exactness.

I should indicate to your Honor that this plot is drawn on logarithmic paper; that it is a straight line plot or at least that the dotted line which is drawn on the paper is a straight line and shows that the audion 7-A up to voltages of eighty volts follow the straight line logarithmic plot.

As to the exponent corresponding to the 3/2 power to be associated with this line, it is not written on the curve and for the moment I do not recall what it is. However, whatever it is, it is just the same or essentially the same for audion 7-A and the General Electric type G pliatron.

And this curve is taken in the range of voltages in which the General Electric tube is made to be operated. It is not in any sense an unfairly drawn curve from that point of view.

Q. 61. Can you point out where the data were obtained for the circles for the audion 7-A?

A. The data for the circles are obtained from Mr. Pierce's notebook. I think it is the bottom set on page 36 of Mr. Pierce's notebook. They were taken on the day succeeding that very comprehensive plot that I spoke of just a few minutes ago.

Q. 62. That is, they were taken on November 30th?

A. Taken on November 30th. The crosses are actually taken from data submitted by the General Electric Company in this case, in the interference proceeding as representing this particular product of theirs.

Q. 63. Referring to the data at the bottom of that page of Mr. Pierce's notebook, that were taken on November 30, 1912, what do those data show in regard to audion 7-A, in a general way?

A. They show that the audion 7-A was behaving satisfactorily as a thermionic device up to voltages of 83.6 volts. In order that you may know what I base that term "satisfactorily" upon, had there been any evidence of ionization in this experiment, such would have been noted on the page besides the experiment. Furthermore, the voltages used were the same voltages used in the same experiment at which I was personally present, November 29th, the comprehensive experiments that I have spoken of above, and there no considerable evidence of positive ionization was found below 80 volts.

Q. 64. So I understand that on November 30, 1912, you considered that in this audion 7-A the voltage was raised to about 80 volts without substantial evidence of positive ionization?

A. I do most certainly. Moreover, I am positive from my own personal experience with this audion that as left with us by DeForest, it would not have behaved in this way. As left with us by DeForest before 80 volts had been reached blue haze would have been apparent in the tube and in fact I need not say would have been apparent in the tube, it was apparent in the tube for voltages very much below 80 volts.

Q. 65. What time are you referring to now?

A. When DeForest left an audion with us on November 1st. In this connection I need not perhaps point out that what I mean by DeForest leaving the audion 7-A with us is that he left the audion 7-A with Mr. Colpitts in his office on October 30th, and that my first contact with it was on November 1st, at which time Mr. DeForest was not present.

Q. 66. What was the filament current that was used in those tests on November 29th, did you say?

A. The actual current used was four-tenths of an ampere. I do not know what I have said.

Q. 67. I thought perhaps you said four amperes.

A. I may have.

Q. 68. Four-tenths of an ampere?

A. Four-tenths of an ampere. That is recorded on page 34.

Q. 69. Is there anything which shows how that value was reached, any preliminary steps before fixing it at that value?

A. If we turn back to the preceding page, 32, there is a record of this same experiment started with a filament current of .375 amperes. That experiment was shortly discontinued because the current was not sufficiently large in the filament.

THE COURT: We will adjourn until 2.15.

AFTER RECESS.

By MR. RICHMOND:

Q. 70. When you directed attention to the audion that you called 7-A last Friday, you pointed out its filament along with its other elements. What is the condition of that filament now?

A. I would have to look at the bulb and tell you. (After inspecting bulb.) Both filaments are burnt out. There are only traces of the ends of them left.

Q. 71. This morning, if I understood you, you said that the much higher input impedence of the audion as compared with previously used amplifying elements, introduced some difficulty in transformer design. Will you explain that a little more in detail and tell how this difficulty was met?

A. The design of transformers for telephone service is quite a different matter from the design of transformers for power purposes. In power transformers, you are concerned with the transformation of alternating currents of one frequency, either cutomarily sixty cycles or twenty-five cycles, and the transformer is designed to be efficient at that frequency. In telephone service, on the other hand, the transformer must work satisfactorily through the entire voice range, which extends from about 200 cycles to roughly 4000 cycles. I said it must work satisfactorily through this range, and that means that it must work uniformly throughout the range with respect to frequency. The reason for that, I may possibly explain later, rather than now;

but I may say here that if the transformer used in connection with a repeater element, in the telephone plant does not operate uniformly throughout its range, then a condition of singing is likely to ensue in which a musical tone of some pitch is heard over the telephone circuit, and thus the effectiveness of the telephone circuit for transfer of speech is destroyed. Now, we had had many years' experience in designing transformers to cover the telephone range of frequencies when such transformers were to be used between impedences customary in the telephone plant. This impedence ran from perhaps 200 ohms to 2000 ohms; but we had never had any experience in designing transformers to work in connection with impedences of the order of 100,000 ohms, and that is a very difficult matter; and it is a matter that has not been brought to its perfect conclusion until the last year or two. The transformers that we had made at first, for this work were made by Mr. Scriven in January, 1913, after a study of the design features and these transformers had a variation in efficiency of perhaps a factor of five throughout the speech range; and because of this variation in the performance of the transformers, the amplification which we could obtain upon telephone circuits was substantially limited. Mr. Scriven started this work on transformers about the first of 1913, and the work was continued from then on; and within perhaps three or four years, we had pretty satisfactory transformers

Q. 72. You have told about improving the vacuum of this audion 7-A by the well-known clean-up process. Would it have been practical at that time for you to have improved the vacuum in any other way?

A. In no other way that I know of without opening the bulb, and I did not want to do that.

Q. 73. You have told about the disclosure that you made to Mr. Jewett and Mr. Colpitts on November

1st, 1912, in regard to a plan for better evacuating the audions. Please tell how these plans developed in the next month, we will say?

A. I told Mr. Colpitts and Dr. Jewett, one or both, I think both, that I intended to use liquid air and charcoal to obtain the degree of vacuum that I wanted, and at that time I had no reason to think that I could not get all the liquid air I wanted in New York City. As I stated before, I was then very familiar with its use for the preceding nine years, and so I asked one of my assistants, Mr. Trimble to go out and get some liquid air sometime shortly thereafter, I do not remember just when, and found to my surprise, that liquid air was not obtainable in any reasonable quantity in New York at that time. The processes of transporting liquid air had not then been developed to anything like the extent they are now developed, and it was apparently considered quite a feat to safely transport a quart or two of liquid air or at most a few gallons of liquid air. For any real work in connection with the production of high vacuum, other than a stunt, large quantities of liquid air would be required, and I found that I could not get them. So I abandoned that idea entirely. It happened that just about that time the Gaede Molecular Pump first came on the market, the first notice of it I saw was an advertisement on the back page of the *Annalen der Physik* for July or August, 1912. That pump is a novel sort of pump, a whirling disc travels so rapidly that the atoms become entangled on it and are carried away out of the vessel to be evacuated. It seemed rather a bold idea to get a vacuum that way, but Gaede had been entirely successful with his previous pumps and was a man of real standing, and I had no doubt that his pump would work all right.

So I decided to use the Gaede Molecular Pump and I got in touch with the representative of James

G. Biddle in Philadelphia, who are well known importers of scientific apparatus, from whom, as I remember it, we had bought our Gaede Mercury Pump, and found that they not only did not have one of the pumps, but they did not have any of the complete advertising literature which I expected. However, they said that Professor Trowbridge of Princeton, had been looking up the matter and probably had more information on it than they had. Within a few days Mr. Colpitts invited me to go down to Princeton with him to see the Physical Laboratory, and I took advantage of the opportunity to talk with Professor Trowbridge about this pump that he was going to get; and while I did not find out very much about it, I had confirmed the impression which Biddle's agent had given me, that Trowbridge was going to get one of these pumps. Shortly after that—when I say shortly, I mean within a matter of a couple of weeks or so—I received some advertising literature from Biddle about these pumps. I do not remember when I received it and I have not the copies of that advertising literature that I did receive, but I have definite recollection of receiving it, showing in some detail what the pump was and how it worked, and also a list of prices. That would be probably some time in the middle or latter part of December.

I went to Princeton, as I recall it, about the 13th of November, and this information would have then arrived as I now recall it about say the end of the second week in December. At that time I definitely had in mind ordering one of these pumps from Biddle. The arrangements for such an order were interrupted by a trip to Cleveland that I made over the last week in December, to attend a meeting of the American Physical Society there, and although the formal order had been typewritten and signed by me, as far as I remember, when I got back from Cleveland—and I remember that I was in Cleveland on New Year's Day, so I must have returned about the third or fourth of January—I found that the order had not been executed, and started at once to get action on it, and after some consultation, it was decided to order the pump directly from our own agent in Germany, rather than to deal through Biddle, with the expectation that we might thereby get somewhat more prompt service and possibly get the pump somewhat more cheaply.

The order was placed by cablegram and after a normal lapse of time the pump arrived some time in the middle of April. In expectation of the arrival of the pump I had asked Mr. Kendall, to whom I have already referred, to do some work in making a vacuum gauge which would indicate the degree of vacuum secured with the pump, and at the same time would not introduce mercury vapor into the pump. I might say here that the moving members in this pump were of such a nature that if mercury got into the pump it would tend to amalgamate with the metals of the pump and I would assume would impair its operation. Mr. Kendall took a type of gauge that I had been working with for the last year, but which was not an invention of mine, which was a hot wire type of gauge, in which the vacuum is measured by the rate of escape of heat from a heated wire. If the vacuum is very good the heat escapes very slowly as in the case of the thermos bottle and if the vacuum is poor the heat escapes more readily.

Immediately when the pump had arrived it was set up and tested with this gauge. But now I must go back just two or three weeks. In expectation of the arrival of the pump I went to Princeton where Professor Trowbridge's pump had already arrived and took the necessary measurements of the base and of supporting members so that I would be prepared as quickly as the pump arrived in the laboratory to put it to work at once, and there are records to show the date on which I made the trip to Princeton. I remember it very well now.

Therefore, when the pump had arrived we set it up, put it to work, attached it to this gauge that Mr. Kendall had made and the pump worked very well indeed. The gauge was not capable of indicating the highest vacuum, but it was good enough to show that the pump was working the way it ought to work.

As soon as we had done that we took one of the audions which we had available, opened it and sealed it on to this new pump and repumped it. At the time we repumped it we used precautions that we had been using right along in the laboratory, precautions of using an oven to bake the bulb, precaution of using B-battery or auxiliary battery as we called it, to heat the metal parts within the tube. Using this technique, we re-evacuated that tube, tested it and found no evidences of harmful ionization at voltages as high as 240 volts.

I did not look upon that as anything more than a test of the Gaede molecular pump at that time. I had already had audion devices which operated in the absence of positive ionization and I was simply pleased to find that this pump worked the way it was advertised to work and I got the results such a pump ought to give.

After that the Gaede pump was used with considerable regularity. It had the unfortunate habit of sticking once in a while in the midst of an experiment, this rotating disc was going somewhat more than a mile a minute and the pump was not quite properly constructed and we had some trouble with it. I remember all that very distinctly because I worked with it to some extent with my own hands. But it was used thereafter for most of the tubes that we evacuated. Our interest at that time was primarily upon getting the proper sort of a filament in a vacuum tube and Mr. Nicolson was making filaments with various sorts of oxid coatings upon them. These tubes were pumped and repumped at various times with this Gaede molecular pump. I considered that I had a better vacuum in April, 1913, than I had before that time, but not so very much better.

Q. 74. How good was it, good enough for what ideal?

A. The vacuum was good enough and the tube was prepared well enough so that at voltages at 200 volts or more its operation would not be interfered with by positive ionization.

Q. 75. What was the emission from the filament of this first tube that you pumped with the Gaede molecular pump in April, 1913?

A. The emission from the filament was not very great, because that was one of the tantalum filament tubes that we had on hand and was repumped and the filament was not large enough and substantial enough and could not be run safely at high enough temperature to give a larger electron emission.

Q. 76. And what was the nature of the discharge when operated at 240 volts?

A. The discharge was a pure electron discharge without positive ions taking any appreciable part in it.

Q. 77. And was it limited by the space charge effect?

A. It was.

Q. 78. Or by saturation?

A. It was limited by space charge effect in that portion of its performance where the voltage was low and by saturation in that part of its performance where the voltage was high.

Q. 79. Was this tube used for an amplifier?

A. Yes, sir. It was tested as an amplifier in a talking circuit and in that circuit it behaved satisfactorily; it gave a normal amount of amplification without any signs of the irregularities that had been so apparent in the DeForest audion of November 1st.

Q. 80. How loud could the input be in this tube of April, 1913?

A. The person speaking spoke in a normal tone of voice such as one would use in commercial telephone service.

Q. 81. Will you please explain a matter that may be commonplace to you but perhaps may not have been clearly brought out, the use of what you called a backing pump in connection with the Gaede molecular pump?

A. The Gaede molecular pump will only produce a pressure of a fraction of a millimeter. That means, that in order to use the Gaede molecular pump to create a vacuum, you must connect on one side of the pump another pump which is capable of producing itself a vacuum of a fraction of a millimeter. Then the Gaede molecular pump will perform the last operation and remove the final traces of gas to the degree desired.

Q. 82. What kind of a pump did you use for this auxiliary pump?

A. In these experiments it is my recollection that we used the Gaede mercury pump.

Q. 83. And that exhausted directly into the open air, did it?

A. No, that in turn exhausted into another pump and that pump we referred to as the Gaede box pump, but that was the last one of the series, that went straight into the air.

Q. 84. So, beginning with the pump that exhausted into the air, there was the Gaede box pump which drew air from the exhaust of the Gaede mercury pump?

A. That is correct.

Q. 85. Then in turn the Gaede mercury pump drew air from the exhaust of the Gaede molecular pump?

A. That is correct.

Q. 86. And about what degree of vacuum was that on the exhaust of the Gaede molecular pump?

A. Apart from the pressure of the mercury vapor, which might be present there, the vacuum might be as good as ten to the minus fifth millimeters, but the pressure of mercury pressure at room temperature is of the order of 10 to the minus 3. Perhaps I could express it in these terms of microns. I am not very used to using them. The Gaede mercury pump will of itself produce a vacuum of the order of 1/100 of a micron or better, except for the presence of mercury vapor which at room temperature assumes a pressure of the order of one micron or thereabouts.

Q. 87. And then this Gaede molecular pump drew air from the audion directly?

A. That is correct.

Q. 88. Just why was it that you needed a new gauge? Didn't you have gauges before?

A. We had McLeod gauges. McLeod gauges operate by the use of mercury and to any apparatus to which they are attached they contribute the vapor pressure of mercury unless some provision is made to exclude it and I did not dare use the McLeod gauge in connection with the Gaede molecular pump for fear I would get mercury vapor into the pump. I was not so much concerned about the vapor from the Gaede mercury pump getting back into the Gaede molecular pump, because you will appreciate that the Gaede molecular pump was itself blowing toward the Gaede mercury pump and would therefore exclude automatically the mercury vapor that might try to get back into the molecular pump.

Q. 89. You have testified that in your work on the mercury arc tube, you used the Gaede mercury pump. Please tell us briefly and clearly why you did not use it for the evacuation of audions?

A. Because it would introduce mercury vapor into the audions, and mercury vapor is a very potent agent in destroying the pure electron flow in a device.

Q. 90. You spoke of the short life of the tantalum filaments in the audions mentioning a figure thirty-five hours?

A. I did mention that figure.

Q. 91. Please tell us something about the progress that was made within the years 1912 and 1913 in your laboratory in extending the life of audion filaments?

A. I had not expected to get long life filaments except through the use of Wehnelt oxide cathodes. Those cathodes were developed in a variety of tentative forms in perhaps May and June, 1913; but by the middle or end of the summer of 1913, Mr. Nicolson's technique in making these had developed to the point where he had a preliminary standardized form of filament, and that these filaments and audions were made that had lives well over a thousand hours in the laboratory; but I remember specifically that in commercial service at Philadelphia, we have records of some of these audions performing for two or three hundred hours. Later on, of course the development of this filament has gone very much further, and now we are using the same general sort of filament in the telephone plant and the life of those tubes is about 35,000 hours, something over a thousand times the life of the De-Forest audion, as he described it to us.

Q. 91a. When was that record of 35,000 hours attained, and how has it been approached?

A. Well, it is rather hard to say when the record of 35,000 hours was attained, because that is a long while, and a test to that length of time occupies several years. We make our expected lives of filaments from laboratory data and from plant information, where we obtain tests, and the tubes of which I speak were made perhaps three years ago or thereabouts. The way we arrived at such a long-life filament is by very expensive painstaking and long series of developments. It is a very difficult filament to make.

Q. 92. Did this gain of life from two or three hundred hours that you mention in 1913, to 35,000 hours that you mention today, come in a jump or was it gradual?

A. Gradual.

Q. 93. What was done about getting a license from DeForest after November 1, 1912?

A. All I know about that is that eventually a license was obtained some time in the summer of 1913, but I had no direct contact whatever with those proceedings.

Q. 94. Did you put audions into repeaters on toll lines before getting the license from DeForest?

A. No. We would not want to do that sort of a thing.

Q. 95. When did you take steps to put audions in as repeaters on toll lines?

A. Those steps were taken during the summer of 1913. It happened that I was absent from the laboratory during the months of July, August and September, through illness, and I was in the hospital part of the time. During that time, Mr. Kendall was told by Mr. Colpitts to take what information he had and construct some temporary circuits to take to Philadelphia to install on the toll lines at Philadelphia, and he did so, and when I came back from convalescence, some time the latter part of September, I found that he had those in Philadelphia, and I went to Philadelphia to see them. I saw them in operation and talked over them.

Q. 96. By way of summarizing a part of your testimony, will you please enumerate briefly the particular lines of activity that you followed out after November 1st, 1912, in order to make the audion available in repeater service, and indicate very briefly what the activity was in each of those lines?

A. In the first place, I ought to say that I had not more than half of my own time available for this work during November, and the time available increased thereafter to some extent. The reason that I had no more time available was that I still had the responsibility of completing the work on the mercury arc repeater, which was naturally very close to my heart, because it was the device I had developed myself, and which in the absence of satisfactory arrangements with DeForest, appeared to have a promise of being a satisfactory telephone repeater.

Now, of the time that I had to devote to the audion, a portion had to be devoted to Mr. Nicolson, who was a new man, and required considerable time and effort on my part to get him properly started; and his job was to familiarize himself with all the literature on electron emitters, particularly with a view to Wehnelt oxides as cathodes, and I spent considerable time going over the literature with Mr. Nicolson.

Another activity that I had to give some time to, was the numerous conferences that are always had in such a case as that when a new device is in process of being developed; but the principal part of the time that I devoted to the audion was devoted to finding how to use it in the telephone plant; and as I explained, that job was an enormous job, and it was not finished for several years thereafter; so, my own time during November and December was devoted to finding out how the audion could be used by finding out what its characteristics were; and for that purpose I had one of my assistants find out what the characteristics of audions

7-A were, when it operated in the absence of positive ionization, and I myself made calculations from those data as to how it would work in a telephone circuit, and I myself made calculations of the 3/2 power law—all prior to Christmas of 1912. My activities of the first of the year 1913,—January and February and March, were in the first place connected with getting Mr. Kendall, who was another new man, started on his work, and his work was intended to be the circuit theory of the audion, but as I have indicated at the start, I put him to work on the 3/2 power law, which I had developed, and later on I had to ask him to devote some time to the vacuum gauge for the Gaede molecular pump. At about that time, that is about February, the arrangements for the von Lieben, Reisz and Strauss demonstration were completed, and Mr. Reisz and Mr. Strauss arrived, and our time was consumed inspecting and testing their apparatus and conferring with them during the month of March or a considerable part of the month of March, as I recall it.

As I have already stated, Mr. Scriven was started on the design of suitable transformers according to the information which I had got from my studies of audion 7-A. Mr. Trimble, who was my mechanical assistant, was instructed to familiarize himself as best he could, with the mechanical process of making audions. I ought to say here that no one in our laboratory, to my knowledge, had any first-hand skill or artisan ability in the construction of devices of the General incandescent lamp sort.

We did not know how to mount and prepare the filaments that were used in incandescent lamps of the tantalum and tungsten sort. Mr. Trimble expressed himself as entirely willing and thought he was entirely capable to learn that art and I told him to go ahead and do it, and we ordered some tantalum wire, some at least from Germany, and I think we got some from the

General Electric Company, but I am not sure on that point and Mr. Trimble with Mr. Weinhardt, who was assisting him, endeavored to make the mechanical structure of audions of the DeForest type using tantalum filament. He had very indifferent success at the start, but by the spring of 1913, he had mastered that trick to such an extent that he was pretty well prepared to make the mechanical portion of audions even with tantalum filaments. I think that covers most of the activities that were undertaken at that time in my group.

Q. 97. Why did you have Trimble work with tantalum filaments if you were planning to have Wehnelt oxid-coated filaments eventually?

A. I probably did not make myself clear. What I wanted Trimble to do was to find out how to make the mechanical part of the structure of the DeForest audion, the glass and metal parts and their mounting and assembly for evacuation. As far as that goes, tantalum filaments are just as good to use for trials as anything else. Besides we did not have the Wehnelt oxid filaments at that time and could not have used those in experimental work.

Q. 98. To be sure that the matter is covered, I will ask you what procedure besides mere pumping you employed in April, 1913, when you pumped for the first time with the new Gaede molecular pump, what procedure to get good vacuum?

A. I think you will find that I have already answered that, but I will repeat that the glass bulb was enclosed in an oven; the temperature of the oven was raised so high as we might safely raise it. That from my experience would be in the order of 350 degrees C. It is my recollection that a thermometer was used in the oven at the time, but I have no record of thermometer readings at hand. In addition to baking the bulb in the asbestos oven during the exhaust, the potential from the high voltage battery which I had had installed for the purpose of making mercury arcs was applied to the plate and discharge was passed from the filament to the plate, heating the plate. The discharge was also passed from the filament to the grid, heating the grid. That was actually done by tying the grid and plate together as one unit and drawing the electrons to both of them at once. I was there at the time that work was done personally.

Q. 99. I think you said that after Kendall had made the audion installation at Philadelphia during your sickness you went there and saw the installation?

A. I did.

Q. 100. What did you see?

A. The installation at Philadelphia was in a room set aside in the telephone building for us engineers to work in and in that room there were mechanical repeaters, mercury arc repeaters and the audion repeaters which Mr. Kendall had taken there. There were also all the circuit accompaniments to those various repeaters—altogether a very large room full of telephone apparatus. I saw the audions used, saw the way they behaved, and talked over the circuits to which they were connected.

Q. 101. Between what points were these repeaters used?

A. The test board man turned over to us whatever circuit either we desired or he might have available, but in general, they were circuits from New York to Philadelphia and Philadelphia either to Baltimore or Washington. We usually performed our tests at Philadelphia as loop tests in which we would pick up a pair from Philadelphia to New York and there tie it across to a pair from New York to Philadelphia, talking back to Philadelphia, insert the repeater at Philadelphia and then go down to Baltimore on one loop which was crossed at Baltimore and brought us back to Philadelphia. In this room we could talk into a transmitter and our voice would go, Philadelphia to New York, back to Philadelphia, through the repeater to Baltimore, back to Philadelphia and be heard by another man in the same room. That was the way we performed our laboratory tests at Philadelphia.

We also made many demonstrations in which people who were in New York talked from New York to people who were actually in Baltimore and in Washington, and I myself was present in Philadelphia when conversations were carried on by commercial subscribers between New York and Philadelphia over these repeaters, over these audion repeaters. That was in October, 1913.

Q. 102. That is, the repeaters were operating in paid toll service between New York and Baltimore or Washington?

A. They were specifically, my remembrance goes to their operation between New York and Washington, because I personally monitored this circuit, which means that I was listening on a connection which allowed me to hear the conversations going both ways on that circuit. I was acting then in the capacity of a telephone observer.

Q. 103. The fact that you heard well, did that prove that the people at the ends of the line, these people who had paid tolls were hearing well?

A. Not at all. The proof of good service is whether the customers have to repeat at all and if repetitions run more than a small fraction of the conversation, the connection is not considered a good connection. These connections that I listened on had little or practically no repetition. Perhaps I ought to explain just what I mean. If party A speaks to party B and party B has to ask, "What did you say," and party A has to repeat it, that is what I mean by repetition.

Q. 104. How did the newly-made audions work as to quality, summing up in a general way, in these tests at Philadelphia?

A. Perfectly.

Q. 105. Would DeForest audions, as you knew them on November 1, 1912, have served in those repeaters at Philadelphia?

A. No, they would not and the reason is that they would have as they did when they were demonstrated to us on November 1st given an irregular and erratic response. I want to make quite clear that when the customer in New York talked to the subscriber in Washington or Baltimore that the entire conversation that the subscriber in Baltimore heard had passed through and was the output of the audion in Philadelphia. The same thing is true for the subscriber in New York. All that he had heard had come through and was the output of the audion in Philadelphia and had those audions in Philadelphia behaved as DeForest audions did on November 1st, the conversation would not have been a commercial success.

Q. 106. You have just spoken of two audions. Will you explain how the repeater is made up and how these two audions figure in it?

A. There are many ways in which a repeater circuit can be built, and I do not think I need to go into these various ways but the way we used it at Philadelphia is what we have customarily called a 22 repeater. A 22 repeater means a two-way two-element repeater. That is an arrangement by which the conversation going in one direction is repeated by one element and the conversation going in the other direction is repeated by a different element and yet those two elements are so combined in the complicated circuit arrangement that to and fro conversations may be satisfactorily carried on. This is done to secure the possibility of greater amplification. There is a circuit that we used with the Shreeve mechanical repeaters customarily in 1911, called the 21 repeater, that is, a two-way, one-element repeater circuit. The two-way two-element repeater circuit allows considerably more amplification to be obtained, and the reason that it allows more amplification to be obtained is this: The electrical characteristics of a telephone line from Philadelphia to New York are very irregular; that is, if you were to measure its impedence at different frequencies at Philadelphia, you would find that that impedence was quite different at different frequencies. The reason for this difference is because the circuit is not uniform throughout its length. It has loading coils on it. If the loading coils vary by very small amounts among themselves or if their actual spacing varies by a comparatively few feet in distance, then the circuit will be irregular. Moreover, the irregularity of the circuit from Philadelphia to New York is probably quite different from the irregularity of the circuit from Philadelphia to Washington and not only that, but every circuit from Philadelphia to New York has its own irregularities and every circuit from Philadelphia to Washington has its own irregularities.

The amount of amplification you can obtain in a repeater circuit depends upon the balance existing in the circuit. By balance we mean the existence of two things that are electrically similar. If the New York-Philadelphia loop were just like the Philadelphia-Washington loop, then those two loops would be balanced and if one of them is different from the other then they are not balanced and in this 22 repeater circuit instead of attempting to balance one actual loop against the other actual loop, we balance a loop from Philadelphia to New York against an artificial network associated with the repeater structure. We also balanced the loop from Philadelphia to Baltimore with an artificial network simulating as closely as we might the actual line from Philadelphia to Baltimore. The degree to which we were successful in making such a simulation determined the amount of amplification we could get and that was the sole determining factor, providing the repeating element was sufficiently good.

In the case of the Shreeve mechanical repeaters, the art of balancing the network was fairly old. We knew quite a lot about how to do it, although the art of how to do it was developing very rapidly at just that time in connection with the transcontinental line development.

The transformers that operate with the repeater element form a part of the balancing network. They have to form a part of the balancing network.

The situation with regard to the audion was quite different. The audion was new and the transformers we used with it were new and we were not very successful at Philadelphia in October in balancing the network against the actual cables. I think I have answered your question.

Q. 107. When you say you were not very successful in making this balance at Philadelphia, how did any lack of success become apparent?

A. By howling or singing in the subscriber's circuit and that is the sort of noise that you hear when you put a telephone receiver up against the telephone transmitter or, it is a sort of noise that you get when a radio receiving set howls or sings. It is a musical note. If that should occur on the commercial circuit—well, it would be unthinkable that that would be allowed to occur on a circuit in a telephone plant, because it would be very distressing to the subscriber and so the amount of amplification of the element was reduced step by step until it was well below that amount of amplification at which singing, as we called it, would occur.

Q. 108. What adjustment was made to effect this reduction?

A. The adjustment made at Philadelphia was an adjustment of the B-battery. Later it was found that a much better adjustment could be made, namely, a high resistance shunt on the grid circuit, but at that time that high resistance shunt on the grid circuit had not been developed, and we relied there upon varying the voltage of the B-battery. This varied the outward impedence of the tube and changed the amplifying efficiency of the set-up.

Q. 109. You spoke of those irregularities in the lines extending from Philadelphia and the difficulty that they presented in effecting a balance. Has anything been done about such irregularities in the lines since then?

A. Oh, yes, indeed. There has been a very great deal done. In fact, at just about the time of these tests in Philadelphia in October, 1913, the entire circuit from New York west to Denver, was being gone over very carefully and all the loading coils relocated, and the line balanced up free of irregularities, and that procedure has been pursued at enormous expense throughout the entire repeated telephone plant.

Q. 110. What would you say was the next big job in the way of using audions in the telephone system after this installation in Philadelphia?

A. The next big job was, of course, the transcontinental telephone line. Prior to that time, some repeaters were installed in Pittsburgh, to my recollection, in the latter part of 1913. I distinctly recollect myself installing a repeater element at Chicago, in January, 1914, for very temporary service for a loop down to St. Louis. The equipment of the transcontinental line was all being designed and going in, and by the middle of the summer of 1914, we had that line cut through and repeaters were operating. I might say here that the line from New York to San Francisco was not used for paid commercial service at that time; but all the portions of it were used for paid commercial service. By that I mean that connections over that same route through the repeaters would be set up from New York to Chicago or New York to Denver, or from Chicago to San Francisco, if they were called for; but for certain reasons of publicity, it was desired not to make commercial service through the entire distance until the opening of the World's Fair in San Francisco in 1915.

Q. 111. After that, what would you call the next big undertaking in the use of audions in telephone service?

A. The next step was in radio telephony, and there, in 1914, we made high-power tubes. On April 4th or 5th of 1915, on Easter Sunday of 1915, we talked from Montauk Point to the roof of the duPont Hotel in Wilmington, and shortly thereafter we talked from Montauk Point in the end of Long Island to St. Simons Island off the coast of Georgia, and with that demonstration to inspirit them, the officials of the Telephone Company provided the necessary funds for us to erect a plant at Arlington in connection with the Navy Department. In the summer of 1915, I personally was in Washington erecting that plant and installing that station, and our men were scattered all over the world, and in the months of September and October we talked from that station to Paris, to Honolulu, to Darien, San Francisco to San Diego, by radio telephony. Those experiments were made possible by the high vacuum audion.

Q. 112. Coming back to the work at Philadelphia, for the sake of clearness please answer this question. You spoke of varying the voltage of the B-battery in the Philadelphia set-up to avoid singing. How did you vary it, increase it or reduce it?

A. Well, the procedure would be as follows: We would have a pair of wires assigned to us. We would pick out the nearest approach to the proper balancing network that we had available. We would attach it to the wires connecting it with the circuit south of Baltimore and listen. If the circuit were quiet, we would raise the B-battery, and if it was still quiet, we would raise the B-battery some more. Pretty soon the circuit would begin to sing. We would then drop the B-battery a considerable amount which was determined by experience below the singing value, and we would then proceed with our tests or turn the line over to commercial calls as the case may be; so that to avoid singing, the B-battery was diminished always below the voltage at which the singing occurred.

Q. 113. Why did you file your high vacuum audion application for a patent when you did file it, and why did you not file it earlier?

A. First, as to why I filed it when I did file it. In 1915, along about the time of our Montauk experiments in April, I became aware of the fact that the General Electric Company had filed a patent application for a high vacuum device. It was not my business to take any action upon that information other than to see that our patent department was thoroughly informed as to what had been done, and they were so thoroughly informed. As a matter of fact, our procedure is such that our patent department is quite closely in touch with all of our work as we do it. I had nothing whatever to do with the question of filing a patent application, then, in the spring of 1915. As I have stated before, I was in Washington during the summer of 1915 away from the office except for flying trips back. In September of 1915, because of the sudden illness of one of my assistants who was assigned to the job in San Francisco, I had to make a very hurried trip to San Francisco to arrange the receiving apparatus for the experiment from Arlington to San Francisco. I returned to New York about the middle of October of 1915. I found that our patent department was very much concerned about this situation. They thought that a patent application should be prepared and executed for me; such a patent application was prepared and I went over it with great care and signed it, and that was some time in October or November. I do not remember the exact date, 1915.

Now, that is what I did about filing a patent application.

Now, why I did not file a patent application earlier was, in the first place, it was not my business to file a patent application as our company is operated. It was my business to inform our patent department of any work that I might do, which, to me, appeared to be such that a patent might be issued on. That is a very considerable responsibility to assign to an engineer who is not familiar with patent practice, as I certainly was not familiar with it at that time and it did not occur to me that the work that I had done, that the suggestions that I had made, that the actual achievement of a high vacuum device in that audion 7-A for example, or the actual telling Mr. Colpitts and Mr. Jewett that I could get a vacuum so good in an audion that it would operate satisfactorily as a telephone repeater in the absence of positive ionization—as I say it never occurred to me that those things were suitable material for a patent application, and I never urged that a patent application be filed. At the time that the patent application was filed, I had been informed that my ideas of what the patent office might issue a patent on, were probably wrong. I might add that at the time that I was informed the General Electric Company had filed a patent application, I was quite convinced in my own mind, that the general field of how to obtain a high vacuum was quite old, and I understood that the patent application which they had filed was one on how to attain high vacuum, and at that time I was not interested in applying for such a patent. However, in all such matters I followed the advice of our patent department.

THE COURT: We will take a short recess.

(Here a short recess was taken.)

MR. RICHMOND: Direct examination closed.

CROSS-EXAMINATION.

By MR. DAVIS:

XQ. 114. You spoke of some work on mercury arc tubes, Doctor, which you called the Arnold mercury repeater, and you spoke of preparing those tubes by passing a large current through the arc. That was to get the gas out of the main anode, I suppose?

A. Yes, sir.

XQ. 115. And that was larger than the normal current?

A. About two and a half times as large.

XQ. 116. That is, the large current was two and a half times?

A. Yes.

XQ. 117. And the other current was what?

A. About one ampere.

XQ. 118. When you came to clear up the auxiliary electrodes you did that in a very different way?

A. I did.

XQ. 119. Why did you use a different way, that is, why didn't you make these auxiliary electrodes anodes in the mercury arc in place of the main anode?

A. Perhaps I might have done that, but that was not the way in which I intended to operate the device and I followed the procedure indicated by the way I intended to use the device.

XQ. 120. You wanted to get those things in the habit of being cathodes, in other words, is that it? And so you heated these auxiliary electrodes with a positive ion bombardment of several hundred volts, and how much current?

A. About 40 milliamperes.

XQ. 121. And they became white hot, I think you said?

A. I presume I said white hot. Those terms you realize are quite relative. I mean very visibly hot.

XQ. 122-23. Do you agree with Mr. Colpitts about the glass getting red hot?

A. I think I have not personally seen the glass red hot, but I have looked through the windows and seen the tube look red and the reason why it looked red when I saw it was that the anode was glowing red hot inside.

XQ. 124. And that light was reflected in the glass?

A. That light was reflected in the glass. That is what I saw.

XQ. 125. Now, in the normal use of that device, the current in the main circuit, the mercury circuit, from the cathode to the main anode was about one ampere. What was the current in the circuit to the auxiliary electrodes?

A. That varied very greatly in the different forms of the device. I think if I said 30 milliamperes I would perhaps be as near the average as any figure that I could name and the voltage at that time about 110 volts.

XQ. 126. Was that the speech current in those auxiliary cathodes?

A. No. That current corresponded to the B current in an audion and I think you would not refer to that as the speech current, although the speech current does exist as a part of that B current.

XQ. 127. It was the direct current upon which the speech current was superimposed?

A. That is right.

XQ. 128. I understand there were two of these auxiliary cathodes in parallel, were they, roughly speaking?

A. I do not think I would use the term parallel in this connection.

XQ. 129. All I want is this, they were both cathodes?

A. Yes, they were both cathodes.

XQ. 130. And this figure of 30 milliamperes you gave was that the current of both of them or the current to one of them?

A. The current to each.

XQ. 131. And you found those precautions were satisfactory, that is, the precaution you took in cleaning up these tubes that we are talking about?

A. Yes, the tubes worked satisfactorily.

XQ. 132. Is the drawing in your patent to which you referred the other day in describing this thing roughly to scale or does it give a general idea of the dimensions of the parts?

A. Yes, I believe it is, although the shape of the auxiliary electrodes that I used in the commercial form of the device is not the shape given in the patent.

XQ. 133. In the commercial form of the device, what was the shape of the auxiliary electrodes?

A. The auxiliary electrodes were composed of three strips of metal about an inch long, two of these three strips were about one-quarter of an inch wide and the third strip was narrower. These three strips were assembled with supporters in such a way that the strips were about 1/32 of an inch one from the other. So you will see with two such electrodes facing each other, there would exist between the two electrodes an almost completely enclosed space through which the are passed. In the patent drawing this electrode is shown as curved in the arc of a circle, or as a portion of a cylinder, perhaps, but in the form in which I actually used it the structure was built in rectangular form.

XQ. 134. How thick were these strips?

A. About 15 mils, I should say; about 15/1000ths of an inch.

XQ. 135. And the total height of the glass vessel, the complete thing was six or eight inches high?

A. About eight.

XQ. 136. You testified this afternoon, if I understood you correctly, about the first tube which you evacuated in the spring of 1913 with the Gaede molecular pump, and you said, did you not, that there was no evidence of harmful ionization up to 240 volts?

A. Yes.

XQ. 137. And that the vacuum was good enough and the tube was well enough prepared so that at 200 volts or more its operation would not be interfered with by positive ionization. I have that in my notes. Is that a correct summary of what you have said or part of what you have said? Did you testify that the vacuum was good enough and so forth?

A. I do not remember using those exact words.

XQ. 138. Is that a correct statement or not about that tube? The first tube you evacuated in the spring with a molecular pump?

A. I think I would state the matter in this way.

XQ. 139. You state it your own way.

A. Although the filament that I used was not of such a size and could not be run at such a temperature to give sufficient electrons to allow of satisfactory operation as a telephone repeater at 200 or more volts, that the mode of preparation of the tube was such that had the filament been of a nature to give enough electrons the tube would have operated satisfactorily as a repeater at 200 or so volts. As a matter of fact, it did operate satisfactorily as a repeater in the circuit in which we tested it. The voltage there was not, however, 200 volts. And it was tested at 240 volts, in which case evidences of ionization were looked for and none were found.

XQ. 140. You think that your last answer is a correct summary of what you said on direct examination on that subject?

A. I would not trust my memory on exactly what I said on direct. I do not recall the question.

XQ. 141. Did you say on direct that that tube gave a pure electron discharge at 240 volts?

A. I presume I said essentially pure because I customarily do so qualify such a statement.

XQ. 142. You mean pure in the sense in which the word pure is used in the patent in suit?

A. Yes.

XQ. 143. Your reservation being that nothing is absolutely pure in this world?

A. And particularly vacuum and electron discharges.

XQ. 144. You said something about the current being limited by space charge in this first tube of yours. I did not understand you to say that limitation was the limitation of 240 volts. Am I right?

A. You are right. That was not the limitation at 240 volts. The limitation there was set by the number of electrons possible to be emitted by the cathode.

XQ. 145. That is the tube had saturated before you got the 240 volts?

A. Yes.

XQ. 146. These various tubes have been referred to by you in those days by certain numbers, were they not?

A. They were.

XQ. 147. And as I understand it there were two numbers ordinarily, the number of the tube which was Mr. Trimble's number, in some cases at least, or Mr. Banta's number, and then there was another number which showed how many times the tube was exhausted; is that correct?

A. That was true in some cases provided you interpreted the second number correctly. If the second number was 21, it did not mean that the tube had been evacuated 21 times; or if 12, it does not mean it was evacuated 12 times.

XQ. 148. There was one case where the number looked like 111, but I understand that that means three?

A. Yes, sir.

XQ. 149. What was the number designating this first tube that you spoke of this afternoon, the first tube evacuated in April, 1913, on the molecular pump?

A. That was 20.2.

XQ. 150. What sort of a filament did that tube have?

A. A tantalum filament.

XQ. 151. And that was one of Trimble's audions made in February, or was it March?

A. It was one of Trimble's tubes, I do not recall when it was made.

XQ. 152. Were all of the tubes in April and May, tubes with tantalum filaments?

A. No, I think not all in May. It is possible that all we have a record of in May were tantalum filaments, but certainly Nicolson was making some Wehnelt oxid filaments at that time.

XQ. 153. Now, the only tubes exhausted on the Gaede pump on which we have record so far as I know are 20.2, 20.4, which is the same tube exhausted again, A-3 and B-3. Is that in accordance with your recollection?

A. So far as I can see, those are the only ones that we have records of.

XQ. 154. And all three were tantalum cathodes?

A. I know that the audion 20 was with tantalum cathodes because I was there when it was pumped. Audion had a tantalum cathode. Audion B had a tantalum cathode.

XQ. 155. And A-3 and B-3 naturally also had a tantalum cathode; is that right?

A. I will have to look that up to see whether they were re-made with another cathode. I can tell in a moment. (Perusing papers.) Yes, A-2 had a tantalum cathode. B-2 had a tantalum cathode, and A-3 had a tantalum cathode; that is right.

XQ. 156. Now, let us go back to tube 20. Tube 20 appears first in these papers you have given us in Mr. Trimble's notebook where we have a story of original exhaust; is that correct?

A. I think it is.

XQ. 157. Now, where do we next hear from that tube 20 that you have spoken of, 20.2; how about 20.1? Where is that?

A. You will have to bear with me a moment. I have not those matters in my mind. I do not remember those tubes by numbers and their histories.

XQ. 158. If you will look at page 105 of your priority Exhibit No. 18, Dr. Arnold, possibly that may help you.

A. What is the question? (XQ. 157 repeated as recorded.) 20.1 appears on notebook page 105 of Exhibit No. 18. Is that a sufficient designation?

XQ. 159. I think so, Dr. Arnold. Is that right, Mr. Richmond, is that sufficient designation?

Mr. Richmond: Yes.

A. That is Exhibit No. 18.

XQ. 160. And this was a second evacuation with a mercury pump; is that correct?

A. Certainly; it says this was pumped with a mercury pump. I have not found yet the reference to its first exhaust.

XQ. 161. If you will look on the last page of your priority Exhibit No. 14, I think you will find first pumping?

A. Oh, yes, I have it now.

XQ. 162. That is one of Trimble's notes, is it?

A. That is. That shows that this audion No. 20 was exhausted on the 17th day of January, 1913, and indicates something about the vacuum read on the McLeod gauge and that it was baked.

XQ. 163. What does it mean "output equals 360 microamperes at 24 volts minus B," if I am reading correctly?

A. I imagine that minus sign is not a minus sign but is a dash.

XQ. 164. Then it means twenty-four volts B-battery?

A. I think that is it, yes. I think that refers to a test that was made on the bulb before it was sealed off.

XQ. 165. And then this next line running at 0.65 amperes refers to filament current?

A. Yes, sir.

XQ. 166. Do you know whether this twenty-four volts B-battery was between the plate and filament or between grid and filament, or where it was?

A. No, I do not know, of my own information, about that pumping procedure on this particular tube. I may say that I took only a cursory interest in these experiments that Trimble was performing, because it was for the purpose of acquiring the mechanical technique rather than having anything to do with the production of bulbs for use.

XQ. 167. And it was re-pumped with the mercury pump of April 25, and was measured for gain, and that is the only measurement you have of that tube in that condition; is that right?

A. To the best of my knowledge, that is right.

XQ. 168. You mean that is all the information there is available?

A. As to 20.1?

XQ. 169. Yes, sir.

A. That is right.

XQ. 170. Do you know why it was re-pumped?

A. No, I do not.

XQ. 170a. Are there any records that would show why it was re-pumped?

A. I very much doubt if there are any records extant that would show why that was re-pumped. I can answer from general knowledge that the usual reason for re-pumping those tubes was that the filament had burned out, but whether that was the case in this tube, I do not know.

XQ. 171. Then the next thing that we know about that tube is that on the same page, page 105 of Exhibit 18, where it says:

> "Audion 20.2 re-evacuated with Gaede Molecular Pump"?

Is that right?

A. Yes, that is right.

XQ. 172. Why was that done?

A. That was done primarily as a test of the pump.

XQ. 173. Now, what is the next thing that happened to that tube? It appears again as 20.3, does it not, on page 108 of the same record?

A. Yes, I presume that is the same tube.

XQ. 174. And do you know why it was re-evacuated?

A. To the best of my knowledge I was not present at the time that was done and had nothing to do with it; but from general knowledge of the work that was going on. I think that was done by the men who were working with the pumps essentially to find out what different result they got when they went back and re-evacuated the tube with the pump that had mercury vapor in it, but that I must make quite clear is just a guess on my part.

XQ. 175. Then 20.2 was the one that you talked about on your direct examination this afternoon, as having been a success?

A. That is right.

XQ. 176. And then they broke the vacuum and re-exhausted it with the molecular pump?

A. Yes, sir.

XQ. 177. Of what date, April 26, 1913, is that right?

A. Or thereabouts. I will find it in a moment. (Perusing papers.) Yes, April 26, I find the date.

XQ. 178. Which is the day after it was evacuated on the molecular pump?

A. Yes, sir.

XQ. 179. And two days later they again evacuated on the molecular pump, and it takes now the name 20.4; is that correct, on page 108, and running on to page 109?

A. Yes, the date of that re-exhaust is given as April 28, 1913, that is two days afterwards.

XQ. 180. Still a tantalum filament?

A. Yes, sir. I fix that by the current through the filament, as given as 0.64 amperes. I think I made quite clear in my direct examination, that the reason that the tube is pumped on April 25, was to test the pump, not to test the tube.

XQ. 181. And on page 111, you find audion 20.5, do you?

A. Yes, sir.

XQ. 182. And that is another re-exhaust of the same audion?

A. I think it is.

XQ. 183. Do you remember whether that is exhausted again, or whether that is the last time?

A. I do not remember these re-exhausts at all, myself. I have to rely on the records in the book, and unless there is a record given here, and I think there is not, that is probably the last time.

XQ. 184. Now, referring to 20.2, 20.3 and 20.4, they all seem to have the same filament current in the test. Does that indicate they were the same filament?

A. No, not necessarily. It indicates they had filament from the same spool, that is, the same diameter of tantalum wire.

XQ. 185. I want to be able to compare the volt-ampere characteristics of these tubes 20.2, 20.3 and 20.4. Are they comparable?

A. Do you mean the filament ampere characteristics?

XQ. 186. No. I mean the plate filament voltage ampere characteristics, with the same filament current?

A. Do you mean is the structure of the tube such that it is reasonable to compare these?

XQ. 187. Yes, that is what I mean. Is the geometry of the tube the same in the three cases?

A. I cannot answer as to that, because these tubes were still rather flimsy in construction and it would not be at all surprising if the grid or even the plate had been displaced quite a bit during these pumping processes. I would not dare compare the tubes of different exhausts one with the other.

XQ. 188. Now, you have described in your direct testimony this afternoon, the procedure of exhaust of this audion 20.2——

A. On the Gaede pump?

XQ. 189. On the Gaede molecular pump?

A. Yes, sir.

XQ. 190. Where do you find a record of the exhaust as you have described it?

A. I am not at all sure that there is any such record. I speak from my own remembrance.

XQ. 191. Do you mean that that exhaust would be performed without any record being made of it?

A. Oh, yes. We would not naturally make a record of that sort of an exhaust. We might or might not.

XQ. 192. And you would glow the filaments and bombard the plates without any record of the time?

A. Yes, sir; particularly if I were there.

~~XQ. 193. Or intensity?~~

A. Yes.

XQ. 194. You would just do it without putting it down?

A. Yes, sir; particularly in those experiments in which I took part, because when I was there I usually directed what the boys do directly and there was no pause for writing things down and that particular test was a test of the behavior of the molecular pump and I was very much interested to see how that pump would work, and that is why I was there myself.

XQ. 195. But you did not even record how long it was being pumped?

A. No, I do not find any record of that. I can, however, say this from my own recollection——

XQ. 196. I am looking for records, Doctor. I am trying to find out what records exist.

A. There is no record of that, but those pumping times were never longer than an hour at the start because I made a definite rule in the laboratory that we would not run the molecular pump more than an hour until we got used to using it.

XQ. 197. Still referring to this first tube pumped on the Gaede molecular pump, 20.2 can you point to the characteristic curves of that tube as shown in your exhibits?

A. I think I can in a minute. That is the curve designated by Sketch No. E. S. 86,907.

XQ. 198. But, Dr. Arnold, may I interrupt you a moment? The E. S. sheet to which you refer contains a great number of curves. I have here a sheet which I understand is a duplicate of those two curves only. Is that right, roughly speaking? I am not asking you to approve it in detail. It is the same cut from which some pictures were made that were in one of our briefs, so that you have undoubtedly seen it before.

A. That looks all right to me, yes.

XQ. 199. Then may we use it, because it is hard to see the other. At what voltage does that tube saturate?

A. According to this curve, it saturates at about sixty volts, about twenty-eight volts, about twenty-two volts, about eighteen volts.

XQ. 200. Let us take the lower curve first because there are two different curves taken at different filament temperatures; is that right?

A. There are two different filament currents recorded here. I have no doubt that the filament temperature varied throughout.

XQ. 201. Then the lower curve was taken with the lower filament current and therefore with the lower filament temperature and with the lower emission; is that correct?

A. That is correct.

XQ. 202. Considering that and on the way up at what voltage and current did it saturate?

A. Roughly about twenty-eight volts. You asked for the milliamperes and I am trying to read them off the scale. A little short of two milliamperes.

XQ. 203. Those figures on the side are microamperes?

A. Yes, sir, and so it states.

XQ. 204. So that as the voltage was raised on this tube to somewhere above twenty volts, the current rose and bent over and became saturated at somewhere around thirty volts and then as the voltage continued to be raised the current decreased from just under 2000 microamperes down to considerably below 1500 microamperes; is that true?

A. That is true as you said it, but you must remember that the time is also elapsing.

XQ. 205. It would be hard to make all these readings at the same time?

A. It certainly would.

XQ. 206. And as you went back on the curve or decreased the electromotive force from the maximum of around 220 volts, the current decreased on a curve widely different from the upgoing curve, did it not?

A. That is correct on the saturation part.

XQ. 207. And the two curves came together at about twelve or fifteen volts; is that right?

A. Well, I should say a little above that. About that, yes.

XQ. 208. And at something around seven or eight hundred microamperes?

A. About that.

XQ. 209. Considering the other curve in the same way at the higher filament temperature the current went up to some figure off the scale which we might call 6500 microamperes, perhaps, at somewhere around fifty or sixty volts; is that correct?

A. That is correct.

XQ. 210. And then as you raised the voltage the current went down to approximately 3600?

A. I prefer to say that as time went on it went down, but it is true that both time went on and voltage was raised. Your statement is partly correct in this case, just as your statement before is partly correct.

XQ. 211. In each case the fact is that the operator applies a certain voltage to the tube and takes a reading and then applies another voltage to the tube and takes the reading?

A. Some time thereafter, yes.

XQ. 212. How long thereafter?

A. Very variable times, depending upon the contingencies of the experiment. In one instance I see a note that one minute elapsed between the two readings, indicating that the change was one entirely of time.

XQ. 213. I had not given the impression or led you to saying that these results were due to any cause whatever. I am trying to trace historically what happened.

A. And I am trying to get the truth in evidence that both voltage and time were changing.

XQ. 214. And then as time continued to elapse and voltage was brought down to zero, slowly through steps, the current went down to about 2700 microamperes, at which point it joined the upward going curve; do you agree to that, Doctor?

A. That is right.

XQ. 215. And that was at about what voltage?

A. About 24 volts, 23 volts.

XQ. 216. About 22 volts. Now, what is the——

A. Twenty-three I think I said.

XQ. 217. Did you say twenty-three volts?

A. It looks to me that way.

XQ. 218. To what do you attribute the loops in these two curves?

A. The changes in the emission of the filament.

XQ. 219. Caused by what?

A. There are very many things which may change the emissivity of a filament. As a good example of that I would cite the case of thoriated tungsten, where a very small amount of thoria such as is put in in the manufacture of incandescent lamps results in a filament whose activity may, as the temperature changes, vary enormously over a rather short period of time. I do not know where this tantalum came from. I do not know what was made in it. I would not go so far as to presume that there was thorium in this tantalum filament because I know nothing about the steps that were taken at that stage of the manufacture of tantalum to make it a proper material for lamp filaments.

I do know that they had great trouble with offsetting in tantalum just as they had with tungsten. It would not be at all surprising if this tantalum material had various materials in them, some of them intentional, which might react upon the emissivity of the filament with time at a given temperature.

Furthermore, although the temperature of this filament is indicated by the reading .64 amperes in one case, and by the reading .69 in another case, I remember rather distinctly the type of procedure used in such experiments in our laboratory which was not to read the filament current, every time the plate current was noted, but to read the filament current at one time and assume thereafter that the filament current stayed constant during these experiments.

In answer to your question, however, my present opinion is that the variation in the emissivity of the filament was due to a change in the surface of the filament, which change may have been conditioned by the materials composing the filament. At any event, it is perfectly obvious that the emissivity of the filament was changing.

XQ. 220. I suppose that the last thing that suggests itself to your mind that has any connection with these loops is gas?

A. Absolutely.

XQ. 221. You are quite sure of that?

A. Yes, that is the last thing that would suggest itself to me.

XQ. 222. Now, Dr. Arnold, this question of thoria on the surface and thorium on the surface, you are familiar with the action of thorium on a filament?

A. Fairly familiar but not from any experiments that I conducted.

XQ. 223. You know it is a matter of a layer of one atom thick?

A. I do not know. I have heard so.

XQ. 224. Do you doubt it?

A. Yes, I do doubt it. However, I do not think that is important. I will admit one atom or two-thirds of an atom, if that will suit better.

XQ. 225. Let us agree that it is an exceedingly thin layer?

A. Very thin.

XQ. 226. Which would be dissipated at any such temperature as that at which tantalum was run, immediately?

A. I do not know what temperature this tantalum filament was run at. I do not know that it would be.

XQ. 227. You are running thirty-five or forty hours of life and for a tantalum filament that is pretty high, isn't it?

A. I do not believe I can answer that question as you put it, because the life of a tantalum filament, as I understand it, is not conditioned as far as I know by its temperature. A tantalum filament, at least those tantalum filaments that we had did not evaporate and disappear. What happened to them was that they broke and I understood, although I was no expert in that art, they broke because of what was called offsetting. They came apart.

XQ. 228. Were you running the filaments on direct current or alternating current?

A. Direct current.

XQ. 229. Don't you know it does not offset on direct current?

A. No.

XQ. 230. You don't know that?

A. No.

XQ. 231. Have you heard it?

A. I heard you say it.

XQ. 232. Have you heard other people say it?

A. No, sir, that is a surprise to me.

XQ. 233. You are not in a position to deny the statement?

A. Not at all. It might be so. At any rate, I know that these tantalum filaments broke. Whether they broke from one cause or another, I do not know.

XQ. 234. They broke while current was running through them?

A. Yes, sir.

XQ. 235. Which is the way any filament does when it burns out?

A. That is right.

XQ. 236. How bright were the filaments?

A. I should say about as bright as a carbon incandescent lamp, as I recall it.

XQ. 237. That is about 1800 degrees Centigrade?

A. I do not know. I think some carbon lamps run hotter than that. I am not sure about that. I did not say that I knew or thought positively that there was thorium in here. I said I did not know what they might have put in. I did not know what was in those filaments.

XQ. 238. Of course you testified on the motion to dissolve that the characteristic thing that gas did in a thing of this sort was to make a big loop like this on a saturation curve, did you not?

A. Perhaps I did: I do not remember for the moment.

XQ. 239. But it does not occur to you that the same kind of a loop on one of your curves could be made by gas?

A. I beg your pardon?

XQ. 240. It does not occur to your mind that the same kind of a loop on one of your curves could be a gas loop?

A. Certainly in this case it would not occur to me that this would be a gas loop, because the gas was pumped out of the tube.

XQ. 241. It is conceivable that there was some gas in the electrode?

A. It is very inconceivable to me, because the electrodes were very hot.

XQ. 242. How hot?

A. Visibly hot. I cannot answer you in degrees Centigrade.

XQ. 243. How long?

A. I cannot give specific times but some minutes.

XQ. 244. At what voltage?

A. The answer to that would also have to be an approximation.

XQ. 245. I do not want an approximation. You have no record of the voltage?

A. No record.

XQ. 246. No record of the current?

A. No record of the current.

XQ. 247. No record of the treatment at all?

A. Yes.

XQ. 248-49. It merely lies in your memory that they were pretty hot?

A. Yes.

XQ. 250. And therefore although the curve here is exactly the kind of curve that was testified on the motion to dissolve was characteristic of gas, in fact, that you said it was most characteristic of gas, you are sure there was no gas in this tube?

Mr. Haight: I object, if the Court please. The witness is entitled to be furnished with the exact words and not counsel's conclusion.

The Court: I will hear you, Mr. Davis. At the moment, it seems to me that the point is well taken, and in order that I may not interrupt the proceedings at an embarrassing moment, I am going to adjourn at five minutes to five, because of a five o'clock engagement.

XQ. 251. Dr. Arnold, on the motion to dissolve, Dr. Langmuir made some experiments, did he not, which we called the regulator kenotron experiment, and the nickel-anode tube experiment; do you remember that?

A. Vaguely. I do not remember the first thing you mention. I do remember the second.

XQ. 252. In the regulator kenotron experiment, there was a tube which had a side tube containing mercury, which in some parts of the experiment was in water, and other parts in liquid air and other parts some other temperature, so as to vary the amount of gas in the tube; you do not remember that?

A. I seem to remember that vaguely, yes.

XQ. 253. Is it not your recollection that one of the points that Dr. Langmuir tried to make, and which he testified was that in general except as it causes an effect on the emission of the filament, the small operations in gas pressure do not affect the saturation curve but show very strongly on the 3/2 power curve?

Mr. Haight: I object to what Dr. Langmuir may have testified to on the motion to dissolve, which is of no materiality here, so far as the cross-examination of this witness is concerned, unless Mr. Davis will couple it with something this witness said.

Mr. Davis: I am. I am leading directly to the question of what he testified to himself.

The Witness: I do not recall.

The Court: Is the objection withdrawn?

Mr. Haight: Yes.

XQ. 254. And that you on the motion to dissolve, in rebuttal on your motion to dissolve, testified to a number of experiments in which you showed that the changes on the saturation part of the curve showed to your own satisfaction that the changes on the saturation part of the curve was very much more pronounced than they were on the space charge of the curve, and you rather harshly criticized Dr. Langmuir for what he said.

A. You will have to specify that question clearer than that, because I have not read that testimony for years, and my recollection is very vague.

XQ. 255. We will look at audion 20.4. Here again I have a figure which is very brief——

A. I have it.

XQ. 256. There are three runs on that, are there not?

A. On this sheet you hand me?

XQ. 257. No. Three runs were made on the audion, three runs are recorded in the notebook?

A. At least there are three such runs plotted on the curve of E. S. 86908.

XQ. 258. Which was the first run. Perhaps you would like over night to look at those runs, Dr. Arnold, and in the morning we will save time by going over those runs on that tube. It is now five minutes to five, your Honor.

A. Very well.

The Court: Adjourn court until ten o'clock tomorrow morning.

(Whereupon at 5 P. M. adjournment was taken until Tuesday, October 26, 1926, at 10 o'clock A. M.)

Vol. II

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DEFOREST RADIO COMPANY, PETITIONER,

vs.

GENERAL ELECTRIC COMPANY

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT

PETITION FOR CERTIORARI FILED JANUARY 8, 1931

CERTIORARI GRANTED FEBRUARY 25, 1931

(35,552)

INDEX.

PLEADINGS AND TESTIMONY.

	Vol.	Page
Docket Entries in No. 589	I	1
Docket Entries in No. 598	I	3
Bill of Complaint in No. 589	I	5
Answer as Amended in No. 589	I	10
Defendant's Bill of Particulars	I	14
Defendant's Supplemental Bill of Particulars	I	20
Bill of Complaint in No. 598	I	22
Answer as Amended in No. 598	I	29
Stipulation	I	36
Stipulation	I	133
Plaintiff's Prima Facie Proofs	I	35
Defendant's Proofs	I	145
Defendant's Depositions	II	959
Plaintiff's Rebuttal Proofs	II	1073
Defendant's Sur-Rebuttal Proofs	III	1789
Plaintiff's Sur-Rebuttal Proofs	III	1910
Appendix to Plaintiff's Record	III	1940

PLAINTIFF'S PRIMA FACIE PROOFS.

Hogan, John V. L.—		
Direct Examination	I	39
Cross-Examination	I	94
Re-Direct Examination	I	126
Re-Cross-Examination	I	135
Re-Direct Examination	I	144

DEFENDANT'S PROOFS.

Arnold, Harold D.—		
Direct Examination	I	553
Cross-Examination	I	628
Re-Direct Examination	II	746
Re-Cross-Examination	II	765
Re-Direct Examination (Resumed)	II	783
Re-Cross-Examination (Resumed)	II	785

INDEX—Continued.

	Vol.	Page
Beal, Ralph R.—		
Direct Examination	II	1044
Beck, Helene—		
Direct Examination	II	960
Cross-Examination	II	976
Re-Direct Examination	II	991
Blackwell, Otto B.—		
Direct Examination	II	804
Chaffee, E. Leon—		
Direct Examination	I	145
Cross-Examination	I	200
Re-Direct Examination	I	373
Re-Cross-Examination	I	388
Clark, Leland B.—		
Direct Examination	II	1016
Cross-Examination	II	1024
Colpitts, Edwin H.—		
Direct Examination	I	481
Cross-Examination	I	527
Re-Direct Examination	I	[illegible]
Colpitts, Edwin H. (Recalled)—		
Direct Examination	II	802
Hewlett, Palmer—		
Direct Examination	II	1005
Cross-Examination	II	1012
Re-Direct Examination	II	1015
Hyde, Ralph—		
Direct Examination	II	993
Cross-Examination	II	998
Re-Direct Examination	II	1003
Re-Cross-Examination	II	1004
Jewett, Frank B.—		
Direct Examination	I	393
Cross-Examination	I	431
Re-Direct Examination	I	436
Re-Cross-Examination	I	437

INDEX—Continued.

	Vol.	Page
Kelly, Marvin J.—		
Direct-Examination	II	811
Cross-Examination	II	857
Re-Direct Examination	II	910
Lamont, G. E.—		
Direct Examination	II	1025
Direct Examination (Resumed)	II	1065
Cross-Examination	II	1067
Re-Direct Examination	II	1067
Millikan, Robert A.—		
Direct Examination	I	440
Cross-Examination	I	459
Re-Direct Examination	I	479
Rodman, Harold Lee—		
Direct Examination	II	1057
Sarnoff, David (Stipulated Testimony)	III	1446
Tuel, Austin Y.—		
Direct Examination	II	1060
Waterman, Frank N. (Stipulated Testimony)	III	1486
Watkins, James O.—		
Direct Examination	II	1053
Cross-Examination	II	1055
Re-Direct Examination	II	1055

PLAINTIFF'S REBUTTAL PROOFS.

	Vol.	Page
Alexanderson, Ernst F. W.—		
Direct Examination	III	1448
Cross-Examination	III	1461
Coolidge, William D.—		
Direct Examination	III	1496
Cross-Examination	III	1532
Hogan, John V. L.—		
Direct Examination	III	1563
Cross-Examination	III	1639
Direct Examination (Resumed)	III	1659
Direct Examination (Resumed)	III	1721
Cross-Examination (Resumed)	III	1767

INDEX—Continued.

	Vol.	Page
Langmuir, Irving—		
Direct Examination	II	1073
Cross-Examination	II	1299
Re-Direct Examination	III	1436
Re-Cross-Examination	III	1439
White, William C.—		
Direct Examination	III	1467
Cross-Examination	III	1490

DEFENDANT'S SUR-REBUTTAL PROOFS.

	Vol.	Page
Arnold, Harold D. (Recalled)—		
Direct Examination	III	1867
Cross-Examination	III	1878
Becker, Joseph A.—		
Direct Examination	III	1789
Cross-Examination	III	1824
Re-Direct Examination	III	1847
Re-Cross-Examination	III	1847
Folk, George E.—		
Direct Examination	III	1852
Cross-Examination	III	1862
Re-Direct Examination	III	1867
Hunter, Frederick L.—		
Direct Examination	III	1893
Cross-Examination	III	1905
Re-Direct Examination	III	1907
Re-Cross-Examination	III	1907
Langmuir, Irving—		
Direct Examination	III	1848

PLAINTIFF'S SUR-REBUTTAL PROOFS.

	Vol.	Page
Bayard, Fairfax—		
Direct Examination	III	1910
Cross-Examination	III	1911
Langmuir, Irving—		
Direct Examination	III	1912

7

United States District Court,
Wilmington, Delaware,
Tuesday, October 26, 1926,
10 o'clock A. M.

NINTH DAY.

Before:
Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Haight: If your Honor please, you will recall that near the close of yesterday's session, Mr. Davis asked several questions of Dr. Arnold, which indicated, and in fact, stated that he had testified on the motion to dissolve to a certain fact. One of the questions to which I objected was:

"XQ. 250. And therefore, although the curve here is exactly the kind of curve that was testified on the motion to disolve was characteristic of gas, in fact, that you said it was most characteristic of gas, you are sure there was no gas in this tube?"

Now, we have searched Dr. Arnold's testimony on the motion to dissolve, and indeed on the priority record, and we find no such testimony. Now, I assume that Mr. Davis would not have stated that, except, of course, as an error, unless he thought there was such testimony; but in justice to the witness, I now ask that statements of Dr. Arnold's testimony given on the motion to dissolve or on the priority, be confined to such testimony; and that counsel's questions indicate when Dr. Arnold had given such testimony heretofore.

Mr. Davis: If your Honor please, the testimony which I had in mind was testimony given in behalf of Dr. Arnold by other experts. I regret that I remembered it as Dr. Arnold's own testimony. It was actually the testimony of Dr. Millikan and of Mr. Van der Bijl.

THE COURT: Then Judge Haight's motion should be granted, and his objection should have been sustained, and I take it that the motion now is to strike it out; and you can re-put the question in such a way as you see fit, Mr. Davis, in view of your refreshed recollection.

I wonder if counsel won't come up and tell me two or three things before we get started, because I have these things in my mind.

(Discussion.)

HAROLD D. ARNOLD, resumes the stand.

CROSS-EXAMINATION (Continued).

By MR. DAVIS:

XQ. 259. Dr. Arnold, may I trouble you to look at your answer to XQ. 137, 138 and 139, on page 631 of the record?

A. I have the page, but the questions escaped me.

XQ. 260. The questions are XQ. 137, 138 and 139.

A. Yes, I have read them over.

XQ. 261. Now, in view of those answers, do you withdraw your answer to Q. 74, page 611?

A. Is that on direct?

XQ. 262. On direct, yes.

A. Why, no, I see no reason for withdrawing that; unless I misread them they say the same thing in sense.

XQ. 263. I said to you XQ. 137: "And that the vacuum was good enough and the tube was well enough prepared so that at 200 volts or more its operation would not be interfered with by positive ionization." You said: "I do not remember using those exact words." I said: "Is that a correct statement or not about that tube?" And you said: "I think I would state the matter in this way." And you went on and stated it in a different way, practically denying having said what I suggested you had said. It turns out on reference to Q. 74, that what you said, as far as I can see, is exactly what I suggested you said; is that right?

A. All that you say is certainly not right. I made a statement on my cross-examination, which to my mind is identical in sense with the statement that I made on my direct examination. When you asked me if I had used certain words on my direct examination I replied that I did not remember using those words, because I certainly do not carry in mind the exact words that I used from hour to hour. I do carry in mind the sense of what I said, but to my mind there is no contradiction whatever between what I said on cross at this place and what I said on direct at the place you indicated.

Mr. Davis: I would like to mark for identification, if I may, the sketch which I showed the witness at XQ. 198.

XQ. 264. I will ask the witness if this is the sketch which I showed him, is it?

A. I hardly know how to answer it. I do not know whether this is the sketch you showed me or not.

XQ. 265. Does it look like it?

A. It does.

The Court: Or a duplicate. I think the witness had in mind whether that was the identical copy.

The Witness: That is what I had in mind. I could not testify to that.

By The Court:

Q. 266. Mr. Davis is not interested whether it is the identical copy but whether it is the paper or a like copy of the one you had.

A. It is like the paper which you showed me.

Mr. Davis: May I have it marked?

(Received and marked "Plaintiff's Exhibit B" for identification.)

Mr. Haight: Is not that in the Arnold exhibit book on priority?

Mr. Davis: I think not.

By Mr. Davis:

XQ. 267. That is a sketch which, as I explained yesterday, and as I think the witness stated yesterday, if I am not mistaken, is the same as some of the sketches, those E. S. sketches in the exhibit book, but we plot two curves on a sheet by itself, instead of having them all in the one sheet. Is that essentially correct?

A. I would like to compare that curve with the actual curve which you say it is like before I dare answer that question.

XQ. 268. Now, you will remember that yesterday we were discussing the tube 20, and that it was exhausted in all six times?

A. I have refreshed my mind on what happened there by reading over the notes.

XQ. 269. Will you please state——

A. And what I find is a record of its having been originally pumped on the 17th of January, 1913, and thereafter, an account of four repumpings; that makes five pumpings in all.

XQ. 270. There was actually one more, was there not?

A. Well, if there is, it escaped me.

XQ. 271. The first time it was pumped, it was called 20?

A. That is right.

XQ. 272. The first time it was repumped, which is the second time it was pumped, it was 20.1?

A. That is not clear in the book. It is my impression that the tube was not then repumped. I think the number was changed from 20 to 20.1, because it was to be repumped and it was desired to be referred to as having been repumped with a subscript and for some reason the subscript 1 was added without any intended designation of repumping. That is my interpretation of the book, but the book does not say whether it was repumped or not.

XQ. 273. You say you have looked over the notes. What notes did you look over?

A. I looked over the notes that are in this so-called exhibit book. Do you want me to name the pages?

XQ. 274. No. Thank you. I asked you if those were the only notes you had access to?

A. Those are the only notes I had access to.

XQ. 275. Now, if you will be kind enough to turn to page 105 of that notebook, which is Arnold Priority Exhibit No. 18, being extracts from Pierce's notebook No. 20, you will note that the record seems to show that the 20.1 designation was given to it before it was repumped on a molecular pump; is that right?

A. That is right, and the heading on that page reads:

> "This audion was pumped down by the mercury pump."

But there is nothing to indicate here that it was pumped down at that time rather than having been pumped down with the mercury pump in its original manufacture.

The matter is not clear. I thing it is probably an unimportant point.

XQ. 276. And on page 101 of the same notebook, this tube was referred to as 20, without the extra designation 1, is it not?

A. That is right.

XQ. 277. However many times it may have been pumped when these readings at the top of page 105 were made, it was immediately repumped with the Gaede molecular pump on that day, April 25, is that right?

A. That is correct.

XQ. 278. And then it was repumped the next day. I won't trouble you on that because we went through it yesterday. It was repumped several times in a few days, as I remember it?

A. That is correct.

XQ. 279. You attributed yesterday the repumping which made it 20.2 to the desire to test the Gaede molecular pump?

A. That is correct.

XQ. 280. To what do you attribute the repumping made at 20.3?

A. I will have to speak from my best belief on that, because I was not present of my recollection at the time it was done.

XQ. 281. Then we will not trouble you if you do not know, Doctor. You said something yesterday about filaments burning out pretty often?

A. Tantalum filaments?

XQ. 282. Yes.

A. Yes, they did burn out very frequently with us.

XQ. 283. Is it conceivable that they would not burn out rapidly enough to cause this repeated repumping shown in the history of this tube?

A. I have no reason to think that the filament burned out between each of these repumpings. No. I have a very definite idea as to why these tubes are repumped this way, if you care to have me state it.

XQ. 284. I do not want mere guesses, Doctor. If you have anything better than a guess, I will be glad to have you state it.

A. I think it was better than a guess, because I knew the general conduct of the work at the time, although I was not personally present.

XQ. 285. If you are speaking of the practice of your own laboratory, go ahead.

A. Very well. At that time, the men who were working with the molecular pump were very desirous of acquiring skill in its use. It was a rather delicate piece of apparatus, to use, as I indicated in one of my earlier answers; and they were also desirous of comparing for themselves the results obtained with the Gaede Molecular Pump and the Mercury Pump. That I believe is the reason why this particular lamp bulb was re-evacuatel several times alternately with the Gaede Mol[illegible]uar Pump and the Mercury Vapor Pump, and I think I should state that as far as this No. 20 is concerned, it relates to a certain glass bulb. It should not be considered for a moment that in the embodiments designated by subscripts 1, 2 3 and so forth, the bulb was alike in its operating characteristics or alike in its vacuum conditions. The one reason for putting on the No. 20 was to keep track of that particular glass bulb throughout its service in the laboratory.

XQ. 286. Now, referring to Plaintiff's Exhibit B for Identification, which is the curve of 20.2 or referring, if you prefer, Doctor, to your own notes, your own record of that tube on one of the E. S. sheets——

A. Is that the curve which you just asked me to identify a few moments ago?

XQ. 287. Yes, you have——

A. May I compare that for a moment? (Perusing papers.) Yes, I have that matter in mind now.

XQ. 288. I spoke to you yesterday about the big loops—on the saturation part of the curve. Now, do you remember that Dr. Millikan in the testimony which he gave in your behalf, in rebuttal on motion in the Interference, beginning at page 838 of the Interference record, which is page 370 of Arnold's rebuttal on motion, testified as follows:

> "Dr. Van der Bijl's diagrams in Arnold Exhibits 55, 57, 59 and 60, all show that, as a matter of fact, the kinds of gases which are likely to be present in thermionic tubes as residuals do produce large changes which are markedly noticeable in the saturation region at pressures at which they are not noticeable at all in the space charge region; so that, in practical devices, tests in the saturation region are in many, many instances much more sensitive in the detection of small quantities of gas in tubes than are tests in the space charge region."

Do you remember that; I mean, do you remember that the Doctor testified substantially to that effect?

A. I have heard you read it.

XQ. 289. I am asking if you remember it?

A. I do not remember hearing Professor Millikan say that. I doubt if I was present when he said it.

XQ. 290. Do you remember reading it in the record?

A. I do not at the moment recall having read that, but I will listen to you read it now.

XQ. 291. Do you agree or disagree with it now that you have heard it read?

A. I agree—may I read it over myself to make sure that there is no small point which escapes me? I certainly agree with it in general.

> Mr. Davis: While he is reading it I will say that this is a heavy record and it is hard to remember just what a witness has testified to. That is what I had in mind when I asked those questions yesterday.

A. (Continued): Yes, I have read this over myself and that is a statement that I can thoroughly endorse.

XQ. 292. You would not call this curve 20.2 reproducible over a very wide range of voltage, would you? That is, you would not call it reproducible where these loops are?

A. Oh, no, indeed. That curve is not reproducible on the saturation portion. If you so desire I will explain about that saturation portion.

XQ. 293. I think you have explained yesterday.

A. No, I do not think I explained yesterday. I think you asked me perhaps what I thought was the reason why the thing was variable, but I did not go into any complete explanation.

XQ. 294. Take the upper curve. At what voltage does the lack of reproducibility manifest itself on this particular curve you have before you?

A. From about 23 volts upward to 240 volts there are not on this curve any two points that are alike.

XQ. 295. At what current does this lack of reproducibility manifest itself?

A. From about 2.7 milliamperes upwards there are no two points which correspond.

XQ. 296. What is the energy corresponding to 23 volts and 2.7 milliamperes?

A. Will you repeat that question, please?

XQ. 297. What is the energy corresponding to that point on the curve where you say reproducibility stops?

A. Is that the way you want me to answer it now? I think you misstated the voltages.

XQ. 298. I wish you would use the ones you have named because I do not want to change them. You name all the voltages.

A. 23 volts.

XQ. 299. And what current?

A. 2.7 milliamperes.

XQ. 300. That is what I intended to ask you.

A. A little over 6/100 of a watt.

XQ. 301. You said, did you not, at page 2321 of the record in the interference, being page 167 of the Arnold priority record:

> "We had previously formed certain very definite opinions as to the power carrying capacity which a telephone repeater should have and these opinions have since been verified and we are now working to the same power requirements that we laid down at that time. These requirements were, in a word, that the repeater should be able to put on the telephone line the same amount of energy that the ordinary desk telephone in common use is capable of putting out on the line. It was on this ground that I stated we knew that we needed to have about one watt power output from the telephone repeater."

You so testified, did you?

A. Yes, I so testified and that is correct as of the present day. Will you let me reframe that? I so testified and I would so testify today.

XQ. 302. At Q. 83—I do not think you need trouble to refer to it—about the vacuum pump being backed up by another pump——

A. In my present direct?

XQ. 303. Yes, yesterday. Do you remember describing how there were three pumps in series?

A. Mr. Richmond described in detail how the pumps were attached in series and I agreed with his description.

XQ. 304. That was the ordinary normal proper way of using a Gaede molecular pump, was it not? I mean you are not claiming any particular originality?

A. Oh, no indeed. That is one way to use the Gaede molecular pump. There are various other ways.

XQ. 305. Will you refer to your answer to Q. 80 yesterday, page 612? You are speaking of this same tube, 20.2, are you not?

A. Yes, that is right.

XQ. 306. I asked how loud would the input be in this tube and you said:

> "The person speaking spoke in a normal tone of voice such as one would use in commercial telephone service."

A. That is correct.

XQ. 307. And it amplified under those conditions?

A. Yes, it did, there is a record of it in the book.

XQ. 308. How was this any better than the tubes which DeForest brought you in November?

A. Because the DeForest tubes were noisy, irregular and erratic in their operation and this one was not.

XQ. 309. The DeForest tube was not noisy in its operation if you were below a certain volume?

A. That is true, as I say it amplified the ticking of a watch and sounds of that general loudness quite well.

XQ. 310. But if you spoke not in a normal tone of voice what happened?

A. I went into that in some detail and as you remember it is a function of the voltage which is in the plate circuit, but the statement is true that it failed in general.

XQ. 311. Now, did you testify on motion to dissolve in this case? Did you give some testimony?

A. Yes, I did.

XQ. 312. You said, did you not, in that testimony on motion to dissolve, on page 13 of your rebuttal testimony on motion, page 481 of the Interference record——

A. Will you wait a moment while I look that up, please? I have it.

XQ. 313. About ten lines down:

> "In addition, the power that the DeForest audion would handle did not give us the margin of safety in telephone repeater operation which

we required. It would handle the energy necessary for an ordinary conversation, but under extreme conditions telephone repeaters are subjected to currents arising from speech of much more than ordinary loudness."

Is that true?

A. That is the testimony, yes, sir.

XQ. 314. And you went on:

"To give the necessary margin of safety, and at the same time to fit in with the voltage of about 130 volts available in the plant for the B battery supply, I estimated that it would be desirable to double the electron current from the filament, and to raise the normal operating voltage from about 40 volts, as prescribed by DeForest for using the tubes as wireless detectors, to the 120 or 130 volts which we had available."

That is your testimony?

A. That is correct.

XQ. 315. And now you say it would not handle the energy necessary for an ordinary conversation?

A. I do not recall that I said just those words, but I have explained in considerable detail just what that audion 7-A would do, and I will explain again.

XQ. 316. I do not think I care for that.

A. Then may I ask you to show me where I said that which you say I said?

XQ. 317. You said in your direct testimony on Friday, did you not, that if you spoke as loudly as the energy at which the DeForest audion began to fail to amplify, that the stenographer would not hear you?

A. That is right.

XQ. 318. How far are you from the stenographer?

A. About eight feet on an air line.

XQ. 319. And you testified on the motion that it would handle the energy necessary for an ordinary conversation?

A. That is right.

XQ. 320. When did you give that testimony, on the 19th of November, 1919, as appears from page 469?

Mr. Richmond: Please give him the page.

Mr. Davis: From the first page on that volume that he has.

A. Yes, the date of the testimony is 19th day of November, 1919. But, Mr. Davis, I want it understood that when I say an ordinary conversation, I am not referring to an ordinary conversation between two persons in a room. I am referring to a telephone conversation.

XQ. 321. What is the difference?

A. The difference is that a person speaks quite differently in a telephone transmitter than he does if he is directing his conversation to a person in the room with him. In general, for an ordinary telephone conversation the average person drops his voice so that a person sitting as much as five or six feet from him can only with difficulty understand what he says. Of course, if a person is talking on the telephone over a long-distance connection then he very frequently raises his voice more loudly than one does in any conversation between persons in an open room. But by ordinary conversation in connection with tests of audion 7-A, I mean the conversations of the sort that one has over the telephone with a person in a nearby place, where he speaks in an easy and natural unstrained tone into the telephone transmitter.

XQ. 322. In your answer to Q. 89, at page 1201 of the present record——

A. You must have the number of the question wrong.

XQ. 323. I have an error in my notes. The page is wrong. It is page 614, Q. 89. You say that you did not use the Gaede mercury pump for this work in the spring of 1913, because it would introduce mercury vapor into the audion and mercury vapor is a very potent agent of destroying the pure electron flow in a device. That is the reason, is it not, that you did not consider the tubes that Trimble pumped in January and February were high vacuum tubes?

A. Oh, no. No, the tubes that Trimble pumped in January or February might be high vacuum tubes or they may not be high vacuum. Trimble was attempting to acquire the mechanical art of making these audions and carrying out the processes of mounting the filaments and heating the filaments while pumping, and all the other tricks of the trade that are probably familiar to people in the lamp industry but were totally unfamiliar to us.

XQ. 324. That is, he was not trying——

A. And the tubes which he made were of all degrees of vacuum, I assume.

XQ. 325. They were always pumped on a mercury pump?

A. They were always pumped on a mercury pump.

XQ. 326. So that they must have had a micron of mercury or so in them?

A. Not necessarily.

XQ. 327. Why not?

A. For the very good reason that when a device is freely open to an open surface of mercury at room temperature, then there exists in the device a pressure of mercury vapor of the order of a micron, but if that device is then sealed off from the source of free mercury and if there is in that device any material whatever that can amalgamate with the mercury, then the very tenuous atmosphere of mercury vapor, coming in contact with the material, which, for example, might be copper, will form an amalgam with the copper. Now, the vapor pressure of mercury amalgams is very much lower than the vapor pressure of mercury itself, so I have no reason to think that the pressure of mercury vapor in Trimble's tubes was necessarily a micron. It might very well be very much lower.

XQ. 328. Do you agree or disagree with the testimony which Trimble himself gave about the vacuum in those tubes?

A. I will have to see the testimony before I can state that.

XQ. 329. In Arnold's priority record, page 92, Interference record page 2246, the last complete paragraph about the middle of the paragraph, Trimble says:

> "We found that the gas effects due to this mercury vapor were about the same as in the tubes as they were pumped by DeForest or McCandless."

Do you agree with that?

A. I do not believe I quite agree with that exactly as it is stated——

XQ. 330-31. Do you agree with the next statement:

> "At one time in this connection," he goes on, "I tried stopping gold foil in the conduit from the bulb to the pump to block off the mercury vapor, but did not make a success of it."

> **Mr. Haight**: I object to the question, because I think the witness did not finish his answer before the second question was put. He said: "I cannot agree to it exactly as stated but——." And then came another question. Am I correct there?

> **The Witness**: I did want to say something.

XQ. 332. Finish your answer, Doctor. I withdraw the other question for a moment.

A. I wish you would re-read that question. (XQ. 329 and answer repeated as recorded in record.) That was the answer which I had not finished. Mr. Trimble, as I said before, was a mechanic, and the terms that he employed in speaking of his work were not terms that I could always, or can now subscribe to exactly. The fact is that those tubes did show gas effects, as did the tubes pumped by DeForest or McCandless, which I think was the meaning of the sentence you read to me, but I am not in a position to agree with the assumption that appears in here on the part of Trimble that those gas effects were necessarily due to mercury vapor. They may or may not have been.

XQ. 333. He says that they were due to mercury vapor, and he says they were about the same as the DeForest tubes, does he not?

A. He does say so.

XQ. 334. Did you read this statement of Trimble's before it was filed?

A. I do not remember.

XQ. 335. You have not any doubt?

A. It is very likely that I did, but I have no present remembrance of it.

XQ. 336. And this was not an oral deposition of Trimble's but was a carefully prepared statement written out?

A. My recollection of the matter is that this is the statement prepared by Mr. Trimble in consultation with one of our patent counsel, and to the best of my remembrance, I had no part whatever in the preparation of that and was not consulted about it, and if I did read it at any time, it was merely as I would have read any part of the evidence casually; but the statement is not in its essence contrary to fact, not contrary to the statement that I would make at present, because the tubes that he made did show gas effects the same as to the effects as did the tubes of DeForest and McCandless; but I can not agree now that they were necessarily due to identically the same gas. I do not know what gas was in the DeForest and McCandless tubes.

XQ. 337. You still are of the opinion that the mercury vapor was a very potent agent in destroying the pure electron flow in a device?

A. I am.

XQ. 338. Meaning by mercury vapor, the amount of mercury vapor corresponding to atmospheric temperature?

A. Why, no. That was not what I meant.

XQ. 339. What did you mean?

A. My answer is based upon my experience particularly with the Von Lieben, Reisz & Strauss tubes. These tubes operated in the presence of mercury vapor generated by an amalgam, and the vapor pressure of that amalgam was stated to me by the inventors to be about zero point three ciphers two millimeters of mercury at room temperature, which is somewhat below the mercury pressure of free mercury in room temperature, as I recall it, and those tubes certainly operated in the presence of ionization of mercury vapor, so I was not confining my meaning at all to mercury vapor at pressures corresponding to room temperature.

XQ. 340. These Von Lieben-Reisz tubes operated as I think you testified, and I know that various witnesses testified in your behalf, because of gas ionization?

A. Yes, sir, they did. The ionization of mercury gas.

XQ. 341. Then your qualification of my statements really is an extension of it, is it not, that is, my suggestion was that the amount of mercury corresponding to atmospheric temperature would impede the operation of a tube and be a potent agent in destroying the pure electron flow in a device. Now, that pressure is about a micron and a half, is it not?

A. Which part of your question am I supposed to answer?

XQ. 342. The last part of it, about the micron and a half.

A. Because the statement in the first part of the question is not quite true, and I do not like to answer the question unless it is true.

XQ. 343. We will take it one at a time. What is the pressure corresponding to atmospheric temperature in the case of mercury?

A. As I recall it, in the neighborhood of a micron.

XQ. 344. I am told it is a micron and a half; is that true?

A. I would agree to that if you say so.

XQ. 345. Your answer to Q. 89 means, does it not, that that amount of mercury pressure would be a very potent agent in destroying the pure electron flow in a device?

A. No—and that is the part of your previous question that I objected to. I do not like the word "would." It might be, under certain circumstances a very potent agent. Under other circumstances, it might have no considerable effect whatever.

XQ. 346. And then about one-seventh or one-eighth of that pressure made the Von Lieben device a low vacuum device, as you have just testified?

A. Made the Von Lieben device operate as an ionization device, yes, sir. I think I did not testify as to just what the pressure of the mercury vapor was in that Von Lieben device. I testified that the inventor told me it was point three ciphers two. I am not very sure about that, but in general I am perfectly willing to admit that mercury pressures of the order of ten microns down to the order of a tenth of a micron, may in tubes of various constructions, be sufficient to cause very noticeable ionization effects.

XQ. 347. Now, the Gaede Molecular Pump gave you a better vacuum than you were able to get from the Gaede Mercury Pump?

A. It did.

XQ. 348. And this was indicated how, in the operation of the tube?

A. By the absence of such effects of ionization as blue haze at high voltages—erratic operation as telephone repeaters at lower voltages——

XQ. 349. I beg your pardon, Doctor, go ahead.

A. Perhaps if I can ask the stenographer to correct that answer right now, I would like the word "absence" to be inserted before the words "erratic behavior."

XQ. 350. So that the answer reads?

A. (As repeated by the stenographer): "By the absence of such effects of ionization as blue haze at high voltages and absence of erratic operation as telephone repeaters at lower voltages."

That is correct.

XQ. 351. Following along the history of this tube 20, the next thing that happened to it was it was re-exhausted on the mercury pump; is that right, and became 20.3?

A. Yes, it became 20.3 after being re-pumped on the mercury pump.

XQ. 352. And you refer to your sketch E. S. 86,908 which is in this exhibit book of yours, part of priority Exhibit 18, it says at the top on the left-hand side:

> "Audion 20.3 evacuated to .002 millimeters pressure with mercury pump,"

does it not?

A. Yes.

XQ. 353. So that there must be something there beside the mercury, if the measurement is correct?

A. Certainly, the gauge indicated the presence of .002 millimeters of gas.

XQ. 354. And that would indicate the mercury at atmospheric temperature plus something else?

A. In the gauge, yes, sir.

XQ. 355. In the tube?

A. It might or might not be.

XQ. 356. What is a gauge for?

A. The gauge reading is taken before the tube is sealed from the pump, and the taking of a reading on a McLeod gauge is a matter of some minutes; and I have no reason to be sure that the vacuum tube when sealed off has just this vacuum. However, I think the presumption is that there was quite a little gas in the tube at that time.

XQ. 357. I thought you had some other kind of gauge by that time?

A. That I used on the mercury pump?

XQ. 358. I do not know, Doctor; perhaps you can tell me.

A. I did have another sort of gauge at that time, but I was using the McLeod gauge on those mercury pumps.

XQ. 359. Where was it connected?

A. I can not call to mind a perfect picture of that set-up, but as a rule, the mercury gauge was connected nearer to the mercury pump than was the tube being exhausted.

XQ. 360. Now, will you please compare the curve of audion 20.3 evacuated on a mercury pump with the curve of audion 20.2, and tell me wherein you find in 20.3 the evidences of these two microns of gas pressure, by comparison with the two curves?

A. I can not find here evidence of any special designated pressure of gas such as two microns, except in the heading at the top of the curve. Perhaps I misunderstand your question.

XQ. 361. Well, are you or are you not of the opinion that the characteristic curve of a tube would ordinarily show whether or not it is a tube of the type set forth in the patent in suit?

A. I am of the opinion that it will not.

XQ. 362. And you see nothing on the upper curve in E. S. 86,908, as compared with the upper curve on 86,907, which would lead you to believe that one was a gas tube and the other was a high vacuum tube or vice versa?

A. Yes, I do.

XQ. 363. What is it?

A. On the upper curve of E. S. 86,908, there is a word "blue haze" inserted up near the saturation on the curve and blue haze would certainly not be obtained in tubes without ionization.

XQ. 364. I meant to ask you, Doctor, and I will ask you now the same question directing it to the shape of the curve as distinguished from the notations of the curve?

A. Given the two curves as drawn and without any additional statement other than the curves themselves, I would not dare to hazard a guess as to whether one was a poor vacuum and the other was a good vacuum curve. I can explain just why I am in this dilemma.

XQ. 365. On page 2183 of the Interference Record, page 29 of Arnold priority record, you produced a logarithmic plot of data taken on November 30th from tube 7-A, which is the same logarithmic plot which was shown to the Court yesterday, is that correct, being Arnold priority Exhibit 9?

A. Yes, that is correct at line 87 on page 29.

XQ. 366. You just testified that you cannot tell from the shape of a curve anything about whether it is high vacuum tube or not?

A. No, I have not testified to that.

XQ. 367. What did you say?

A. I cannot remember the words I said but I can tell you the sense which is this, that I do not believe that the curve EB, IB, curve of such vacuum tubes as these may be taken as a true indication of the degree of vacuum within them.

XQ. 368. Then why did you take the trouble on page 2183 to point out that the logarithmic plot on this particular tube 7-A was a straight line?

A. That was not very much trouble.

XQ. 369. Why did you take the trouble?

A. It was done because such a straight line logarithmic plot is mentioned in the patent application.

XQ. 370. And your own patent application filed before you had seen Dr. Langmuir's application spoke of the tube following the Child law, did it not?

A. I do not recall.

XQ. 371. Now, let us look at 20.4, which is on this same sheet E. S. 86,908 and the data beginning on page 108.

A. Do you wish me to refer to the tables or to the curves?

XQ. 372. I would like you to refer to both page 108, where the tables are and to this curve E. S. 86,908. Referring first to the page 108, the tube was re-evacuated on the molecular pump, was it not?

A. It is so stated on page 108.

XQ. 373. And you have no doubt of it?

A. I have no doubt of it whatever.

XQ. 374. On the first run blue haze showed at 51.6 volts, is that correct?

A. That is the first entry of blue haze, yes.

XQ. 375. And each of the readings from that point up to the highest voltage is accompanied by a notation of blue haze, is it not?

A. Well, the next four readings are accompanied by such notation.

XQ. 376. Are there any other readings?

A. Yes, there are three other readings on that same page and there is no such note of blue haze on them and they are taken at lower voltages on the plate than the last four entries that blue haze related to, but not all at lower voltages than the first record of blue haze appears there. That is a very complicated answer and perhaps I had better state it this way. Blue haze first appears at voltage 51.6, is again recorded at 57, at 62, at 73 and at 72.5. However, at the next voltage of 56.5 it is not recorded, showing that the tube had improved its vacuum by the passage of the blue haze.

XQ. 377. Which curve on E. S. 86,908 corresponds to this run which we have been discussing?

A. At the moment I think none of these curves do.

XQ. 378. You do not think that run was plotted?

A. No, I think not.

XQ. 379. Then what is the next run on this tube, is that the run at the left-hand column of page 109?

A. Will you please tell me just what you mean by a run?

XQ. 380. I do not know, Doctor.

A. Neither do I.

XQ. 381. I see a curve on this sheet and I suppose it corresponds to some series of readings, does it not?

A. Yes, sir.

XQ. 382. I would assume that the entries at the bottom of page 108 were one run of that tube, am I wrong in that assumption?

A. I cannot answer that unless I know what you mean by a run.

XQ. 383. Well, he went up and he went down.

A. That is correct; and if by a run you mean every time you go up and come down then I know just what you mean. We might agree on that as a definition of a run if you are willing.

XQ. 384. I am not interested in terms. I supposed that a run was a series of readings taken in a definite series for a definite purpose to find out something.

A. If that is your definition I will accept that.

XQ. 385. At any rate, there are further readings beginning again from the lower value in the left-hand column on page 109.

A. Yes, sir.

XQ. 386. Are those readings plotted on E. S. 86,908?

A. Those are plotted apparently as the dotted curves on E. S. 86,908.

XQ. 387. In that case current is highly irreproducible at what voltage?

A. These dotted curves are of rather peculiar structure and relate to two increases and decreases of voltage.

XQ. 388. Take the first one first.

A. The upward and downward variations in voltage did not give the same current values above about 48 volts as shown on the curve, but the curve is not very accurate in that particular portion and I can make my answer more definite by referring to the data if you think it is important enough.

XQ. 389. Now, subsequently other readings were taken which correspond to the smaller loop of these dotted line loops?

A. That is correct.

XQ. 390. Where is the data? That is at the bottom of that same column, is it not, the left-hand column on page 109?

A. Yes, the last third of the column roughly.

XQ. 391. Then other readings were taken which are not plotted, is that correct? I am referring to the readings on the right-hand column on the same page.

A. Yes, those readings do not seem to be plotted.

XQ. 392. In those readings there are several entries of blue haze, are there not?

A. There are three, to be exact.

XQ. 393. And in one case the same voltage, 108, is given right together, two current values, in one case 10,600 and in the other case 5400, is that correct?

A. The 10,600 is an entry of blue haze and there is no such entry at 5400, showing that the larger reading was attended by blue haze.

XQ. 394. And further down on the right-hand side there is a reading 134 under the volts and 7600 with a dash and the words "fell to"? What does that mean?

A. That at 134 volts there was a current of 7600 microamperes which as time went on diminished to a reading of 5600 microamperes at which time the plate voltage was—well, the record is not quite distinct there as to whether the plate voltage was 138 or 134, but I assume it was probably 134 volts. I should point out of course that in this column the filament current is different than it was in the first column on that page.

XQ. 395. Yes, the last set of curves was taken with a .69 amperes in the cathode filament; is that right?

A. Falling to .68 for the last of the observations, that is correct. You see, the currents used in these experiments were subject to variation because they were generally drawn from dry cells and as the dry cells would run down the current would vary somewhat.

XQ. 396-97. I do not quite see how that would account for that because the voltage is given—take for instance the top of that column filament current 69, filament voltage 57. Further down the notations were repeated and then you have 68 with a line drawn under the eight and still 57 volts——

A. That I think is quite easily explained, because in making these readings one approximates the last figure and if the reading at 69 were 69 and 57.5 it might well be recorded as 57 and if the lower one were 68 and 56.8, it might be recorded as 57. There was nothing critical in mind as to these currents and voltages and the records are presumably accurate to a reasonable extent.

THE COURT: We will take our morning recess now.

(Here a short recess was taken.)

(After a short recess.)

XQ. 398. Will you look at page 2242 of the Interference Record, which is page 88 of Arnold's priority record, folio 263; Mr. Pierce is testifying and he is speaking of this some 20.2, is he not?

A. So he says.

XQ. 399. He says:

> "We pushed our voltages higher and higher, going to 243 volts without any blue haze. Previously we had never gone much if any higher than 100 volts without encountering blue haze, so that the improvement given by the new molecular pump was very noteworthy."

Is that a correct statement?

A. That is correct.

XQ. 400. The whole statement is correct, as I read it?

A. Yes, you have read it correctly.

XQ. 401. No. Do you agree with it, Doctor?

A. Oh, yes, that corresponds with my remembrance.

XQ. 402. Now, will you look at page 103 of the Pierce notebook which is Arnold's priority exhibit No. 18, that is a record of some readings on a certain adjustable audion tube, is it not?

A. So it says.

XQ. 403. What kind of a vacuum was in that tube —if you do not remember, just say so, Doctor?

A. I was looking at the record to see if there was any record of a pressure reading here, but I do not see any. I remember that tube. It was a very complicated sort of a tube with a movable element, attached to a large, a fairly large piece of iron, made to be moved by a magnet from without the tube; and although I see no record here of the vacuum, it is my opinion that he probably had a pretty poor vacuum in there.

XQ. 404. On account of having so much iron, and so forth, in there?

A. Yes, the iron was down a cylinder, a cylindrical case in such a way that that iron could not be heated to a very high temperature in an evacuation.

XQ. 405. In this series of readings, the voltage appears to have been carried up to pretty high figures; for example, 284; is that correct, in the first column at the right-hand side of the page?

A. Yes, I see that reading.

XQ. 406. Is there any reading of blue haze on that sheet?

A. No, there is not any.

XQ. 407. There must have been blue haze, must not there?

A. I would think very probably there was some blue haze, although I would not be too sure about that, because those adjustable devices allowed one to increase the distance between the anode and the cathode at will, and if that distance were made rather considerable at the time this voltage was 284 volts, it is possible there might not have been any blue haze there.

XQ. 408. But this is on April 18th?

A. That is the date, yes, sir.

XQ. 409. And 20.2 was April 25th?

A. That is the date.

XQ. 410. And 20.2 was the first audion that went up above 100 volts without showing blue haze?

A. Well, I see the dilemma in which you have apparently induced me here. I am not sure that I agreed with Mr. Pierce, even if he made the statement that there had been no device that went above 100 volts without blue haze up to that time, and certainly now, with this record before me, I am not in a position to state positively that there had been no device prior to that time that went to 100 volts without blue haze.

(No XQs. 411 to 450, inclusive.)

XQ. 451. You made the statement yesterday, if my recollection is correct, that where we find in these sheets, these Pierce sheets, an entry describing a series of readings, and noting a series of readings, and the factor "blue haze" did not occur, that we might rely on the fact that there was no blue haze; is that your position?

A. Well, again, your question is a double question. I do not recall making that exact statement, and certainly that is not, as you have stated it, my position.

XQ. 452. What is your position?

A. My position is this, that when blue haze is recorded in these notebooks, it was certainly present; that when it is not recorded in the notebooks, either it was not present or it was not considered of importance enough to record at the time the observation was made. In other words, the absence of the marking "blue haze" is an indication, and merely an indication, that there was no blue haze present. It is not a positive proof.

XQ. 453. Was this tube N-2 baked, do you remember?

A. When it was pumped on the Gaede pump, do you mean?

XQ. 454. When it was pumped, yes. I do not remember what pump it was pumped on, but when it was pumped?

A. Oh, no. I misunderstood your question. I thought you asked about tube No. 20.2.

XQ. 455. I am speaking of N-2.

A. This tube N-2. I have no recollection as to how it was pumped.

XQ. 456. Now, these tubes in Philadelphia in the fall of 1913, what sort of cathodes did they have?

A. Wehnelt oxide cathodes.

XQ. 457. And on what pump were they exhausted?

A. The Gaede molecular pump.

XQ. 458. How many tubes were evacuated on the Gaede molecular pump in 1913?

A. I have no idea. A considerable number. Perhaps—several score, at any rate.

XQ. 459. When did you first get a good tube with a Wehnelt cathode?

A. That requires apparently my definition of a good tube. Our work on Wehnelt cathodes was directed toward producing a good Wehnelt cathode and we got a good workable Wehnelt cathode in the early summer or late spring of 1913. It was a cathode which we could use. Usable Wehnelt cathode is perhaps a better expression than a good Wehnelt cathode. Now, as to when we first got a tube which with one of these Wehnelt cathodes would operate satisfactorily for telephone repeater service, I cannot state. You appreciate probably that the tests that we made with tubes involving these Wehnelt cathodes were tests as to the Wehnelt cathodes and there was no effort in the early part of the work to produce tubes which were of such a nature as to be directly applicable to the telephone plant. We tried a great variety of compounds on the filaments in order to arrive at a suitable one and with each compound there were certain problems of evacuation that made the tubes all differ one from another.

XQ. 460. I notice on page 183 of Pierce's notebook No. 20, which is Arnold's Exhibit 34, a reference to book No. 26.

A. Did I understand you to say Exhibit 24?

XQ. 461. Exhibit 34. The very back part of this book.

A. Yes, I have it.

XQ. 462. "The entry is not to be confounded with N9.111 on May 26, 1913, book 26, pages 86, 91-98, E. S. 89,851" signed Nicolson.

What was this book 26?

A. It must have been one of our regular laboratory notebooks. I do not know which one.

XQ. 463. I would like to see that book and I would like to see all the books containing records of the exhaust of tubes on the Gaede molecular pump in the year 1913. May I see them?

Mr. Haight: I would suggest that you ask us.

Mr. Davis: It is addressed to whom it may concern.

The Court: You are asking counsel for the defendant to produce those books, I assume?

Mr. Davis: I am, sir. Dr. Arnold is the head of this great laboratory.

The Court: He is here as a witness, and of course the request is addressed to the defendant. You can pass on, having made that request of counsel, and they will let us know whether they are ready or whether they will produce it or not.

By Mr. Davis:

XQ. 464. Now, you have spoken, coming back to November 1, 1912——

The Court: I do not know that as I need to say it, but you are as familiar with the various methods of getting books as I am.

Mr. Haight: We do not intend to withhold the books if we have them here.

Mr. Davis: We did serve written notice before the trial for the production, but Mr. Haight is not standing on the formality.

Mr. Haight: It would not be effective on the DeForest Company to produce books of the A. T. & T. It would lay the foundation for the offering of secondary evidence, but we are not standing on anything of that kind, and if we have the books here we will get them. The notice that was served on Mr. Darby was very general and comprehensive in its nature.

By **Mr. Davis**:

XQ. 465. Coming back now to November 1, 1912, there were, if I analyze your testimony correctly, three effects or conditions which you noted, first, when the battery voltage was too high there was always blue glow in the tube; second, sometimes when the battery voltage was high but not high enough to make the blue glow, the mere act of conversation or loud conversation would cause a blue glow intermittently; and third, even when the battery voltage was below the point where this last effect would take place, conversation above a certain standard of loudness would not be properly reproduced; is that correct?

A. This is a correct statement, yes, of the facts as to the operation of the DeForect audion at that time.

XQ. 466. And you rather sharply distinguished the first and the third of these three effects in your testimony yesterday, did you not?

A. I think I attempted to explain all three of them. I do not know just what you refer to by a sharp distinction. Certainly they are very different. If there is any point that is not clear there, I will be glad to explain that over again.

XQ. 467. I was referring to your answer to Q. 15, where you said: "Quite apart from that——" and I was trying to bring out and I understand you to agree with the fact that blue glow when the battery voltage was too high was a different thing from the effect No. 3 when the sound was below a certain magnitude, the sound is not reproduced?

A. It is somewhat different as to cause and somewhat different as to evidence; that is to say, when one listened under the two circumstances the speech was not well reproduced, but in case of blue haze the difficulty was frequently one of attendant noise. In the case of the lower B battery the effect was one of distortion of the speech without as much attendant noise. Do I make that quite clear?

XQ. 468. Very clear, Doctor. Now on pages 564 and 565, in answer to some questions from the Court which are not numbered, you went into quite a detailed explanation of this third effect, illustrated by the fact that for example if you should try to reduce the current and the amount necessary to reduce it brought it down to zero and then tried to carry it further it was not possible to carry it further, do you remember that explanation?

A. Yes, sir, I do remember that.

XQ. 469. I suppose what that means is this, is it not, that in order that you may reproduce telephone conversation in a tube you have to be able to produce in the circuit from the tube an alternating current having substantially the same wave form as the wave form of the current which went into the tube and went on to the grid?

A. That is correct.

XQ. 470. In order to do that you must have the capability in the tube of responding by changing current to any change which you are going to make in the grid voltage?

A. Yes, I think that is well stated.

XQ. 471. As for example, if the tube was only capable of carrying a milliampere and some change which the grid asked you to make, or asked the tube to make, involved a milliampere and a half, then the current would rise to a milliampere and could not rise any further and that would make bad reproduction, would it not?

A. No, I think that in itself would not make bad reproduction, as you have stated it, because I think you have the numbers stated a little wrongly.

XQ. 472. Are we not talking really about what is called over-modulation?

A. I do not dare to subscribe to such technical terms as those unless they are very carefully defined. I think the way you stated it before is much more clear, which is that as the voltage is impressed upon the grid rising and falling, the current in the plate circuit must be capable of rising and falling to corresponding amounts, but my answer to your question as to increasing from one milliampere to a milliampere and a half was based upon this, that if the plate current is called upon to increase to a milliampere and a half and it can only increase to a milliampere, then I think the distortion in the speech would be hardly noticeable but if it were called upon to increase to three milliamperes, for example, and could only increase to one milliampere, then the speech would be rather badly distorted.

Another way of stating the matter is that experience shows telephone speech can be very considerably defaced or distorted as regards its electric wave form before the ear is capable of noticing that it is unpleasant.

XQ. 473. Now, have you a name in the telephone art for that effect?

A. Yes. In a general way, I think we refer to that effect as "over-loading"; but it is not an effect that we meet in our telephone business.

XQ. 474. Because you know how to avoid it?

A. Because our tubes do not show this effect.

XQ. 475. Why don't they show this effect?

A. Because they have a very copious electron emission, something of the order of several times that required by speech. We have done that by putting in a long filament of high emissivity of the Wehnelt oxide type.

XQ. 476. You took out a number of patents, did you not, Dr. Arnold, on applications filed after November 1st, 1912, and prior to November 1st, 1915?

A. Yes, I think there were several patents issued on applications made between those dates.

XQ. 477. One of them was No. 1,114,845, issued October 27, 1914, on an application filed May 16, 1914, and appearing at page 2345 of the Interference record in the Arnold-Langmuir Interference. I show you the drawing of this patent and ask you if you recognize it, the drawing being on page 2347?

A. Yes, I have looked at the drawings.

XQ. 478. What was the idea of this patent?

A. One idea in this patent was to provide a resistance in the plate circuit of an audion device, so that if the voltages impressed upon the device should, for any reason, become of undue value, or should an accident happen to the device, as might happen, by the tube breaking and the grid or filament touching the anode, or should, for example, the filament break and in breaking bend in such a way as to touch the anode, that then the resistance which was inserted, would prevent an undue current from flowing in the B-battery which if it did flow, would produce an acoustic shock in the ear of the telephone subscriber. Perhaps I can make that a little bit clearer as my sentence was somewhat involved. If in a repeater set-up we were to short the terminals of the B-battery at the tube, then there would be a surge of current through the B-battery circuit, and through the transformer, which would give a loud click in the telephone subscriber's receiver and that is recognized as a very undesirable thing in telephone practice. Now, this resistance which I inserted, and which is shown at numeral 8 in Figure I of the patent, was for the purpose of preventing such surges in case of an accident, and in order that this resistance might not interfere with the passage of the useful telephone currents through the repeater, it is bridged by a condenser marked No. 9, it being well understood that the useful telephone currents will flow through the condenser being alternating currents, but the harmful surges that I wish to prevent will not flow through the condenser to such a degree. In short, this device is a protective device, similar to a fuse.

XQ. 479. This statement you have made is quite different from the statements made in the patent as to the object, is it not?

A. I have not read the patent.

XQ. 480. Suppose you read it.

A. I cannot state this from memory.

XQ. 481. (Reading):

> "It has been found in the usual audion structure that when energies of considerable magnitude, such, for instance, as are encountered in ordinary telephone systems, are impressed upon the input circuit of the audion, a blue haze appears in the bulb of the audion. This blue haze may be produced in the bulb either by raising the potential of the battery in the output circuit of the audion to an excessive value, or it may be produced by an increase in potential beyond a certain value between the grid and the filament. When the blue haze is present, the audion becomes inert and ceases to function as an amplifier. For instance, when used as a telephone relay, the

> transmission ceases almost entirely when the blue haze appears. It has been found experimentally that the establishment of the condition of discharge described above as the blue haze may be prevented by placing, in series with the battery, a balancing resistance of such high value that the increase in current which would normally take place when the condition in the bulb corresponding to the blue haze exists, results in such an increase in fall of potential across the resistance as to render the maintenance of the condition corresponding to blue haze impossible."

Does that refresh your recollection as to your reasons for putting that in there?

A. It refreshes my recollection as to the patent. I had forgotten that that was what the patent stated; and with my recollection refreshed by that, I do remember that at the time of filing this patent, that was one of the considerations in view. The main consideration in the use of the device was the one which I have stated, and I had for the moment forgotten that in the patent application, the matter of blue haze was mentioned. I may say this that the statement in the patent application is quite correct as to the fact that if blue haze does occur in an audion, it is to a considerable extent similar to a short circuit in the audion, and so produces undesirable results.

XQ. 482. That is the only reason given in the patent, is it not?

A. Yes, that is the only reason given in the patent.

XQ. 482a. And in the claim it says, line 91, does it not:

> "Said balancing resistance being of such high value that the increase of current which normally takes place when a blue haze exists in the bulb of the audion, results in such an increase in fall of potential across said resistance as to prevent the maintenance of said blue haze"?

A. Yes, that is what the claim says. I find in speaking from recollection, I had forgotten the contents of the patent. I thought I remembered the patent from the picture, but I find I was mistaken.

XQ. 483. Now, when you filed this application, were you talking about the tubes in the condition in which you had then brought them, or were you talking about the tubes shown to you by DeForest?

A. I doubt if I was talking about either. I think that the tubes contemplated here were any tubes which might have gaseous ionization within them. At that time, I have no recollection as to what was in mind as to the exact type of tube.

XQ. 484. You did not mention in the application any improvement which you made yourself in the audion, did you?

A. I shall have to look at it. (Perusing papers.) No. Apparently not. Apparently this does not relate to the audion any way as a device. It simply relates to a resistance inserted in there for protective purposes.

XQ. 485. I call your attention to patent No. 1,128,279, issued February 16, 1915, on an application filed May 16, 1914.

Mr. Haight: We shall have to find that.

XQ. 486. The patent beginning at page 2348 of the Interference Record in the Arnold-Langmuir Interference, and the drawing being on page 2351. This has to do, has it not, with an arrangement in which a plurality of audion elements have a common anode?

A. Perhaps I had better take the time to read this patent through, since I had forgotten what the other one was about.

XQ. 487. I was only asking you, Doctor, in a general way what it referred to; look at Claim 2. Claim 2 states:

> "In an electric wave repeating apparatus, a plurality of audion elements having a common anode."

In this case, the improvement is in the audion itself largely, is it not?

A. I have not read the patent through carefully, but it appears to me to refer to a method of use in the specification, rather than to an improvement in the audion element. It says, line 15, page 1:

> "Its object is to improve the quality of transmission by producing in the output circuit electric waves free from distortion with respect to the input waves."

XQ. 488. My understanding, Dr. Arnold, is that Mr. Colpitts had filed an application on some method of using two audions to pass current both ways or something of that sort and that the invention here consists in the improvement over Mr. Colpitts' idea which we discussed the other day when he was on the stand, consisting of putting both of the audions in one bulb, as it were, and that the claims are directed toward that sort of an improvement.

A. Yes, I see now on line 68, page 1, it says:

> "Two audion elements may be combined in one structure for this purpose, and the present invention is an improvement in that disclosed in the application of Edwin H. Colpitts, Ser. No. 810,196, filed Jan. 3, 1914."

XQ. 489. And it says, does it not, on page 1, line 23:

> "The principal parts of an audion element or structure are a heated filament or other source of ionization, an anode usually called a 'plate,' and an electrode——"

and so on, and then it goes on at line 30:

> "Characteristic features of the audion are that current can flow in one direction only in the ionized stream, and that the strength of current in the stream flowing from its source to the plate is modified by electrostatic rather than by electromagnetic force as in some other types of 'gaseous' repeaters."

What is the significance of that statement?

A. That statement describes very clearly in the common terminology of a few years ago the performance of a vacuum tube device of the audion character in the condition in which the discharge is a pure electron discharge. It is obvious that today one who was familiar only with the terminology of today might be misled by the term "source of ionization," line 25, page 1. But that term was a common term and is still not an uncommon term for an electron-emitting filament, as I think I had occasion to use in my direct testimony the term negative ion and the term positive ion. They were all called ions originally and nowadays we do make a distinction between a negative ion and the electron by terms in order to clearly indicate the difference in mass between the negative ion and the negative electron, but in the terminology of about this time or a little earlier ionization was used to include positive and negative ions and electrons, and further on, line 32, where it says, "The current can flow in one direction only in the ionized stream," that defines clearly a pure electron device taken in conjunction with the heated filament, for if there was anything there other than the pure electrons then the current could flow in both directions. Of course, it is conceivable that the words might read also "upon a device which had nothing in it but pure positive ions," but that is not indicated by the context since there is no source of positive ions indicated. So in general, I would say that those words which you have read indicate clearly and definitely a high vacuum audion device operating in the presence of a pure electron stream and I think would so have been understood as of the date of issuance of the patent, 1915.

XQ. 490. Did you ever see a Tungar rectifier?

A. At a distance. I never saw one very close at hand.

XQ. 491. You are not familiar with it?

A. I am not familiar with it, no, sir.

XQ. 492. You know as a matter of fact, do you not, that very perfect rectification can be obtained in a tube containing a very considerable quantity of gas at moderate voltages?

A. No, I do not know that that was the case. I think you will have to define your term "very perfect" a little more accurate if you want me to subscribe to your statement. I understand that the Tungar rectifier is not a very perfect rectifier. I understood that its use was rather being discontinued. I may add, however, that the matter of rectification is subject to mathematical computation and if one is given the number of electrons present and the number of positive ions present and their masses respectively, then with due mathematical labor one can find out how much current will flow in the one direction carried by the positive carriers, and how much will flow in the other direction carried by the negative carriers and if they are present in anything like the same numbers then the current carried by the negative carriers will be very much larger than that carried by the positive carriers.

XQ. 493. In your present application involved in the Arnold-Langmuir Interference, you had what purported to be an explanation of the action of the high vacuum tube, did you not?

A. I do not remember that patent application at all clearly.

XQ. 494. Will you look at the drawing there, Dr. Arnold, which is opposite page 36 of the Interference record in the Arnold-Langmuir Interference?

A. Yes, I have that picture before me.

XQ. 495. There is a curve OABC'K, which is set up in that application as being the curve of a high vacuum tube, is it not?

A. I am confused for the moment because the picture appears to be a picture associated with my application, but the context does not seem to be. It seems to be associated with Dr. Langmuir's application.

XQ. 496. Perhaps we have the wrong figure. It is opposite page 36.

Mr. Richmond: Tell him where the specification is.

XQ. 497. Doctor, you are right about the picture, but the Arnold application follows the drawing rather than precedes it. I mean it precedes it.

A. I have it now, yes, sir.

XQ. 498. It begins on page 6 of the record, that is, the specifications. Will you look at page 9, near the bottom of the page, line 28, according to the number there?

A. The portion which you have indicated reads, line 25:

> "If the temperature of the cathode, instead of being maintained at the value assumed in the preceding discussion, is raised to a higher value, another curve, (OABJK of Fig. 2) is obtained with no gas ionization. In this condition of operation more electrons may be drawn away at any given voltage and larger currents will be obtained."

Is that the portion to which you refer me?

XQ. 499. Yes. Now, the curve OABHG is supposed to be a curve having a certain amount of ionization in it, is that correct?

A. You would help me if you would give me the line.

XQ. 500. Line 14, page 10, and begins: "Now suppose a small quantity"——

A. I do not find any reference to it.

XQ. 501. G is mentioned on page 11, line 28.

A. Yes, according to the portion of the text that you have pointed out to me this curve OABHG is illustrative in a theoretical way of what will happen if as stated on line 26, "If still more molecules per C. are present or are readily liberated in the tube the instability may begin at and proceed along the dotted part G."

XQ. 502. Now, will you look at your patent 1,129,942, March 5, 1915, application filed May 28, 1914, specification begins at page 2356 of the Interference record and the drawing is at page 2360. This specification filed May 28, 1914, uses the expression, "Thermionic repeaters," in line 15, page 1, does it not?

A. Yes, this says in line 5: "have invented certain new and useful improvements in gaseous repeaters in circuits of low impedance." Then beginning with line 14:

> "Still more particularly, it relates to the use of thermionic repeaters for securing amplification of currents in circuits of low impedance."

XQ. 503. Why did you call it a gaseous repeater?

A. Because that is the classification name in the Patent Office, but that terminology is of one of our patent attorneys and not of mine. I did not write these specifications myself.

XQ. 504. And you naturally take any specification which your Patent Department writes for you that does not seem to be to you unreasonable and which seems to you to describe the invention without very much criticism, is that correct?

A. I do not think that is quite correct.

XQ. 505. What do you do?

A. I criticize patent applications that are submitted to me for signature as to the facts set out in them with reference to my work.

XQ. 506. Whether they describe your work properly?

A. Whether they describe my work properly.

XQ. 507. I assume you do that. If they describe your work wrongly, had the connections wrong and the whole theory wrong, you would call attention to it?

A. Yes, I would call attention to it if it had the theory wrong but I do not concern myself so much with theory in these applications. I may say this, that I would not knowingly allow any seriously misleading statement to appear in a patent application over my signature.

XQ. 508. I assume that, Doctor. But you give your Patent Department a pretty wide latitude up to that limit?

A. Yes, sir.

XQ. 509. As in this case letting them call it a gaseous repeater when it was not?

A. Yes, sir.

XQ. 510. Because you thought that was a term they used?

A. I was so told and in fact I understood and still understand this is a classification name used in the Patent Office in Washington. I suspect probably the high vacuum patent that we are now litigating about is so classified.

XQ. 511. Then you go on at line 18, page 1, and as an example of thermionic repeaters you mention the DeForest audion and the Von Lieben-Reisz repeater. Then you go on at line 24, speaking of vacuum discharge repeaters and say that that expression is intended to include repeaters of the thermionic type and also those in which currents flow between electrodes in space maintained in a conductive state by the arc or otherwise. That would be including your mercury repeater, would it not? In fact, it goes on to talk about your mercury repeater in the next sentence, does it not?

A. Oh, yes, you are quite right.

XQ. 512. So that the expression vacuum thermionic repeaters as used in this patent is used in the sense broad enough to include a great many things?

A. Well, I doubt if the sense here is sufficient to include a mercury arc repeater.

XQ. 513. But the expression vacuum discharge repeater includes mercury arc?

A. Oh, yes.

XQ. 514. And the expression thermionic repeater includes the DeForest audion. That is all I want to bring out.

A. Yes, and the Von Lieben-Reisz-Strauss device.

XQ. 515. And here again you make no disclosure of the improvements which you had made in the audion at that time?

A. I cannot answer that question without reading the patent and seeing what it is about. I have not got it in mind at all.

XQ. 516. I will make the statement that you do not and let you contradict it later if you want to if you think it worth while unless you prefer to read it now.

A. I can answer it by reference to the claims.

XQ. 517. Very well.

A. Each one of the claims starts—no, perhaps I better not answer that without studying the patent because it is rather difficult to understand.

XQ. 518. I also call your attention to your Patent No. 1,129,943, issued May 2, 1915, on application filed May 28, 1914, at page 2362 of the Interference record, the drawing being on page 2365. For some reason the drawings in this Interference record are after the patent instead of before them. It is very confusing.

A. I have the patent before me.

XQ. 519. This again is stated to be a gaseous repeater, is it not?

A. Yes, sir; gaseous repeater in circuits of low impedance is the title of the patent.

XQ. 520. And illustrates the three-electrode vacuum tube in the drawing?

A. It does.

XQ. 521. And these connections which are disclosed in the patent were designed by you for use with what sort of a tube?

A. It is my present recollection that this patent relates only to high vacuum audions, but I cannot attempt to define the scope of the patent.

XQ. 522. I did not ask you for the scope; that is for the patent lawyers, and not for you. I simply meant to ask you whether the invention of the patent was made by you for use in connection with the high vacuum audion?

A. Yes, it was.

XQ. 523. But you did not mention the high vacuum audion in the patent, did you?

A. I think I may take your word for that, without reading it through, if that is agreeable.

XQ. 524-25. Please do not take my word, because I have not read it through myself, Doctor, but correct the statement later, if you want to. I have not read it through recently. Now, Patent No. 1,128,280, page 2375, the drawing being on page 2377, is issued February 16, 1915, on an application filed June 8, 1914. Now, by this time your patent lawyers apparently had gotten over the idea of using gaseous repeaters in their titles, and they call this a "thermionic detector." Do you notice that?

A. Will you read me the patent number again?

(Patent No. 1,128,280.)

THE COURT: Where is that, Mr. Davis?

MR. DAVIS: Page 2375.

A. Yes, the heading of this is "thermionic detector," and in the first paragraph it says:

> "New and useful improvements in thermionic detectors."

XQ. 526. Looking to the drawing, it appears to be, does it not, a rather complex tube having several elements connected together in various ways?

A. No. I would not say so. It has one filament, two grids and one plate, rather similar to the ordinary DeForest audion set, but the filament is cut in two parts, one part appears on the one side of the plate and the other on the other side of the plate. It is rather an unusual structure, but not complicated.

XQ. 527. The invention in this case has to do with a tube rather than with the use of the tube, does it not; it is a new type of tube, which perhaps has a new use, but the invention claimed is the tube, rather than the use, is it not?

A. I notice that every claim starts, "In a thermionic detector," which does indicate to me that the patent is one on the structure of the tube, rather than its use.

XQ. 528. There is nothing in that patent about these improvements which you were telling us about yesterday, is there?

A. I will answer your question in this way: That the patent specification could, I believe, not have been prepared or would not have been prepared in the form in which it is, did it not relate to a device of the kind that you refer to, namely, a high vacuum device, and the reason I believe this, is that in reading on page 2, beginning at line 10:

> "Now if the potential of either input electrode becomes more negative, the current from the filament to the plate can do no more than fall to zero, since the unilateral conductivity of the space will not allow a current in the opposite direction."

That, in words, is a pretty clear statement of a pure electron device. On the other hand, this particular patent is certainly not a patent designed to cover the invention of the high vacuum audion, as such.

XQ. 529. It is a patent which relates to an application or improvement on that; is that right?

A. An improvement in structure, yes, sir.

XQ. 530. But it does not disclose the thing of which it is an improvement?

A. It certainly does not disclose it in any detail——

XQ. 531. Do you consider that one skilled in the art, if the art exists——

Mr. Haight: The witness had not finished.

Mr. Davis: I beg your pardon.

A. (Continuing): I was going to say it does not disclose it in any detail, but as I said before, I feel quite certain from the phrasing of the specification that the matter of the high vacuum audion must have been clearly in the mind of the attorney who phrased it, otherwise he would not have used that phrasing.

XQ. 532. Do you consider that one skilled in the art as it existed at that time, reading the specification, would know how to build such an audion?

A. As to the features disclosed in this patent, yes.

XQ. 533. But those features would not be any good unless they were maintained at high vacuum, would they?

A. They would not have their maximum usefulness unless in a high vacuum device.

XQ. 534. They would not have the use which you contemplated when you filed the application?

A. I am not prepared to say that this sort of structure might not be useful in some of the tubes, such as your company makes, where there is gas present in the tube.

XQ. 535. Yes, Doctor, but you were making an invention of an improvement of a high vacuum audion, that is what you had in mind and what you were thinking about when you filed the application; that is the use you intended to put this improvement to, was it not, as an improvement in the high vacuum audion?

A. I cannot do very much more than refer to the statement here: "An improvement in thermionic detectors," which was written at that time, and I think the patent itself speaks pretty clearly, for certainly what it is, and I think for what it is intended to be.

XQ. 536. June 8, 1914, that was about the time you were ready to make the first test on the transcontinental line?

A. June 8, 1914?

XQ. 537. Is that right?

A. That was about the time we were ready to connect through for the first demonstration, the parts of the circuit had been in operation with audion repeaters before that time.

XQ. 538. At that time you considered you had fully solved all this problem with high vacuum, and knew how to make the tube?

A. For telephone repeater service.

XQ. 539. And were proceeding with the development of more powerful tubes for radio?

A. Yes, that is correct.

XQ. 540. And there was not a ghost of a thought in your whole organization among the respective heads like yourself, of using any low vacuum tubes in telephone service, was there?

A. I can not agree with your statement just as you make it, because we not only then, but do now, contemplate the use of low vacuum tubes in our telephone service.

XQ. 541. You mean ballast?

THE COURT: What is that?

MR. DAVIS: Ballast.

A. No, I do not mean ballast tubes. What I have in mind is tubes in which we actually make use of ionized gas discharge; but that I think is immaterial at the moment, because we were not at that time contemplating using telephone repeater elements in which gas ionization played any considerable part.

XQ. 542. And yet you do not in your specification, do you, describe or say anything about this special high vacuum which you then knew how to make or how to make it?

A. This patent does not disclose the vacuum in detail. It indicates that it was a pure electron device, but it is not a patent on a vacuum, or on a method of getting a vacuum, or on a condition of vacuum. It is a patent, as I see it, on the arrangement of the filament grid and the plate within the bulb.

XQ. 543. Now this patent No. 1,168,270, on page 2391, is another patent of yours, issued January 18, 1916, on an application filed December 14, 1914. That has to do with a protective device, does it not; the drawing is on page 2392?

A. Yes, sir. It is entitled "A Protective Device for Electric Circuits."

XQ. 544. And the particular thing to be protected is a vacuum tube, is it not, and the circuits therewith associated?

A. Yes, it is a vacuum tube, having a filament and a plate but no grid, and used in a particular circuit. I think the patent relates to the method of use and not to the construction of the device.

XQ. 545. Now, will you look at page 2403, patent No. 1,200,796, October 10, 1916, on an application filed September 3, 1915, the drawing is on page 2405; is that another of your patents, Doctor?

MR. DAVIS: Will you look at it here, Doctor? Would your Honor like to adjourn now for lunch?

THE COURT: Then we will come back at 2.15.

AFTER RECESS.

MR. DAVIS: I would like to inquire from my friends on the other side what action they have taken or are prepared to take with reference to our request for the inspection of certain documents.

MR. HAIGHT: We will let you see anything that we have. The only thing that we have not got here, which I have neglected to state this morning, because I did not want to interrupt your cross-examination, was that book.

MR. DAVIS: The only question is a question of order and we will look this over tonight but in case we have not got them when the defendants close their case, we will take whatever steps are necessary.

THE COURT: You will work that out in a practical way.

By MR. DAVIS:

XQ. 546. Have you had an opportunity to look over the particular patent of which we were speaking when we adjourned for luncheon?

A. Yes.

XQ. 547. What does it relate to in a general way?

A. This patent is entitled "Power limiting devices," and relates to the use of vacuum tubes having two elements for purposes of protecting against over voltages.

XQ. 548. That is using the tube itself as a protective device?

A. The tube plus the circuit, yes, sir.

XQ. 549. All of these applications which issued into patents which we have been discussing were filed within a reasonable time after the invention was made respectively, were they not?

A. I doubt if I can answer that question in such a general form. I certainly cannot answer it with respect to any particular patent without reference to the records in our patent department. Frequently there are lapses of a year or so.

XQ. 550. Most of those applications were filed in 1914 and some in 1915. It is true, is it not, that they were all invented after November 1, 1912?

A. That is true.

XQ. 551. So that, without trying to ascertain what a reasonable time is they were invented after November 1, 1912, and most of them were filed in 1914. You did not file the application for the invention of the Langmuir patent, the application which was involved in the Interference, until November 2, 1915, that is correct, is it not?

A. That is correct.

XQ. 552. And that was because there was a period in which you thought it was not an invention?

A. I have a bit of difficulty with your wording. I would hardly say I thought it was not an invention. I will say it did not occur to me that it was an invention. There is a distinction there that is clear in my mind at least.

XQ. 553. There was a period in which you did not think that it was an invention?

A. During that period there was no thought process at all concerned with whether this was an invention or was not an invention. It simply did not enter my mind that it might be an invention.

XQ. 554. It is true, is it not, that the Telephone Company was a commercial concern which rested upon patent rights and it was making patent claims whenever it found anything patentable?

A. As a general statement I suppose that is true. I do not think I am qualified to answer that statement very well. I do not think it rests upon patent rights entirely.

XQ. 555. Dr. Millikan on page 875 of the Interference record at page 407 of Arnold's rebuttal on motion made exactly that statement. Would you disagree with him?

Mr. Haight: I object.

Mr. Davis: I do not insist on the question. I do not think it is very important.

The Court: All right.

XQ. 556. And then later you were advised by the Patent Department that it was an invention, is that correct?

A. I was advised by our Patent Department that in their opinion a patent application should be filed upon this subject matter as they thought that a patent might be issued on it.

XQ. 557. They gave you such advice as justified you in taking the usual inventor's oath?

A. Yes, their advice plus my knowledge of the contents of the application justified my taking the usual inventor's oath.

XQ. 558. That is, if you had been advised and believed it was not an invention, you would not have taken the oath?

A. I do not remember the wording of the inventor's oath, but if my memory is correct it is that one swears that he believes he is the first inventor, and to that extent, at any rate, if that is the wording of the oath, I could subscribe to it now as well as then but it is not my recollection that you swear that you have made an invention. That I presume is to be determined by the Patent Department and the courts.

XQ. 559. I do not think any inventor will be held responsible for judgment on a question of law of that kind, but it is a question of good faith if you think you are the first inventor you have the right to make the oath.

A. I thought I was the first inventor, yes, sir.

XQ. 560. Were you present at a meeting or conference which was held on Easter Sunday, 1915, on the occasion of certain wireless telephone experiments?

A. Easter Sunday 1915, I was in Montauk, Long Island, conducting with the help of a number of assistants a wireless demonstration from Montauk to Wilmington, Delaware, and at that demonstration were a considerable number of people and various conversations were held at that time. I, however, was concerned principally with the operation of the apparatus of which I had charge and took very little part in the conversations, nor do I remember them at all clearly.

XQ. 561. Dr. Millikan has testified to an interview at which you were present and at which other things happened and I want to know whether your recollection agrees with Dr. Millikan's as to what took place at this interview. He says at page 874 of the Interference record:

> "On Easter Sunday, 1915, I was one of those who had the good fortune of talking by wireless with remarkable distinctness from Montauk Point to Wilmington. It was on this very day that Dr. Jewett informed me that he had just learned that Dr. Langmuir had been developing tubes like those which his company had had in actual use for more than a year and that the General Electric Company had approached the Telephone Company with a suggestion of interesting them in this development. I never saw a more astonished group of men than Dr. Jewett, Dr. Colpitts, Dr. Arnold, Dr. Van der Bijl and their co-workers, when they

found that Dr. Langmuir had made patent applications in which he had claimed that he was the discoverer of pure electron discharges," and so forth.

Do you remember that?

A. I do remember conversations about this matter with Professor Millikan, but I cannot place them with positiveness as of that day and place. Certainly they were at just about that time.

XQ. 562. And you remember, do you, that Dr. Jewett informed you of the fact that the General Electric Company had an application for Langmuir?

A. No, I do not remember that Dr. Jewett informed me. It would be a little unusual for him to do so, because he was not my immediate superior. I do not remember how I was informed. If Dr. Jewett intended to inform me, he would naturally have passed the information through Mr. Colpitts.

XQ. 563. Well, Dr. Millikan's testimony is as to a group of men consisting of Dr. Jewett, Dr. Colpitts, Dr. Arnold and Dr. Van der Bijl, apparently present together on this Easter Sunday?

A. We were together, yes, sir, on that Sunday.

XQ. 564. And it was at that meeting, according to Dr. Millikan's testimony, that this information was given, that is, that Dr. Jewett made that statement. You have no recollection of that?

A. Well, I have no definite recollection of that being the subject of disclosure by Jewett to me at that time, but I am quite definite in my memory that the fact as stated by Professor Millikan, of our knowledge of the application filed for Langmuir came to my attention at just about that time, but my mind on that Sunday was concerned with a variety of things other than this. I was running the plant there, and trying to get a conversation through a snowstorm down to

Wilmington. My memory of some details of what occurred that day is remarkably clear, but not on this.

XQ. 565. Then when my good friend Judge Haight said on page 222 of the typewritten record (*not printed*):

> "But in October of 1915, they learned for the first time in the American Telephone & Telegraph Company that Langmuir was claiming an invention, had a patent filed for an invention which they knew that Arnold had made.
>
> "So they immediately did the only thing that could be done and filed an application for a patent on behalf of Arnold"—and so on.

He was in error as to the date, was he?

A. I do not know exactly what Judge Haight had in mind there. My own recollection is that—well, my own recollection does not run as to October, because at that time I was in San Francisco. It may be that at that time the company learned that the United States application had been filed. I do not know about that. I think Judge Haight will have to speak for that himself.

XQ. 566. But you knew it in the spring?

A. I knew it along about Easter time, yes, sir.

XQ. 567. Now, Dr. Millikan further testifies on page 407 of this book, which is page 875 of the Interference record, and I want to know whether you remember the occurrence:

> "When Dr. Jewett asked me what I thought about their going into Interference with Dr. Langmuir, I told him that I thought it was a public duty, wholly apart from the right of his company to have the use of their own developments, for if any commercial concern, whether it was the General Electric or the A. T. & T. Co. could get patents on the whole of a scientific field which was developed by scientists a dozen years earlier

for the good of the public, then there was something fundamentally wrong with our patent system——"

Do you remember that?

A. I remember Professor Millikan expressing those sentiments with the utmost clearness during about that time, and the only time that I saw Professor Millikan, to my recollection, was during the week of Eastern Sunday, 1915, and from then on I did not see him until perhaps late in the fall of 1915; so his sentiments must have been conveyed to me as of about that time, but I am sorry that I do not recall exactly the conversation that Professor Millikan testified to at Montauk.

XQ. 568. Well, the implication——

A. The implication is entirely correct.

XQ. 569. Then the implication is that the Interference was to be obtained to prevent Langmuir from getting a patent; is that right?

Mr. Haight: I object to that. I do not think the witness should be called upon to construe Professor Millikan's testimony.

Mr. Davis: I am not asking the witness to construe Professor Millikan's testimony. He says the implication contained in the testimony is correct. I am asking him what the implication is.

The Court: What you are asking him for, is, I assume, Mr. Davis, to state the substance of that impression of Dr. Millikan's, if he can not state the exact language?

Mr. Davis: Yes, if your Honor please, I would like to have——

XQ. 570. That is, the question I am asking you is this: Was the application filed for the sake of getting a patent to Arnold or was it filed for the sake of stopping the patent to the General Electric?

The Court: That is a step beyond. Then you withdraw the question?

Mr. Davis: I ask that question.

The Court: Very well.

Mr. Haight: Let the question be read.

The Court: That question was withdrawn.

(XQ. 570. repeated by the stenographer as recorded.)

Mr. Haight: May I admonish the witness that his answer should be upon his own knowledge? I presume if he does not know he should not indulge in any guess or conjectures, because the Telephone Company is a pretty big organization, and this witness is only a cog in the wheel.

A. To my knowledge, the invention was filed for the purpose of securing a patent for me on this subject matter, if the patent should prove to be patentable.

XQ. 571. And on November 2, 1915, as you have just said, you filed the application, and on November 18, 1915, your attorneys wrote a letter, did they not, to the patent office asking that an Interference be declared with the Langmuir application supposed to be then pending, page 18 of the Interference record?

A. The letter which you have shown me addressed to the Commissioner of Patents requests that any allowable claims of the Langmuir application which could be made by Arnold, should be suggested to him for the purpose of Interference.

XQ. 572. And the Interference was actually declared on August 8, 1915, as appears on page 27 of the Interference record and on November 25, 1915, page 2446 of the Interference Record you filed, or your attorneys filed for you, a motion to dissolve the Interference?

Mr. Richmond: Mr. Davis, are you sure of the year?

Mr. Haight: You said 1915.

Mr. Richmond: You said 1915 twice.

Mr. Davis: I hope I am right. The Interference was declared on August 8, 1916, is that right, Mr. Richmond?

Mr. Richmond: It may be, I do not know. I do not think it was in 1915.

Mr. Davis: It appears from page 27 of the Interference Record that the Interference letter was dated August 8, 1916. My note is wrong, your Honor to that extent.

XQ. 573. Now, this motion to dissolve on page 2446 of the Interference record is dated New York, November 24, 1916. Do you remember that motion to dissolve, Dr. Arnold?

A. I recall that there was such a motion to dissolve, but I do not recall the wording of it, nor the time of its execution.

XQ. 574. We will have to rely on the record for the date which appears on page 2451 of the Interference record as November 24; and one of the grounds of the motion was that the claims were not patentable to either party, was it not?

A. I really can not tell without reading the motion. I do not carry that in my mind.

XQ. 575. You remember that the point of the motion was that the thing was not patentable, don't you?

A. I have clearly in mind that there were doubts in our minds as to the patentability of certain parts. I am not at all sure of any doubt as to the patentability entirely.

XQ. 576. Now, here is the third ground of the motion: "That the claims constituting the counts are not patentable to either party." It goes on to cite a

Wehnelt article, a Lilienfeld article, a Marsh article, a Lenard article, and an article by Majorano. Is that correct?

A. Your statement of the contents which you have just read me is correct. And perhaps I can add to the answer this, that it was my own personal belief at the time that claims as broad as that were included in the original application would probably not be allowed by the Patent Office and that is frequently the case in patent applications because an effort is made in such applications naturally to introduce claims as broad as possible, and it is my recollection that those claims practically and entirely were thrown out in the Patent Office as unpatentable, so that to that extent my opinion was the opinion of the Patent Office.

XQ. 577. You remember that one of the claims of the original interference was allowed and is now one of the claims of the Langmuir patent?

A. I think that is the case, yes, sir.

XQ. 578. Do you remember a paper filed in this Interference on your behalf appearing on page 2445 of the Interference Record?

A. No.

XQ. 579. An affidavit of one Peter I. Wold in which he asks for more time in order to find some references to show that the issue was unpatentable?

A. No, I do not remember it.

XQ. 580. And on that motion to dissolve testimony was taken?

A. That is correct.

XQ. 581. And in that motion you testified as a witness?

A. Yes, sir.

XQ. 582. Among other things to the behavior characteristics of the DeForest audion?

MR. HAIGHT: I object. I think counsel will have to point out to the witness exactly what he refers to without general statements, because we had the unfortunate experience yesterday of getting wrong on that.

Mr. Davis: I am testing the witness's recollection, if your Honor please.

Mr. Haight: I submit that it cannot be tested without the witness's——

The Court: I think the objection is well taken.

XQ. 583. Will you please open that book at page 470, Dr. Arnold, which is page 2 of the rebuttal testimony on motion? That is your testimony, is it not?

A. I have it.

XQ. 584. That is your testimony, is it not?

A. Yes, sir.

XQ. 585. And referring to the page before is the testimony given on the 19th day of November, 1919?

A. That is correct.

XQ. 586. You say in your answer to Q. 2:

> "During November, 1912, I experimented with an audion which had been left with us by Dr. Lee DeForest, and in connection with these experiments, I became curious to know what the relation is between current and voltage in a pure electron discharge."

Is that correct? Did you say that?

A. That is correct.

XQ. 587. And on page 472, about the middle of the page you said:

> "As a matter of fact, this whole calculation of the 3/2 power law did not appeal to me as being of very much importance, because the simplifying assumptions which I had been led to make in working it out were such as could never be met in any practical commercial device. I had, in fact, been

surprised to find that the equation held even as approximately as it did for a DeForest audion where the presence of the grid and other disturbing factors would naturally be expected to cause considerable departure from results computed with the ideal assumptions which I had made. I have here some figures showing the way in which the particular DeForest audion to which I have referred above did conform with the ideal equation. The data was taken in November, 1912."

That was your testimony?

A. That was my testimony then and it still is.

XQ. 588. And then you give data, a table of data on page 473, which is page 5, and on page 475, which is page 7, you give a plot of that data; is that correct?

A. Yes; that is correct.

XQ. 589. And that is the same data and the same plot as you showed this Court yesterday as your Exhibit 9; is that right?

A. May I look at Exhibit 9 to make sure of that?

XQ. 590. Surely.

A. That is a part of the same data plotted in the same way as far as I can see.

XQ. 591. That is to say, you produced this data and this plot in 1919, as a plot of the prior art, of the DeForest audion; is that right?

A. Well, it was produced as a plot of audion 7-A, which which I had been working. I am not sure what the argument was in this matter.

XQ. 592. You know, do you not, that the argument was that the issue was unpatentable because that is the way a DeForest audion worked?

A. I do not recall the argument myself as to this particular plot.

XQ. 593 Suppose we look at what you said.

The Court: Do you mean the DeForest audion as it was without further evacuation?

Mr. Davis: Yes. My position is that this witness in 1919, when he was trying to knock out this issue, testified to this curve and this data as a curve of the standard DeForest prior art audion and that is the only possible construction that I can put on that testimony. Now he claims it as his reduction to practice.

XQ. 594. For example, you said at page 476, which is page 8, did you not,

> "Although this correspondence between the theoretical calculation and the results obtained in the actual DeForest audion was interesting, it was not at all important,"

and so on, and on page 480 you said:

> "My first active interest in vacuum tube devices of the audion type dates from the time that Dr. DeForest left one of his tubes with us in the Fall of 1912, and, as I have stated above in answer to Q. 2, I experimented with this tube in an attempt to find out how it operated from a practical and theoretical point of view."

And you said at page 482, which is page 14; or at the bottom of page 481:

> "In order to make possible the use of the tubes at voltages of the order that I had decided was desirable, it was obvious that steps must be taken to overcome the difficulty that arises when you attempt to operate the original DeForest audions at this voltage. I have no doubt that some of the DeForest audions as originally made would have operated at 120 volts entirely satisfactorily. As a matter of fact, the one that I gave data for in answer to Q. 2 operated to 80 volts, and would very probably have gone considerably higher."

That was the one 7-A, was it not?

A. Those statements that you have read are correctly read from the record and are statements of fact. The audion to which they relate is the original DeForest audion 7-A which I produced here a few days ago and about which I testified.

XQ. 595. But not in the condition in which it was left by DeForest?

A. Certainly not quite in the condition in which it was left by Mr. DeForest.

XQ. 596. Not quite in the condition?

A. No. No device of that sort can be used for a considerable period of time and remain in the same condition.

XQ. 597. You said on page 2182 of the Interference Record, did you not, which is page 28 of Arnold priority record:

> "In respect to its capacity for a considerable voltage range of operation without gas effects, this audion 7-A did not belong in the same class with the original DeForest audions that were left with us in November, 1912."

A. Will you give me that page number again?

XQ. 598. Page 28 of the Interference Record, Arnold's record on priority. This is headed "Use of Pure Electron Discharge Data from Audion 7-A." You said:

> "In respect to its capacity for a considerable voltage range of operation without gas effects, this audion 7-A did not belong in the same class with the original DeForest audions that were left with us in November, 1912."

You said that when you were contesting priority, did you?

A. That is read correctly from the record.

XQ. 599. And that was said by you at the time when you claimed to be the first inventor?

A. To the best of my knowledge and belief I never have disclaimed being the first inventor, so that I certainly was claiming it at that time.

XQ. 600. Let us get it straight. The testimony which I have read you first in which you first produced this curve and the plot and the data for which the plot was made was given by you at the time when you were testifying in your own behalf on the motion to dissolve; is that true?

A. That is correct.

XQ. 601. And this testimony I have read you last was given by you after the motion to dissolve had been determined and when the Interference proceeding was at issue on priority?

A. Yes, sir, and the two statements are not to my mind irreconcilable.

XQ. 602. And on page 34 of that same volume, which is page 2188 of the Interference record, you testified, did you not?

> "Almost all of the early audions with which we worked were destroyed, but on account of the unique character of 7-A, its superior vacuum and the important use we had made of the data which it gave us, it was one of a few early audions that were put into the Western Electric Company's Museum."

A. That is correct.

XQ. 603. And that is the same audion to which you referred as an ordinary DeForest audion in your testimony on the motion?

A. Will you refer me again, please, to that place?

XQ. 604. Page 14, top of the page of Arnold's rebuttal motion, being page 482 of the Interference Record:

> "I have no doubt that some of the DeForest audions as originally made would have operated at 120 volts entirely satisfactorily. As a matter of fact, the one that I gave data for in answer to Q. 2 operated to 80 volts, and would very probably have gone considerably higher."

A. You have read correctly from the record but that to my mind is not a statement to the same effect as the statement which you have just asked me to corroborate.

XQ. 605. Dr. Arnold, at the time when you knew that your counsel were trying to destroy this invention, to destroy the patentability of this invention and you were called as a witness to that effect, you produced this curve of the audion 7-A and said it was the curve of a DeForest audion without saying that you had made any changes on it or had done any work on it; is that correct?

A. That is not correct. I did not detail any processes that had been pursued in order to modify its characteristics, but I am quite sure that I testified that the tube had been used.

XQ. 605a. Of course you had to use it to take the characteristics. Did you say anything which would give one the impression that the audion had been transformed in its characteristics?

Mr. Haight: I object to that. The witness cannot be an expert to testify as to what impression would be conveyed by what he testified to.

The Court: To that extent I think that the objection is well taken.

(Discussion.)

XQ. 606. Now, when you came to testify by these prepared statements on the question of priority, Dr. Arnold, these statements I think you said this morning were carefully prepared and discussed with your lawyers, and so forth, and you recognized the thing was important; do you remember that?

A. I do not remember saying that, but I certainly did recognize that the matter was important, and they were carefully discussed. I do not recall saying so this morning.

XQ. 607. And carefully prepared?

A. And very carefully prepared, yes, sir.

XQ. 608. Now, in all those statements—I have myself not been able to find, and I am asking you to answer the question I am going to ask you on the assumption that I am right—I have not been able to find any place in which you said that you intentionally or deliberately or knowingly improved the vacuum on that tube. I have found many places in which you said that you did improve it, and that you cleaned it up, and that you had a clean-up action, but I find no place in which you deliberately said you did. Yesterday, I think it was, you did testify, if I understood you correctly, on page 597, of a deliberate premeditated attempt at a clean-up; is that right?

A. I do not recall the exact words of my testimony yesterday, but I can re-state the fact which may, I hope, agree with the statement of yesterday, which was that in the experiments which I asked Pierce to conduct. I instructed him to repeatedly increase the voltage to such a value as would bring on blue haze, and that I knew that thereby the vacuum would very probably—I may have stated certainly—be improved, because I was familiar with the corresponding clean-up effect in X-ray tubes. That, I think, must have been the sense of my testimony yesterday.

XQ. 608a. It was substantially what you said yesterday on page 597. Now, you did not say that, did you, in your testimony on priority?

A. Very probably not in those words. I do not recall that testimony in complete detail.

XQ. 609. Now, of course, it was quite important whether this thing had happened to this DeForest audion in your hands or the hands of Pierce, whether it was an accident or a premeditated thing, was it not?

MR. HAIGHT: I object to that, if your Honor please.

(Discussion.)

THE COURT: It seems to me the question to be put by Mr. Davis, the real point of that as I understand it, is not that something that was material was omitted, but the evidence that was produced was affirmatively misleading in the absence of the supplemental testimony.

MR. DAVIS: If your Honor please, may I explain what I understand the facts to be?

THE COURT: Yes.

MR. DAVIS: These statements were very carefully prepared, make no mistake about that. They were prepared with the utmost care. Now, we know, and there is no question that Dr. Arnold had a DeForest audion on November 1st. The records show that he directed Pierce to make some readings, to take his characteristic curves, and the notebooks show uninterrupted characteristic curve readings going on up to November 30th, perhaps, all kinds of characteristics and the notebooks are all just alike; that is, you look at the heading of the page, and it is "Characteristic between grid and plate," and the next page, it is characteristic between plate and cathode, or whatever it may be. There is no intention of anything being done except taking readings of characteristic curves, and there is not a scrap of original record that anything was done or attempted to be done or intended to——

THE COURT: To the DeForest tube?

MR. DAVIS: To that 7-A audion.

THE COURT: To alter its characteristics?

MR. DAVIS: There is no question these characteristics were altered, that is very clear, and our position is, and has been, it was due to an accident, the very existence of which was not known to Dr. Arnold and an accident which he never reproduced and was unable to reproduce, as he did not understand it. I say that much, just to give your Honor the background about which this thing is about.

THE COURT: Yes.

MR. DAVIS: Now, then, you can read that testimony, that prepared statement of Dr. Arnold, that prepared statement of Mr. Pierce as corroborating witness, and all those statements, and you will find language which seems to me that they did something to that audion; but every time you analyze that language, you see it is carefully prepared to give the impression, but actually does not say any more than they passed current through it. He says in one place, for instance, having cleaned up the plate, we proceeded to clean up the grid; so having cleaned up the grid we proceeded to clean up the plate.

The record showed they took a reading of the current which would flow from the grid and enough readings to plot the curve, but there is nothing in the notebook which showed they intended to clean up or they knew they had cleaned up the grid; and yet, as I say, there these statements are, but never in all that record do they dare to make the statement that this witness has made in this court room, that they knew they were cleaning up, or intended to clean up.

Mr. Haight: Why do you suppose the witness comes here and makes the statement, if he did not make it there? Has suddenly his conscience gone back on him, so that he comes before a court where he can be cross-examined and cross-examined at length; that his conscience has suddenly changed, and the witness has now the boldness to come and state things that he did not dare to state in the sanctum of the office of his own attorney?

Mr. Davis: If your Honor please, a great many years have gone on since these things happened and a great deal of pressure has been put upon this situation. Dr. Arnold's mind has dwelt on this matter a great deal. This morning, for example, we had an illustration when we asked him what a certain patent of his was for. He told us he gave us the statement and looking at the patent itself, it was for an entirely different reason, but I am not criticising it.

The Court: I am not misled by that. I happened to have one experience of my own on the witness stand, where I had no doubt in the world that a certain fact existed, and I so testified, and the expression of the opposing counsel's countenance told me that he was surprised, and to show him that he was dead wrong, I called for the paper. He was right, and I was wrong, so those things do not disturb me very much, because I realize from that one experience the frailty of my memory, and consequently, the frailty of the memory of other human beings, but we do get a general trend, a general tendency; so that it seems to me that you have suggested in your last statement, Mr. Davis, a somewhat different proposition than you did in either of the other two. At the moment, I see no objection to your asking the question which was suggested at the last part, that is, what they did ultimately to clean up at that time, if I get your thought in your last statement. Now, then, the first question dealt with the appreciation of the importance, and it seems to me you shift now in this last line—I do not mean shift in any improper sense, but I mean drawing his attention to the laboratory rather than to the Patent Office in your last question.

Mr. Davis: I am coming to that, if your Honor please.

The Court: Will you do this so that we may know exactly where we are—put a new question which you think is proper to be answered, bearing in mind the discussion that has been had. I do not mean that that discussion shall affect you except as it throws a light on the question which you have put.

XQ. 610. Did you tell your counsel at the time or before the time these statements were prepared, Dr. Arnold, that you did instruct Mr. Pierce to go up to a blue glow in order to get a clean-up?

A. To the best of my recollection now, I did, but I am not entirely clear as to just what I told the counsel who prepared the affidavit. Certainly if I told him that it would have been in conformity with the facts, and if I did not tell him that, it would have been an omission which I would have regretted.

XQ. 611. Do you know why that statement was not included in your prepared statement?

A. No. I do not know why it was not included in my prepared statement.

XQ. 612. You attended how many of the hearings in this interference? You were present before the Examiner of Interference, were you not?

A. And at the Court of Appeals.

XQ. 613. And the Board of Examiners in Chief, were you not?

A. Oh, wait a minute. To the best of my present recollection, I was in Washington twice, and once in the Patent Office, but I do not remember which tribunal; it was in the Patent Office.

THE COURT: We will take a short recess now.

(After a short recess.)

XQ. 613a. Coming back again to November 1st, 1912, what was the voltage and current which the audion would handle properly?

THE COURT: That is 7-A?

MR. DAVIS: The audion which was exhibited by DeForest, and which Dr. Arnold found in Mr. Colpitts' office on November 1st.

A. There were two or three different audion elements left by DeForest, the voltage and currents for them were different among themselves, not however very greatly different, and the voltage for satisfactory operation as a telephone repeater at ordinary voice loudness in the sense of a low conversational tone as used over the telephone instrument or for faint sounds, fainter than that which I have just defined, I would say the voltage that could be used was about forty volts or a little lower, perhaps between thirty and forty volts. I want to make that matter of loudness quite clear, and since there is some difficulty in the interpretation of those terms——

XQ. 614. Can not you forget the loudness? All it means is you must not overload, if you use the expression in the rough way in which I am using it; is not that it?

A. No, no. You must not get blue haze.

XQ. 615. You spoke of a voltage on the device at which it would not blue haze however loudly you might speak?

A. Yes, there was such a voltage.

XQ. 616. But that was not the normal voltage?

A. That was the voltage somewhere in the order of thirty volts as I recall it. The whole range of operation ran from the voltage of thirty volts plus or minus a few volts to the vicinity of forty volts, plus or minus a few volts, and at the upper voltage blue haze would occasionally and intermittently appear.

XQ. 617. If you overloaded?

A. If you overloaded, and at the lower voltage the articulation would be poor, if you spoke too loudly.

XQ. 618. If you overloaded?

A. Yes, if you overloaded.

XQ. 619-20. Now, you testified in your priority record, page 12, page 2166 of the Interference record:

> "And since the voltage in those original tubes ran about 40 volts and the current about 150 microamperes, the maximum available output power would be less than six milliwatts."

Is that still your recollection?

A. That is not my recollection, but I can read it.

XQ. 621. Near the top of page 12 of that book!

A. Was the last word in the preceding question "milliwatts"? (Question repeated by the stenographer.) That is the fact.

XQ. 622. You went on, did you not:

> "On the other hand, the Arnold arc repeater, operating at 220 volts, could put on the line about 3 watts. The power that an ordinary telephone transmitter may put on the line is of the order of 1 watt."

Is that true?

A. That is true. I would emphasize particularly the word "may" in the sentence.

XQ. 623. Now, you testified on page 2193 of the Interference record, which is page 39 of the same book which you have:

> "We understood thoroughly in November 1912 that the principles of operation of the high vacuum repeater bulb that I contemplated were the same as for the original DeForest and McCandless audions such as DeForest audion 7-A when they were kept below the voltage at which gas effects appeared."

Are you still of that opinion?

A. I am.

XQ. 624. So that so long as you did not ask the DeForest tube to do more than a certain amount of work, it is your view that it did that work all right?

A. Providing the voltage on the plate was sufficiently low.

XQ. 625. Provided that your plate voltages and current were low enough, and you did not overload it?

A. I will put it clearly this way—provided the plate voltage did not reach the place where ionization became apparent and provided the input speech was not sufficient to produce ionization, then, if the input speech was not so loud as to cause distortion because of the inadequate electron supply, the reproduction was satisfactory.

XQ. 626. But all those limitations together amount to a very severe limitation as a practical matter from a telephone standpoint?

A. Yes, a limitation that would have made the device of practically no value in the telephone plant.

XQ. 627. Now, will you please look at your priority Exhibit No. 25? This appears to be a photostat copy of page 5 of Kendall's notebook No. 42, noting the commencement of commercial service with an audion repeater at Philadelphia on October 15, 1913.

The bottom of that page, if I understand it correctly, gives the energy conditions under which those tubes went into service, service which has sometimes here been called commercial service and sometimes called experimental service, but whatever you call it, it shows the energy conditions. What were those energy conditions in current and voltage?

Mr. Haight: I think I ought to object to that question, because I think it contains an erroneous statement. Mr. Davis says that service that has sometimes been referred to as commercial service and other times as experimental service, and I do not think there has been any such evidence.

(Discussion.)

Mr. Davis: I will ask Dr. Arnold to answer the question including any characterization of the circuit, either commercial or uncommercial, and not being bound by it, as if I had not said it.

A. The record to which you direct my attention at the bottom of page 5, Exhibit 25, shows that 9.30 o'clock on the 18th of October, 1913, telephone repeaters 6.11 and 23.11, if I read the record correctly, were installed with twenty-eight dry cells impressed on element 6.11 and twenty-five dry cells impressed upon element 23.11 and at 9.40, ten minutes afterwards the record says, "Talk O. K. Somewhat louder." And at 9.55 P. M. the record says, "Talk O. K. On the edge of singing. This does not show much gain."

The data is sufficient to indicate that about forty-two volts were in the plate circuit of audion 6.11 and about forty volts in the plate circuit of audion 23.11; it does not indicate the plate currents which were flowing at that time, but it does indicate that the devices at that time were not operating to give much gain because it so specifically states. I think I cannot answer any further from the record or from any knowledge of my own with respect to the power in that circuit.

XQ. 628. The currents are given just above, are they not? Seventy microamperes, seven minutes, and so on, 170 microamperes, nine minutes.

A. I see the record to which you refer.

XQ. 629. I am told I am in error in reading "mi" minutes. It is miles.

A. I see the record to which you refer and that record was apparently taken before the elements were put into the circuit and that does indicate that audion 6.11 with twenty-eight volts had a current of 170 microamperes, and that audion 23.11—no, it does not state what current was in audion 23.11 with twenty-five cells. I wish the stenographer will go back and correct twenty-eight volts to twenty-eight cells in the preceding sentence.

XQ. 630. It gives here 23.11 on N. Y., which means New York, 23 cells 70 microamperes.

A. Where are you reading from now?

XQ. 631. I am referring to this line here, Doctor; 23.11 on N. Y.

A. Yes, I see.

XQ. 632. What does "on N. Y." mean? What does it mean? Doesn't it mean what it says?

A. I presume it does, but I am trying to puzzle out just what it says.

XQ. 633. You had two circuits, one to New York and one to Washington and here you have one audion marked with "On Wa." The other one is marked "On N. Y." Does it not mean that one was on the Washington circuit and one on the New York circuit?

A. I would not be sure about that. It says, "After this test over, test between networks," and then immediately follows what you have quoted, "6.11 on Wa." and "23.11 on N. Y." It seems to me not improbable from my recollection of things that happened down there at Philadelphia that this might refer to a test on the Washington and New York simulating networks, but I am not sure about that. This record is not my record and I have to speak from my best interpretation as to Mr. Kendall's record.

XQ. 634. The record was put in to show the commencement of the commercial service with an audion repeater at Philadelphia, and it says at the top: "Test between New York and Philadelphia to see about cutting this circuit."

A. It looks to me like "putting."

XQ. 635. And it mentions various cells, 39 cells and 21 cells and 31 cells and finally it comes down to 28 and 22 and against that there is a notation, "Which is to be used in service." I take it that that 28 was on the New York line and 22 on the Washington line, or *vice versa,* or Baltimore. I do not know which. But that is the figure of the number of cells to be used for service, is it not?

A. I see you are reading now. Yes, that is what it says, and that undoubtedly is what it means.

XQ. 636. And just below the line to which I call to your attention, it shows the same figures 22 and 28 which are to be used for service, one on the Washington and the other on the New York. So you have on the Washington 28 cells and 110 microamperes.

A. That is what the record says. On the other hand, the first record that I see here of service being started gives the voltages, as I understand the record, as 28 cells and 25 cells, respectively. However, the difference between 25 and 28 is not very large.

XQ. 637. Let us take the 28 as the maximum and forget the 25 and 22. 28 cells gave 110 microamperes. 28 cells I suppose is 42 volts.

A. Thereabouts.

XQ. 638. How much was the energy?

A. The energy in the plate circuit, if that was 42 volts, is the product of 42 and 110, or 4.6 milliwatts.

XQ. 639. That is about two-thirds of the energy which the DeForest audion would handle properly?

A. Thereabouts. I would like to call your attention to the fact that this does not show much gain as indicated right at the bottom of the page.

XQ. 640. You had a tube in the spring of 1914 which would handle five milliamperes at ninety volts. Is that right?

A. Can you refer me to the reference?

XQ. 641. Yes, I think I can find the place. On page 136 of the Arnold priority record, page 2280 of the Interference Record, folio 408, you say:

> "I had clearly in mind a special tube which we were running on life test at that time and which throughout the week of the day when I talked with him was operating with about five milliamperes of electron current at about 90 volts."

And this statement referred, did it not, to a talk which you had with Dr. Langmuir in the spring of the year 1914? I may be wrong about the date of the talk, and if I am I wish you would correct me. I gather from page 2289 that the talk was in April, 1914.

A. I will have to ask for the quotation you have read to me.

(XQ. 641 repeated.)

A. The testimony on the page to which you have referred does refer to a conversation with Dr. Langmuir during April, 1914.

XQ. 642. Then later you produced some high-power tubes which were used in important wireless demonstrations. Were they of the type shown in Fig. 4

of the drawings attached to your application, which you will find opposite page 36 of the Interference Record?

A. They were of that general type.

XQ. 643. There is a very unusual construction of the plate in this case. Perhaps you can explain to the Court briefly what that construction is.

A. The plate in this case consists of a ribbon—

XQ. 644. Bent back and forth like a slice of—

A. Just a second. It is a ribbon of Driver Harris 41 alloy, which is a resistance alloy, largely consisting of nickel, bent back and forth in such a way as to make a complete electrical conducting path from one end of the plate to the other end of the plate, the electric circuit going zigzag down the length of the plate.

XQ. 645. There are two plates?

A. There are two plates, one on either side of the filament with a grid between the plates and filament.

XQ. 645a. The peculiarity of the construction to which I wish to call attention is that the plate instead of being as it is in the other figures, a mere strip of metal, a mere sheet of metal, is made up of this long strip of Driver Harris material zigzagged back and forth so as to practically act as a plate so far as the electrons are concerned; is that correct?

A. That is correct, and the reason for that is so that the plate may be heated during exhaust by sending the current through it. In the tubes which immediately preceded this and which we used at Montauk point, the plates were solid plates, but as we were called upon to manufacture these tubes in large numbers to be used in Washington, it became necessary to expedite the pumping processes and so we made use of this artifice to shorten the time of pumping. Instead of bombarding the plates and driving the gas out by heat generated by bombardment alone, we passed a heating current through the plates and thus got them hot much more quickly and with much better conservation of the filament which used to suffer under bombardment.

XQ. 646. You have spoken a good deal about the Wehnelt cathode and you said it was very difficult. It was quite a job to develop this cathode, did you not?

A. That is a fact.

XQ. 647. And that it is a rather expensive cathode, is it not?

A. I would hardly say it is a rather expensive cathode. I presume that the amount of cathode in an ordinary tube would not cost over half a cent or something of that order.

XQ. 648. The tubes with that cathode were for a long time much more expensive than the tubes with the plain tungsten cathode, were they not?

A. The question of the expense of the tube was not of the cathode but was one of the goodness of the tubes, and the tubes that were made with this cathode were superior to any tubes made with any other cathode, and were produced at a very much higher vacuum, and in order to do that longer time was required in the pumping operation.

The cost of the tube lies quite considerably in the pumping processes, part of it of course is in the fabrication of the glass and metal parts, but a considerable part is in the labor of people who pump the tubes and that is why the Wehnelt oxid tubes have been more expensive. They were pumped much longer and with much greater care than metal filament tubes.

XQ. 649. It was necessary to pump them more. It is harder to clean up that cathode than it is to clean up a tungsten cathode?

A. I am not sure if that is the case, because I have in mind certain tubes which we are now making with tungsten cathodes that we have to pump for twenty-four hours, whereas no such time is required on certain other tubes with Wehnelt oxides. No, the question is one of the degree of vacuum required and the amount of voltage and current at which the device is to be used.

XQ. 650. You spoke, I think, of 35,000 hours' life of the cathode of the tube. That is a special tube for telephone repeater service?

A. That is the regular tube which we make for telephone repeater service all over the country. The tube is especially designed for telephone repeater service.

XQ. 651. That is what I meant. I did not mean to imply that it was not part of your regular production, and a very important part, but it is not a tube that you would sell for radio reception purposes?

A. We do not sell any tubes for radio reception purposes to other than the Government and to the Government we sell tubes which are made with Wehnelt oxid filaments and which have lives somewhat shorter than this probably, perhaps of the order of five or six or ten thousand hours, but their lives have not been determined with the accuracy that we use for the telephone service.

XQ. 652. Can I trouble you again to look at that drawing in your application and to this curve which we considered this morning for a moment? I understand that the curve OABC'K and the curve OABCD are curves of the good tubes described in that patent application. That is correct, is it not?

A. They are illustrative curves of a tube operating in the absence of positive ionization.

XQ. 653. And this curve OABHG is a sort of curve that the DeForest audion would give?

A. I cannot say that.

XQ. 654. What can you say?

A. I can produce a curve that the DeForest audion did give which is perhaps somewhat similar to that; that is, the curves that we have in the record, which were taken with the DeForest audion 7-A during its various stages of procedure, but I am not prepared to say that that dotted curve can be taken as representative of the DeForest audion curve. As a matter of fact, I have no idea that that curve was drawn to exact scale.

XQ. 655. I was not thinking of exact scales, Dr. Arnold. I was trying to get some general principles. You agree, do you not, that it is characteristic of a gas tube to have a rather sudden rise in voltage above the ionizing potential?

A. Tubes that are very gassy do have that, providing the filament is hot enough to give a copious electron emission.

XQ. 656. Provided it does not saturate, it does not get there, or provided saturation is not close enough to affect it. For example, this curve on E887,498 which is one of the early curves of audion 7, before it became called 7-A, the dash curve to the left with the ascending arrow——

The Court: What is the page?

Mr. Davis: Unfortunately those books are not paged.

Mr. Richmond: The exhibits are numbered.

Mr. Davis: I know they are. It is Exhibit 8.

The Court: I have it.

XQ. 657. That curve which starts at the origin and goes up and is toward the left more than the other curves, a dash line with a little arrow and bending over sharply at about 6,000. Is that such a curve as you were thinking of as a gassy curve?

A. Yes, that curve was obtained, I think, with the audion detector 7, with considerable positive ionization present, which ionization disappeared at the top of the curve for a considerable extent and the current dropped rapidly downward.

XQ. 658. Then you think there is something that can be told about a tube by a study of its performance?

A. There is if you have seen the tube and know how it behaves.

XQ. 659. For instance, I remember that Dr. Millikan spoke of a sharp rise at the ionizing voltage as being an excellent test of a gas tube. Do you agree with that?

A. I would like to see his statement before I say whether I agree with it or not.

XQ. 660. I had a very good note of that statement but I have lost it.

A. I can say definitely, however, that in thermionic devices in which there is a considerable amount of gas under certain circumstances there may be a sharp rise at the ionizing voltage, and this sharp rise is actually made use of in scientific experiments to determine the ionizing potential of the gas. So that if a sharp rise occurs at the ionizing voltage in the absence of other causes which would explain the phenomenon, the phenomenon might very well be due to gas.

XQ. 661. The point being that a great many things can happen and many influences can be at work in these tubes?

A. Yes, sir. And they may all affect the characteristic curve. Some in one way and some in another, and one has to know the conditions very, very thoroughly before he dare to express an opinion as to the significance of the curve.

XQ. 662. Dr. Millikan said at page 449 of your record in rebuttal on motion, page 917 of the Interference Record:

> "I do not think that it is possible to specify without specifying many other conditions. In general, as is shown by the curves which I have referred to from H. A. Wilson, from Thomson, and on typewritten pages 268 (printed page 363) *et seq.*, of my rebuttal, and also by the curve given by Dr. Langmuir on page 99, there will be a region which is reached by a sufficient increase in voltage, at which the current begins to shoot up in the presence of appreciable quantities of gas because of the increased multiplication of ions, increased emission, or both, for, of course, they are intimately connected. I do not think it is possible with our present knowledge to lay down any general rules as to when that increase will occur, for it depends upon the previous treatment of the tube, the nature of the filament, distance between electrodes, and perhaps other factors also."

Do you agree with that statement?

A. I agree with that statement but I want to make it very clear that it does not relate to the matter of your previous questions, because the rise in current about which Dr. Millikan is here speaking, as I understand it, is not the rise in current of which I was speaking a few minutes ago. This is a rise in current which comes about, as I understand it, by the introduction of new gas into the vacuum space of the tube during certain stages of operation while my previous answer related to behavior when the tube had more or less gas in it originally.

XQ. 663. And if you have a tube which contains a certain amount of gas and observe the current say at fifty volts on that tube and get a current of say two milliamperes and then pump out the gas [illegible] observe the current and find it to be one milliampere and then continue to pump some more and find that the current does not go any further but stays at one milliampere, you have there Dr. Millikan's test, have you not?

A. I think you better point out to me or define to me in some other way what Dr. Millikan's test is. I do not know of any test that goes by that name.

XQ. 664. You heard Dr. Millikan testify here?

A. Oh, yes, he testified of the three-electrode test. Is that the one you mean?

XQ. 665. No. Dr. Millikan testified with regard to a test which he regarded as a good one which consisted merely in pumping and noting when the current stopped falling with increased vacuum.

A. Yes, I did hear him testify to that.

XQ. 666. I was asking you to imagine such a test as that case. I suppose that is what the paragraph of Dr. Millikan, which I read, referred to?

A. Then we completely misunderstand each other.

XQ. 667. Perhaps it is hardly worth while to straighten it out. Under what conditions do you consider it is proper to use the volt ampere plot to give information with regard to whether or not the tube is the tube of the patent?

A. I do not believe I can specify a set of conditions so exact that I would want to pin an opinion as to whether the tube was or was not a tube of this issue, if it did or did not have certain characteristics. By characteristics I mean the EB, IB characteristics, providing that I was not furnished at the same time with other additional and corroborative evidence.

If the structure of the tube was one with which I was quite familiar and in which I had investigated what the current voltage relationship was at various pressures of gas, and then if someone brought me a tube just like it and said, "Here is an EB, IB characteristic which I have taken on this tube," and if that conformed to my experience with that type of tube in high vacua and did not conform with my experience with that type of tube in poor vacua, then I would think that that was a pretty good evidence that the tube submitted was a high vacuum tube.

XQ. 668. In the commercial manufacture of tubes by the Western Electric Company, if you will look at page 159 of your record on the motion, not the rebuttal, but the record on motion——

A. Would that be the red ink?

XQ. 669. No. I am sorry. I should have referred to the rebuttal on motion. Tell us in a general way what the exhaust schedule is on these commercial tubes. That is, take a small commercial tube. I do not want to trouble you with the exhaust of a big tube. What do you do with the tube now or what did you do with the tube at the time of this interference? I want to get an idea of the exhaust precautions in the commercial manufacture of the tube. Take it as of the [illegible]e when this testimony was given.

A. I cannot speak with any great definiteness on that because although that entire tube manufacture is in my department, it has been a good many years since I have had anything to do with the actual manufacturing processes. However, the general process is to attach a tube to be exhausted to a vacuum pump and heat the tube hot in an oven and heat the metallic portions within the tube hot and continue the exhaust until the blue haze has disappeared within the tube, and then seal the tube off. That was our practice some years ago when I was more familiar with it than I am now.

XQ. 670. What was the impedance of an ordinary telephone receiver in 1912, roughly, do you remember?

A. It is my recollection that it was about 200 ohms, but that is subject to a wide correction. My memory is poor on that.

XQ. 671. And in the modern receivers which you use in modern radio it is higher than that?

A. They have all sorts of receivers that they use in modern radio. We use in our radio work our ordinary telephone receivers. It is merely a matter of transformer design whether you use one receiver or another.

XQ. 672. You spoke the other day of the charging up of the grid with paralysis of the DeForest audion on or about November 1st, which could be cured temporarily or alleviated by attaching the grid terminal with the finger. Is that a correct statement?

A. That is a correct statement.

XQ. 673. That, of course, did not exist when there was ionization in the tube, did it?

A. No, paralysis and ionization were mutually prohibitory.

XQ. 674. At the other ends of the scale, were they not really, more or less?

A. At any rate they did not exist together.

XQ. 675. Now on page 2174 of the Interference record which is page 20 of the Arnold priority record, this is your testimony, and you are talking about what happened after November 1st. You say:

> "At first I paid almost no attention to Mr. Pierce's work, but when I did give it some attention on or shortly before November 16, 1912,"

and so on. Then at page 2175, you say:

> "And I gave him directions for getting direct current data from which I might derive the general operating characteristics of a 3-electrode device, in order that I might be able to make the necessary mechanical modifications to get operation best adapted to telephone service. He set about this direct current work at once."

And then you say on page 2176, which is page 22:

> "I will explain with reference to Mr. Pierce's notebook 20 and the accompanying sketches how we had proceeded with audion No. 7 to clean it up before using it for the demonstration."

And then you say at the top of page 2179:

> "Having cleaned up the grid by leaving the plate on open circuit we proceeded to clean up the plate by leaving the grid on open circuit."

I understand that in the present testimony you do not take the position that what you did had any effect on the gases in the plate or grid; is that right?

A. I do not recall that I testified that it had no effect on those gases. It would have some effect upon the gases of the plate and grid, and this is the way it would work: If the audion had been used at, we will say, 50 volts, and had been in the habit perhaps of blue hazing at about that voltage, then if as the result of blue haze, the gas in the space was partly consumed, and then if the voltage was again increased above 50 volts to, we will say, 60 volts, there would be a further liberation of gases from both the plate and the grid, which gas might be later again cleaned out of the space by the action of the blue haze discharge; but this process could not go on very long nor could such a tube be cleaned up to stand a very much higher voltage than that for which the plates had been heated during the process of manufacture.

XQ. 676. Now, Doctor, you said this:

> "Having cleaned up the grid by leaving the plate on open circuit we proceeded to clean up the plate by leaving the grid on open circuit."

Did you or did you not do that?

A. Yes, sir, I did.

XQ. 677. And you testified in this paragraph on page 597:

> "And I knew that by doing so I would be improving the vacuum in this device, not improving the vacuum condition of the electrodes particularly, but cleaning up the gas that might exist in the space."

Now, will you please state how you reconcile these statements?

A. I reconcile those two statements by the word "particularly." As I have just explained the amount of gas which one would get from the plate and from the grid is quite small, and nevertheless it has a real effect. I very carefully specified in my direct testimony that the plate and grid would not be very much cleaned up.

XQ. 678. There was no intention of cleaning up the plate or the grid, was there?

A. There was an intention on my part of improving the vacuum condition within the audion——

XQ. 679. Dr. Arnold, was there or was not there an intention of cleaning up the grid or the plate?

A. I suppose you will insist that I answer that yes or no.

XQ. 680. I would like an intelligible answer. I am not specifying how you answer it, but answer it.

A. The purpose of the experiment was to improve the vacuum, and I knew that the process which I instructed Pierce to pursue, would do two things: Get the gas out of the plate and the grid to a certain extent, and eliminate that gas within the bulb by the action of the blue haze, providing always the treatment was not carried far enough so that too much gas was got out of the plates, and my purpose in having Pierce carry this tube up to high voltages, time after time, was to move upward the voltage, at which the blue haze occurred, if that were possible, and it proved to be possible to a certain extent.

XQ. 681. Doctor, please separate what you know now—and I know it is very hard to do it, it is hard for you and it is hard for any one—please separate what you know now from what you said and knew then, and just answer this question: That is whether you did or did not intentionally clean up the grid?

A. My answer will have to be yes.

XQ. 682. You did intentionally clean up the grid?

A. Yes.

XQ. 683-4. You did not say that in this testimony, did you?

A. This morning?

XQ. 685. No. In the testimony on priority?

A. Possibly not, I do not remember.

XQ. 686. I am talking now about intention as distinguished from act. You say, "Having cleaned up the grid," but you did not say at any point so far as you remember, that you intended to clean up the grid in this testimony on priority?

A. I do not recall any such statement in this testimony on priority.

XQ. 687. So that you knew you were cleaning up the grid?

A. I am not so sure about that.

XQ. 688. Or the plate—treat the plate and grid as the same thing?

A. I cannot state as to the exact statements in that testimony, but certainly it was my understanding that the import of that testimony was that I was consciously cleaning up the grid and the plate. As to the exact wording of the testimony, I cannot testify now.

Mr. Haight: It is before you there, is it not, top of page 25?

The Witness: I find at the top of page 25 of my testimony on the priority record, the statement beginning:

> "Having cleaned up the grid while leaving the plate in open circuit we proceeded to clean up the plate by leaving the grid on open circuit, as recorded on page 24 of note book 20."

That does not say in words that I cleaned up the grid by leaving the plate on open circuit, but I think the implication is quite clear.

XQ. 689. I have not the slightest doubt. I never had, when I first read it; will you please show me on that page of the notebook referred to where it says that you cleaned up anything?

Mr. Haight: I ask your Honor's attention to the fact that the notebook is not Dr. Arnold's notebook but somebody else's notebook. I do not know whether I can object to the question.

The Court: I do not think so, because it seems to me Mr. Davis is inquiring for pertinent facts. He is trying to separate present impressions from past intentions, and that sort of thing. It is a difficult task, and I think he is entitled to ask the question.

Mr. Haight: I do not object, but I thought I should direct your Honor's attention to that.

The Court: Some time I will ask——

Mr. Davis: This is in Arnold's priority Exhibit No. 6, the early part of this book.

The Witness: There is no statement to that effect at all on those pages of Mr. Pierce's notebook.

XQ. 690. You never made another audion by, or treated another audion by this process by which you produced this remarkable change in audion No. 7, did you?

A. I think that just that type of procedure was employed in a good many audions that we made with just the same type of result. I cannot at the moment indicate which ones they were, but I think there were many cases in which we had audions with slight blue haze which by operating for a short time, had the blue haze disappear.

XQ. 691. Oh, Doctor, you have testified that this DeForest audion brought to you on November 1st, 1912, was an audion of the prior art, and that you revolutionized it, and made it into a high vacuum tube by a series of treatments which you laid out and specified, and that it is such an exceptional and unique audion that it was preserved ever since in the museum because of these changes which you made upon it?

A. Will you please show me where I testified to that effect?

XQ. 692. I shall be very glad to show you those things; which particular statement do you want?

A. Where I said that it was such a revolutionary device—where I said it was preserved because of the changes that I had made in it. This certainly does not conform to any remembrance of mine of what I have testified to at any time.

XQ. 693. At this time of the afternoon, I prefer to withdraw the question and to look up all these references later, Dr. Arnold. Will you please tell your own understanding of the facts as they are; we will look up the references later; did you or did you not make a change in that audion?

A. I did.

XQ. 694. And a very important change?

A. Well, a change of some importance. I would not accent the "very."

XQ. 695. You said it was unique, did not you, in your testimony?

A. Very likely I did. I certainly do not know of any other one like it.

XQ. 696. And you said it was preserved in a museum because of its unique character?

A. I do not recall that statement; perhaps I made it.

XQ. 697. I have read it to you and gave you the citation today.

A. But that unique character was to my knowledge not because of anything that I had done about it, or characteristic that it was kept in the museum. I think the unique character I referred to was because it was one left by DeForest. I have not the testimony very clearly in mind.

XQ. 698. I think we will have to find that reference.

Mr. Davis: Page 34.

. . . .

XQ. 699. On account of the unique character, page 34, page 2188 of the Interference record:

> "Its superior vacuum and the important use we had made of the data which it gave us, it was one of a few early audions that were put into the Western Electric Company's museum——"

A. That is correct, and those are three separate things; the unique character was the fact that it was one of the original DeForest audions; the superior vacuum is what we have been talking about; and the important use we have made of the data, is all in the evidence.

XQ. 700. You had then succeeded in producing a superior vacuum and making a tube, a DeForest audion, into a tube that would work, in your judgment, at 80 volts; is that correct?

A. It did work at 80 volts.

XQ. 701. Satisfactorily?

A. Not satisfactorily as a commercial device, I presume, but it worked without much ionization at 80 volts, that is evidenced by the record.

XQ. 702. Now, you did not try to make any more high vacuum audions until April?

A. I did not personally try to get a high vacuum in any other audions until April, but Mr. Trimble, who was working under my general direction, did endeavor to make some audions and in this process he did actually get some with fairly good vacuum, in fact, really good vacuum.

XQ. 703. He did not try to?

A. I would not say he did not try to, because the job that I set him was to become familiar with the mechanical art of making these devices.

XQ. 704. Now, as long as in February, 1913, you had a demonstration of the artificial line reproducing or simulating the actual line which you were then actually building or contemplating from New York to San Francisco, had you not?

A. At about that date.

XQ. 705. And very distinguished people were present at that demonstration, were there not?

A. That is right.

XQ. 706. Including Mr. Vail himself?

A. I will have to look it up if you want me to answer as to that date.

XQ. 707. There is testimony to that effect in the record that Mr. Vail was there?

A. All right. I will agree with that.

XQ. 708. And Mr. Thayer was there? In that line you had a low energy level?

A. Yes, sir.

XQ. 709. You used ordinary DeForest audions for the repeaters excepting at the last repeater, where you used two of your mercury-arc repeaters; is that your recollection?

A. My recollection was that we had a different termination than that, but I do not know that it is material.

XQ. 710. Well, the point is that the repeaters—I will stop any time you want, your Honor.

THE COURT: Go ahead.

XQ. 711. The point I am trying to make, Dr. Arnold, is that the repeating throughout the line, except at the end, was done by DeForest audions?

A. That is correct.

XQ. 712. And the energy level of the line was held down in order that that might be done?

A. That is correct.

XQ. 713. So that although you sent speech over the line you kept the energy level of that speech exceedingly low?

A. That is correct.

XQ. 714. And that would have been impractical in an ordinary commercial line?

A. It would have because of the noise induced on ordinary telephone circuits by exposures to power circuits and other causes.

XQ. 715. That is, you keep a high energy level in order that your accidental noises may be relatively small; it is like listening to a broadcasting station if you listen to it pretty near, you do not mind a lot of static, but if you listen to a distant station, the static is troublesome; is not that a fair comparison?

A. I think that is a fair comparison.

THE COURT: When was this conversation?

XQ. 716. This was in February, 1913, Doctor, was it not?

A. Thereabouts.

XQ. 717. There was no attempt to use these tubes, although it was a demonstration of considerable importance; now did you tell Mr.—it was the artificial line in a laboratory and an artificial line in a laboratory, Dr. Arnold, is a collection of resistances and inductances and condensers which simulates the real line; is that right—there may be other things for all I know?

A. That is generally true, yes.

The Court: I did not get it as being in the laboratory. I thought it was actual.

XQ. 718. I think the whole thing was all in the laboratory, Doctor?

A. The whole thing was in one room.

XQ. 719. They made something that had the characteristics of this line that they were going to build, as near as they could estimate what those characteristics would be, and then they put this feeble current over it, and then at the end amplified it by one or more so-called arc repeaters, so that it could be heard; now, did you tell Mr. Vail that you were working at this low energy level?

A. I doubt if I spoke to Mr. Vail at all that day, because Mr. Vail was not a man that was approached without a good deal of circumspection.

XQ. 720. Was the statement made to these gentlemen who were witnessing this thing, that this was a demonstration of it at a low energy level?

A. I can not recall as to that.

XQ. 721. And no attempt was made to make any of these high vacuum tubes in time for that demonstration?

A. No. No attempt was made to make any of these in time for the demonstration.

Mr. Davis: If your Honor please, this is a good place to stop.

The Court: Won't you tell me again why the use of the tube cleans it up; you referred to it in the opening, but I have lost the reason for it, and you referred to it in the X-ray tubes becoming harder?

Mr. Davis: If your Honor please, it is a very complex subject.

The Court: You have told me?

Mr. Davis: It is a very complex matter. We are going into it in some detail in our testimony.

(Discussion.)

The Court: Will you help me on just one point, Mr. Davis? The witness used words with regard to the 7-A tube that Pierce or whoever it was, using the tube, thereby drove the gas out of the electrodes, and then the voltage was increased up to the ionization point, and then the gas consumed. I suppose it is the clean-up method that I inquired about a moment ago.

Mr. Davis: There are various forms of clean-up on different voltages and different conditions. For example, one clean-up——

The Court: I do not ask you to do this in order to tell me your evidence.

XQ. 722. They are all clean-up, I understand, but due to different causes; is that right?

A. They are all commonly referred to as clean-ups.

Mr. Davis: There may be half a dozen reasons for it.

The Court: Ten o'clock tomorrow.

(Whereupon at 5:10 P. M., adjournment was taken until Wednesday, October 27th, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del.,
Wednesday, October 27, 1926,
10 o'clock A. M.

TENTH DAY.

Before:
Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Davis: If your Honor please, our friends on the other side were good enough to let us have last evening some of the papers of which I spoke yesterday and others we are to have today; and I understand that in some way it will be possible for me to further cross-examine Dr. Arnold to get information as to the meaning of abbreviations, and so forth, and things of that sort, or anything that comes up in these papers, if we decide we need it. Your Honor will realize it will take some little time to analyze these papers, and I understand that there is some understanding that the technical question whether it is rebuttal, and so forth, will be waived to that extent; is that right, Judge Haight?

Mr. Haight: I do not know that there has been any understanding. I think that you made the statement yesterday and I do not know whether I said anything or not. I quite appreciate that it is quite difficult, if not impossible, for Mr. Davis to go through these books if he wanted to ask Dr. Arnold any questions about them. Only one of the books, however, is his book; they are books of other people, and I do not know exactly where we shall draw the limit. I appreciate perfectly well that your Honor will have it under your control as to whether it is rebuttal or whether it is not. I do not see any reason why I should not accede to Mr. Davis'.request.

(Discussion.)

Mr. Davis: And I want to be quite sure, if your Honor please, if it should develop there were entries in this book which seem to be inconsistent with the testimony which this witness has given, I should want to show those parts to the witness and ask him what his explanation was.

The Court: I understood that.

Mr. Davis: With that exception, if your Honor please, I have finished the cross-examination.

Mr. Haight: And the further cross-examination is to be limited to those particular books.

Mr. Davis: I have finished the cross-examination and I shall not ask any further cross-examination except first, as such comes up in connection with any re-direct; and second, as such comes up to be properly in connection with these books and papers.

The Court: Your cross-examination can not be completed now but only for the information disclosed by the books with which you are not now familiar. I understand. Any re-direct?

Harold D. Arnold, resumes the stand.

Re-Direct Examination.

By **Mr. Richmond**:

RDQ. 723. Referring to the Arnold mercury arc tube with which you worked before November 1, 1912, I think something was said in your cross-examination about a comparatively high voltage on the auxiliary electrodes when they were being bombarded. Will you please explain about that?

A. The auxiliary electrodes in these mercury arc repeaters were cathodes and they were placed on the edge of the main mercury arc stream. The potential that was applied to these cathodes varied under different conditions. Under the normal operating conditions that we finally arrived at, these electrodes were at the potential of 110 volts negative with respect to the main anode of the arc, but in other embodiments of the device, potentials of 220 volts were used in operation, and in the pumping procedure, as I have testified, voltages very much higher, certainly as high as 400 or 500 volts were used in bombarding these auxiliary electrodes.

The way this bombardment occurred is quite simple. I was interested in heating the auxiliary electrodes to get the gas out of them. The mercury arc stream furnished an abundant supply of both positive ions and negative ions. By applying a high negative potential to the auxiliary electrodes the positive ions, and in this case they were positively charged mercury atoms, were drawn from the arc stream, accelerated under the action of the voltage and impinged on the auxiliary electrode with a speed and energy corresponding to the voltage which was applied to the electrodes in the way well known in physical theory.

The flow of current to these auxiliary electrodes was limited in the device itself by a process that I will describe briefly.

The current was carried almost entirely by positive ions from the arc stream to the electrodes. These positive ions produced a positive space charge of electricity and as has been I think very clearly explained previously, such a space charge limits the flow of current at a given voltage and it was this space charge of the positive ions that did limit the current flowing from the arc stream to these electrodes to about the forty or fifty milliamperes that I have testified to as the current usually obtained to these auxiliary electrodes.

I may add that electrons played no considerable part in this current flow into the arc stream, because the auxiliary electrodes, although visibly hot were not sufficiently hot to have a large thermionic emission nor were they of material suitable for thermionic emission.

RDQ. 724. Did you understand this positive space charge effect at the time we are speaking of?

A. I did. It was a phenomenon that was well known qualitatively. I did not at that time know the exact numerical relationship between the current and the voltage. That had not been worked out to my knowledge at the time I was doing the work to which I referred, which began in the summer of 1911.

RDQ. 725. I think that in your cross-examination mention was made of a 1913 tube, designated audion 19-B. Will you please tell briefly how that appears in the record in the Arnold priority exhibit book?

Mr. Davis: I object to the question on the ground that I have no recollection of having taken up this audion B-19 on the cross-examination.

(Discussion.)

Mr. Richmond: I think that what I want to bring out about that tube is just what is in the record, and if Mr. Davis objects to the question I would just as soon let it come out in our brief.

The Court: All right. Of course, you can get it, I assume, by recalling the witness if you want to but not in re-direct. Then the question is withdrawn?

Mr. Richmond: Yes.

RDQ. 726. Why did Trimble exhaust these audions in January, 1913?

A. Because I instructed him to attempt to perfect himself in the mechanical technique of making audions of the DeForest type of structure, and a part of that procedure is to evacuate the tubes, and a very important part of the procedure is to learn how to so conduct the exhaust that the filament will not be destroyed during the exhaust. Therefore, the work that Trimble was doing was an entirely normal procedure in view of my instructions to him.

RDQ. 727. Will you please refer to that sheet of the priority Exhibit No. 19, designated E. S. 86,907——

A. This curve, Exhibit 19, your Honor.

RDQ. 728. (Continuing.) I think it is the first sheet; it is the first blueprint in Exhibit 19.

A. I have it.

RDQ. 729. (Continuing.) —and discuss the two loop curves for audion 20.2, and the effect of temperature changes and gas effects and filament composition, the effects on such loops?

A. Referring to these curves, it should be noticed that the right-hand portion of the curves are taken in what is commonly known as saturation; that is to say, the voltage applied is sufficient to pull across the space all of the electrons that the filament is capable then of emitting. Therefore, the values of the current that are found in those portions of these curves which have loops, are determined by the emission of the filament, and not by the condition of the space.

Now, I would like to outline the conditions that may influence the emission of the filament, and these conditions are in general two: The first is the temperature of the filament; and the second of the general conditions, is the nature of the surface of a filament. I will speak first of the temperature of the filament. That is primarily determined by the current flowing through the filament under the action of the A-battery, and should the voltage of the A-battery vary, the current through the filament would vary, and its temperature would vary. It is a well known physical fact that the variation of electron emission with variation of temperature, is exceedingly rapid. Therefore, a small variation in the voltage of the battery used to supply current to the filament, would result in a large change in the temperature of the filament, and its power of emission.

Secondly, under this general head of temperature, I must mention another cause which sometimes contributes to the temperature of the filament, and that is the bombardment by positive ions. It is well known that if a discharge passes in a thermionic device in which there is gas ionization, the positive ions are driven against the filament. This evidences itself in some cases by the actual erosion of the filament and its destruction, but even though the bombardment of positive carriers may not be severe enough to injure the filament, it does provide heat for the filament in just the same way as I have explained a few moments ago; the bombardment of the auxiliary electrodes in the mercury arc by positive ions did cause heat to be generated at these electrodes.

Therefore, in a tube in which there is a considerable amount of gas present, and a thermionic discharge passes, one must suspect the possibility of bombardment of the filament and its consequent rise in temperature. Now, the energy delivered to the filament by the bombardment of positive carriers is proportional to the voltage across the space of the device. The higher the voltage, the harder the positive carriers hit the filament and the hotter the filament gets, and if the filament does so increase its temperature by bombardment, then its electron emission will gradually increase, because, as I have said, the electron emission is well known to increase rapidly with the temperature.

Referring now to the loop of the top curve of the sketch to which you have directed my attention, beginning with 60 volts applied on the plate and extending to 240 volts applied on the plate, it is seen that the curve of emission drops as the voltage is increased; nevertheless, if there were positive ions present, they were generating four times as much heat at 240 volts as they were at 60 volts, because the heat which they generate is directed proportionately to the voltage by which they are driven; and were such positive bombardment playing a part in the operation of this device, the current which in this picture is shown as diminishing from 60 volts to 240 volts, would have increased and not have diminished..

These two are the only large causes contributing to the temperature of the filament, and the normal expectation of the behavior of a filament current with time when the filament was supplied with current from a battery, would be that the filament current and the temperature would decrease with time, and therefore the emissivity of the filament would decrease with time, and the curve would droop, as it does in this picture.

Therefore, as far as the effect of temperature upon the emission of the filament is concerned, I see in this curve results which can be explained on the theory that the filament current diminished but results which are entirely contrary to the theory that gas ionization was playing any part in the performance of this tube.

Now to return to the second of the general considerations affecting emission of the filament, which is the condition of the filament surface, again there are two factors which are principally concerned in determining the characteristic of the surface of the filament. The first is the effect of the materials which are within the filament itself and the second is the effect upon the surface of materials which may have been deposited upon the surface from its surroundings.

As to the first of these, it is a well known fact that small amounts of certain impurities, whether knowingly or unknowingly introduced into metallic filaments, do substantially and in many cases enormously increase their emissivity and it is also well-known that changes in emissivity produced in this way may be progressive in their nature. I will simply indicate as an example of that performance the well-known characteristic of tungsten which has thoria within it, but the same type of action which is exemplified by that will also undoubtedly occur if a filament has within it oxids of other materials or even if it has within it gases which are occluded.

In this connection I should say that it is also a well known fact that tantalum has the property of occluding within its surface a large amount of gas which will not come out until the tantalum is melted and does not come out at all or if at all comes out very slowly at any temperatures below the melting point.

Therefore, irregularities in the electron emissive power of the surface of filaments is largely determined by the various constituents of the filament itself and these variations being dependent upon the life and use of the filament would be entirely competent in my opinion and from my experience with these devices to explain variations as large as those shown in the figure in which the emissivity is shown as diminishing by roughly 40 per cent. during the course of the experiment.

And finally the second phenomenon that reacts upon the emissivity of a filament is the change in its surface which may be produced by things that are deposited on its surface from its surroundings. As to the potency of this factor I have only to call to your attention the behavior of a thoriated filament in a highly evacuated thermionic device. It is I think clearly substantiated that gas residues which are so small as to leave a device unquestionably within the domain of this present patent which is in litigation, are nevertheless entirely sufficient to modify, and in some cases to practically destroy the especial emitting power of the thorium which comes to the surface of the thoriated tungsten filament.

In this audion No. 20 pumped on the molecular pump, there was certainly some gas present because it is impossible to get a perfectly pure vacuum. Such minute traces of gas as were undoubtedly present, would from my experience give a reasonable explanation of changes in the surface emissivity of the tantaum filament, corresponding to the change of roughly 40 per cent., which is evidenced on this curve.

It was in view of my consideration of these two general classes of phenomena, each with its two subclasses of phenomena, and their effect upon the filament that I based my statement that the action of gas in this audion would be the last thing that I would think of as explaining the nature of these loops.

The first thing that I would think of would be a change in temperature due to the filament battery. The second thing that one might investigate would be the possibility of ion bombardment, but that is ruled out because of the direction and slope of the curve.

The third thing that one might think of would be changes in the composition of the filament. And I am of the opinion that those were very important. And the fourth thing that one might think of would be the effect upon the filament of this very tiny residue of gas which might cause chemical combination at its surface.

Now, as to the loop below the one of which I have spoken, the same remarks apply. The only additional statement that I think I should make is to call attention to the fact that about half way across the page is a dotted line with a notation opposite saying one minute. If we refer to the data from which the curve is plotted we will see that the data indicates that there was an unusual delay in taking those readings and specifically mentions one minute.

The effect on the curve there at a voltage of 117 volts, which diminished the electron current appreciably, was a change not due to a change in voltage, because the voltage remained constant, but was a change of one of these three kinds that I have mentioned, either a change in temperature of the filament, a change in its surface condition because of a redistribution in its internal components or a change in its surface nature because of the reaction of its surface with minute traces of gas.

RDQ. 730. How did this audion 20.2 to which we have just referred stand in relation to your expected attainment for the telephone repeater?

A. It showed a sufficiently good vacuum condition for a good telephone repeater. It showed a structure which was capable of withstanding satisfactorily applied voltages higher than those we contemplated using; in fact, about twice as high, namely, 240 volts. It showed a possible electron emission of about the order that I had in mind at the top of the loop at the top of the page.

RDQ. 731. Page what?

A. The top of the page E. S. 86,907. The tube, however, was not mechanically and structurally of a design suitable for service in the telephone plant. I should perhaps point out that the curve illustrated on this sheet in which currents of the order of six or seven milliamperes are indicated with voltages of the order of sixty volts, is indicative of the current that flowed from the filament when the grid and the plate were electrically connected, and therefore are not representative of the currents that would flow in the device, when the electrical connection was such as is used in a telephone repeater, in which the plate is connected to the phone and throughout the B-battery, and the grid is connected to the alternating current source of supply.

RDQ. 732. Then, does that curve on that sheet represent the volt ampere relation when the gain tests were taken with that tube on April 25, 1913?

A. I am quite sure that it does not.

THE COURT: Do you mind reading that again?

(RDQ. 732 and answer repeated as recorded.)

THE WITNESS: It is my recollection that the curve on this sheet was taken with the grid and plate electrically connected together, so that electrons were drawn in parallel to both grid and plate. This would result in the passage of a larger current across the space at a smaller voltage than would be the case with the tube connected in a repeating circuit.

RDQ. 733. And as compared with connecting the grid to the plate, how would the grid be connected for the talking tests or the gain tests, I think you already said?

A. The grid would be connected through a transformer to the speech input which it is desired to amplify, and although the electrical connection would actually run from the grid to the filament, there would be a B-battery, or if any battery, at least a very small battery included in that connection, so that no considerable flow of electrons would be drawn to the plate.

RDQ. 734. I understood you to say that when you pumped this audion 20.2, you would not have made a record of the procedure in evacuating it according to the normal course of your work. Will you please explain that answer?

A. I would not have made a record of the procedure in pumping, because the purpose of that test was to test the operation of the new Gaede molecular pump. The procedure as it relates to the treatment of the tube itself was not at that time in question; and the procedure followed, was the procedure which was old to us at that time. The important matter in my mind, was to discover whether this new Gaede molecular pump did operate satisfactorily to procure a very high vacuum; and my entire attention was directed to that.

RDQ. 735. For the tubes that were used at Philadelphia, in October, 1913, and thereafter, what kind of filaments were used?

A. To the best of my knowledge Wehnelt oxide filaments entirely. It is possible that a tantalum filament may have been used there, but if so, I do not now recall it.

RDQ. 736. Will you please refer to Exhibit No. 25 of the Arnold priority exhibits? On cross-examination, your attention was directed to the voltage of 39 cells and 21 cells about a quarter of the way down the page, and the decreasing values of those voltages until they got down to 28 cells and 22 cells, at which point the record states: "which is to be used for service." Can you point out any reason for that reduction of voltage?

A. Yes. The reason is very clearly stated on the page just above the quotation which you have given, where it says: "because of singing." If I may read this in a little more detail, the book states:

> "31 cells and 24 cells cut to 30 cells and 23 cells, because of singing."

I think I explained quite clearly what this singing is. It is a condition that exists when repeaters are used if the telephone circuit is not so designed as to be thoroughly balanced throughout. The circuit that we were then using at Philadelphia, the circuit that Mr. Kendall was experimenting with was not adequately designed to avoid singing, and therefore the amount of amplification which could be used on that circuit was limited. The method that Mr. Kendall pursued in decreasing the amplification of his amplifier units was a method that is not infrequently used in present-day radio practice, that of decreasing the B-battery voltage.

RDQ. 737. Did that decrease in voltage indicate that anything was wrong with the audions?

A. Not at all. It had no relation with the internal behavior of the audion elements.

RDQ. 738. Referring to the time, Easter Sunday, early in April, 1915, did you know at that time what Langmuir was claiming in respect to the subject matter of this litigation?

A. I did not. All that I knew was what had been told me by someone, I think through Dr. Jewett, and went no further than the statement that he understood Dr. Langmuir was applying for a patent on the sort of high vacuum device that we were using.

RDQ. 739. When did you first learn with any degree of definiteness what was the basis for the claims?

A. When I returned from San Francisco, which to the best of my recollection was the last week in October, 1915. I found then that the papers, as far as they could be obtained, had been assembled and I was shown the papers or such of them—I was shown some papers by our Patent Department.

RDQ. 740. What do you mean by papers?

A. I mean——

RDQ. 741. Memoranda, publications?

A. I do not want to state with any exactness what those papers were, because I cannot remember the nature of the papers themselves, but I am quite clear that some papers, either memoranda or patent specifications or printed publications or something of that nature was shown me at that time. In other words, I am quite clear in my memory that I was not merely told about it but I was shown some of the written evidence.

RDQ. 742. You were questioned yesterday in regard to these diagrams on pages 6 and 7 of the Arnold rebuttal testimony on the motions. I will get the page in the record. Those are pages 474 and 475 in the Interference record. Just please explain briefly about those diagrams, what they mean and their significance.

A. The diagram that is marked by Figure 1 is a plot of the plate current versus the plate voltage of the DeForest audion of November, 1912, on ordinary cross-section paper, and the Figure 2 is a plot of the same data on logarithmic paper.

RDQ. 743. At the time in November, 1912, when you cleaned up audion 7-A as you have testified, please tell what was your attitude toward that phenomenon in respect to your understanding of it, and your intentions and I will add your emotions.

Mr. Davis: If your Honor please, I object.

The Court: Will you make your objection specific, Mr. Davis?

Mr. Davis: I certainly object as to the witness's emotions unless it can be shown that they have some value which I do not now see.

(Discussion.)

The Court: If it has not any pertinency it will not do any harm. I just do not see it myself at the moment.

(The stenographer repeated the last question.)

A. At that time I was very anxious to obtain data on the electrical characteristics of an audion which was working in the absence of positive ionization and I wanted to have what is commonly called a hard device for those tests in order that I might carry the voltages to as high a point as possible and I was pursuing the normal course that everyone knew at that time would make a device of this sort harder, namely, I used it in certain ways which tended to clear up the gas, and part of the gas was cleared up. Although I wanted to get the audion harder, my purpose was not primarily to get a high vacuum in that device. My purpose was to get data from the device from which I could learn the electrical characteristics of a device that operated in the absence of positive ions. But I knew the device was getting harder and that is exactly what I wanted, because it would let me go out to higher voltages.

RDQ. 744. In your cross-examination the following testimony was read to you from the rebuttal testimony in behalf of Arnold on the motion:

> "In order to make possible the use of the tubes at voltages of the order that I had decided was desirable, it was obvious that steps must be taken to overcome the difficulty that arises when you attempt to operate the original DeForest audions at this voltage. I have no doubt that some of the DeForest audions as originally made would have operated at 120 volts entirely satisfactorily. As a matter of fact, the one that I gave data for in answer to Q. 2 operated to eighty volts and would probably have gone considerably higher."

When you gave that testimony as part of the rebuttal testimony on the motions, it was as part of the answer to the following question, was it not?

> "Q. 3. On pages 582 and 583 of his deposition, Dr. Langmuir said that at the meeting of the Physical Society in October 1913, you expressed doubt that he 'had ever obtained a discharge free from blue glow at voltages of 100 or 200 volts, or more,' and that you said that according to your experience 'the 3/2 power relation was not followed in practice'; also Dr. Langmuir said 'Dr. Arnold then said that, for his purposes, these discharges at higher voltages were of very little interest because, in telephone work, they did not use anything but low voltages. I believe that he said

that the standard voltage with which they intended to use these devices, was 24 volts, and that he considered that voltages of 100 volts or so were impraticable in telephone work.' What is your comment on these statements?"

To sum up briefly when you were asked about the testimony on page 482 of the transcript and the testimony was quoted to you as I have quoted it, it was in answer to that question?

A. The testimony that I gave then was in answer to that question, yes, sir.

Mr. Davis: If your Honor please, there is just a matter here. We are going to be troubled particularly in the Court of Appeals if this case should happen to go there, with the reference to the transcript, which is the old transcript, and there will be a transcript in this case, and I will just suggest that we now agree on some name which should always be used for the transcript that Mr. Richmond has referred to.

Mr. Richmond: I would suggest the District of Columbia transcript.

Mr. Davis: The Interference Record.

Mr. Richmond: All right.

Mr. Davis: So long as we always use the same name.

The Court: Then the Interference Record is your abbreviated terminology?

Mr. Richmond: Yes, your Honor, I will try to remember it.

RDQ. 745. You were criticized yesterday in the cross-examination for not having told about the clean-up of this audion 7-A at the time you gave that testimony that I have just quoted. Does that question require you to allude to the matter of the clean-up? What was your judgment then and what is it now?

The Court: Do you want the question read, Mr. Davis?

Mr. Davis: Yes.

(RDQ. 745 read as recorded.)

Mr. Richmond: May I change the question a little?

The Court: Strike it out entirely or amend it?

Mr. Richmond: Just the last part——

RDQ. 746. Did you think that the question called for an allusion to the clean-up, and what is your present opinion in regard to it?

Mr. Davis: As to the first part of the question, if your Honor please, I was not conscious yesterday of having criticized the witness at all. I was asking the witness questions, if any criticism came they were due to the witness's answers to the questions.

The Court: I supposed that was merely to the form.

Mr. Davis: To the form.

The Court: And does not go to the substance?

(Discussion.)

The Court: I do not see I can sustain an objection to that, but I think this question, although you may take the answer to it, and not under Rule 46, if you want—I am not impressed with the value of the evidence.

Mr. Haight: All right. We will re-frame it, with the indulgence of Mr. Richmond, or rather at his suggestion, and with your Honor's indulgence, let me ask this question:

RDQ. 747. Dr. Arnold, yesterday your attention was directed to an extract from certain testimony given by you in rebuttal on the motion to dissolve, namely, that which is found at the beginning of page 13 and page 14 of the printed Interference Record, that is to say, the rebuttal testimony being pages 481 and 482 of the Interference record of the Court of Appeals of the District of Columbia, and you were also referred to certain statements you made in an affidavit which was used in the priority proceedings and you made the statement that these statements were not inconsistent or words to that effect. Will you please state what you meant by that?

A. In the first place, on my testimony in rebuttal on the motion to dissolve there was no question put to me which necessitated any reference to an unusual treatment of audion 7-A even if at that time I had thought I had subjected it to an unusual and inventive sort of treatment. At that time my position was that the majority at least of all the material which was being applied for as patentable in the Patent Office was pretty clearly described in the prior art and that was our contention. And it was our contention not only that the DeForest audions but the high vacuum audions that we were making at that time were audions in which the vacuum had been secured by methods which were old in the prior art. There was therefore no reason at all that I can see or that I could see then that would lead me to refer to any treatment which I had given to audion 7-A, which treatment was of a natural sort for any man who is trained in that line of work to give such a device.

Later on the patent tribunal in the Patent Office informed us that there was patentable matter in this application, that there was some patentable matter and he did rule out quite a bit of the material which I had felt quite clearly in my mind was old in the prior art.

However, in view of his official decision as to patentability I reviewed the work that I had done to see where for the first time the features which I understood he had indicated as patentable did appear. As

I reviewed that work I found that the data that I had taken on this audion 7-A after it had been subjected to considerable use very apparently came within the Law Examiner's view of what was patentable. Now at that time, naturally, I referred to that and brought it to the attention of the patent tribunal.

It is perfectly true, that at the time I did that work I knew I was getting that tube harder. One has only to look at the record itself to see that, I mean one has only to look at the data in the notebooks to see that the tube was getting harder and harder and I naturally looked at that data and I knew it was getting harder and harder. But it did not occur to me until the Law Examiner had made his decision as to patentability, that what I had done in that tube could possibly have any bearing whatever upon a patentable issue. Therefore, until the Law Examiner decided it never occurred to me that there was anything that I had done to audion 7-A that was unusual or should be mentioned.

The Court: We will take our morning recess now.

(After a short recess.)

RDQ. 748. I understood you to say that the invention disclosed in Patent 1,114,845 is a protective or safety device for preventing the evil effects which may be accompanied by blue haze?

A. That is a correct statement of the content of this patent.

RDQ. 749. Is the device of this patent applicable to high vacuum audions?

A. It certainly is. It is applicable to any audion device where there is a possibility of failure of the device which may result in the flow of an unusual and undesirable current in the plate circuit.

RDQ. 750. Are there conditions under which blue haze may occur in a high vacuum tube and if so point them out?

A. There certainly are. They are conditions usually by which gas has entered the space of the audion through improper manipulation of the glass or through improper treatment of the parts of the device. It is unusual for the device which has a high vacuum to have its vacuum get poorer but it is by no means unknown for this to happen. Just by way of example, if there is a tiny leak through the lead-in wire, then gas may enter the most highly evacuated space and cause blue haze and there are other conditions which may cause blue haze such as improper use in test circuits or what-not.

RDQ. 751. I think you were asked on cross-examination whether Patent 1,129,942 makes a direct reference to a high vacuum audion and you stated that you could not answer without reading the patent. Assuming that it does not make a direct reference to a high vacuum audion, will you explain why such a reference should be lacking?

A. This patent application I see was filed on May 28, 1914, and at that date it had not occurred to any of us in our laboratory that the high vacuum audion was patentable. It would have been inconceivable to me that without having in our minds the patentability of a high vacuum in an audion we would have mentioned that in a patent application. I may add, this date is just about a year prior to the time that I personally first had brought to my attention the remote possibility of a high vacuum audion being held patentable.

RDQ. 752. Would your answer apply to the other patents on which you were questioned in cross-examination, the other patents granted in your name, I mean?

A. The answer would apply to all patents applied for prior to the end of 1915, for the reason that I have stated.

Mr. Richmond: Re-direct examination closed.

RE-CROSS-EXAMINATION.

By MR. DAVIS:

RXQ. 753. You understand, do you not, Dr. Arnold, that an inventor filing a patent application is bound to set forth the best manner known to him of using his invention?

A. I am not very skilled in that matter. I thought that what an inventor had to do was to show one way of using the device that he sought a patent on. I did not know that it had to be the best.

RXQ. 754. You filed the applications and you knew when you filed them that the thing that you were describing in them as you described it was either inoperative or very barely operative and absolutely useless in a telephone circuit, is that right?

A. No, that is not true.

RXQ. 755. In what respect is it not true?

A. Will you please read the statement by Mr. Davis to me?

(RXQ. 754. was repeated by the stenographer.)

A. (Continued): I will refer to the particular patent which I have before me which was applied for May 28, 1914, patent No. 1,129,942. This patent is entitled "Gaseous repeater in circuits of low impedance." The purpose of the patent may be indicated by reference to one of the claims, for example, the first which reads:

> "The combination with a source of feeble electric currents, of a thermionic repeater having an input circuit directly connected to said source of current and an output circuit of high voltage, and a second thermionic repeater having an output circuit of low impedance and having an input circuit directly connected to the output circuit of said first mentioned repeater."

There is a statement of a useful thing, a combination useful with the device with which I was working on May 28, 1914, the date on which this application was applied for. Therefore, I most certainly did not know that I was applying for a patent on a useless thing or a device which could not be used for the purpose described. While I have not gone through all these patents in detail, I have not the faintest doubt that the statement which I have made with reference to this could be made with reference to each and every one of those patents. I am convinced in my own mind that they were all useful and appertained to useful devices.

RXQ. 756. If those patents were read by a person skilled in the art, let us say at the date when the applications were filed, would they have understood that they called for an audion having a special high vacuum which you think you have procured as a result of your work, or would they understand that it was referring to the unmodified DeForest patent?

A. I suppose a person so skilled in the art that these relate to was a person in the laboratory of the American Telephone & Telegraph Company, and the persons employed in their field work under date of——

RXQ. 757. I will ask you to speak of persons skilled in the art outside of your own organization.

A. In 1914, to my knowledge, there was no place where devices of this sort were being used in the art outside of the telephone practice and to all those who were using these devices this matter would be quite clear.

RXQ. 758. Do you think that a person skilled in the art, and not connected with your organization, reading this application at the time it was filed, would have known that the reference was to a type of audion quite different from the DeForest audion?

A. If you mean by a person skilled in the art, a person skilled in the telephone art or in the electric lamp industry or in some other industry more or less related to this, then it is my opinion, whatever my opinion may be worth on this matter, that what sort of a device he thought would be best in these circuits would depend entirely upon his own personal experiences with these devices.

RXQ. 759. And if he had not had personal experience with a new high vacuum device he would then assume that these specifications call for the old low vacuum devices?

Mr. Haight: I object to the use of the word "new" high vacuum devices. That is having the witness endorse the proposition that they are new high vacuum devices.

The Court: In respect to that, what have you to say?

Mr. Davis: I will say new high vacuum devices such as you claim to have produced in the spring of 1913.

A. It is inconceivable to me that anybody could have a clear idea of using a device that he did not know anything about and I would suppose that no matter how expert he would be his ideas would be limited by his own knowledge.

RXQ. 760. You say in this patent, do you not, at line 82, page 1:

> "It has been discovered that audions of the usual type may be so constructed that, without the use of transformers, they will step up the input voltage of either direct current or alternating current of any frequency in one step to as much as 30 times its original value, or in two successive steps to as much as 500 times its original value."

Was that true of the DeForest audion in the condition in which DeForest left it?

A. No. The fact is that 30 was not present in DeForest audion, and I think you will find that this patent to me is directed toward a modification of the DeForest audion which makes this factor 30 possible. You will observe by the pictures accompanying the patent that the grid is placed in rather peculiar relation to the filament and plate, a relation quite different than that in the DeForest audion. For example, on Figure 4, the first bulb shown has the grid very near the filament. That type of bulb will produce this step-up of 30 times or even more in voltage, but the last tube in that line of Figure 4 has quite a different grid, quite differently arranged and that tube will not step up the voltage appreciably but will amplify the current. So I am quite sure that the DeForest audion that I was familiar with at least would not produce the results.

RXQ. 761. And in order to get these results you had to have the kind of vacuum which you claim to have produced in the spring of 1913?

A. No, sir.

RXQ. 762. This would work just as well with the vacuum such as DeForest had in the tubes that he brought to Dr. Jewett?

A. No, sir.

RXQ. 763. What are the facts, then?

A. I answered no to both your questions because your second question said they would work just as well.

RXQ. 764. Please bring out the facts.

A. They would work with audions of the DeForest type of vacuum. They would work better with audions of a higher vacuum if you wanted to use large voltages, but this patent is directed in no way whatever to the vacuum of these devices. It is directed entirely to the arrangement of the grid and the plate and the filament for purposes of varying the voltage amplification.

RXQ. 765. I will state for your information that the statute requires that an inventor shall particularly point out the best manner known to him of using his invention. I will ask you if you know any reason why that statute was not complied with in the preparation of these applications?

Mr. Haight: I object.

The Court: I think the objection is well taken, and furthermore, I think your question has been answered by the witness at least indirectly if not directly several times, probably not several times, in that the thing claimed here is not the vacuum but the thing that is set out. The fact that his device would work better in any vacuum higher than that of DeForest is a matter, as I see it now, apart from the subject matter to which the patent is directed.

Mr. Davis: Some of the patents are on vacuum tubes.

(Discussion.)

The Court: Now, will you put a question that is specifically referring to that one patent, Mr. Davis, because I think the objection is well taken to the patent that had been mostly dealt with by the witness.

By Mr. Davis:

RXQ. 766. Figure 3 of that Patent 1,128,279, the drawing of which is on page 2351 of the Interference record, shows a vacuum tube, does it not?

A. I think I can answer yes to that.

RXQ. 767. And that vacuum tube would work very much better if it had the kind of vacuum which you claim to have produced in the spring of 1913, than it would if it had the kind of vacuum which was in the tubes that Dr. DeForest brought to Dr. Jewett in the fall of 1912?

A. Yes, I am quite sure it would work very much better under those circumstances.

RXQ. 768. Do you know any reason why the patent specification was so drawn as not to state that fact?

A. No, I know of no reason why it is or is not mentioned. I had nothing to do with the drawing, the form of this patent specification, simply approving it as to the contents.

RXQ. 769. You were speaking this morning of the possibility of gas coming out of the tantalum filaments and affecting the vacuum or the conditions of the surface, were you not?

A. I said that it was well known that tantalum has a property of occluding or having within it a considerable quantity of gas, which gas may not come out until the tantalum is melted. I think that is what you referred to.

RXQ. 770. Do you know how tantalum filaments are made?

A. I know nothing whatever about the manufacture of tantalum filaments.

RXQ. 771. You do not happen to know that the tantalum filament is always made and can only be made by arcing in a vacuum for a long time to get the gas out?

A. No, I know nothing whatever about it.

RXQ. 772. And you do not know that if there is any substantial amount of gas in there it is not tantalum at all, but becomes a gaseous chemical compound of tantalum which is brittle?

A. I know in a general way something about that because some of our men in the laboratory have experimented with plates of tantalum and have found that they did have enormous amounts of gas within them, so I certainly think you are wrong in asserting that if you have gas in tantalum it is not tantalum any more. Experience is all against you there.

RXQ. 773. I am not making any assertions, Dr. Arnold. I am asking you for facts.

A. Excuse me. Your statement is wrong to which you asked me to assent, then.

RXQ. 774. At least I am trying not to make any statements. You do not know the history of the work that Von Bolton did in producing a tantalum filament?

A. Never heard of him. Do not know anything about his work.

RXQ. 775. Now, you spoke again this morning of the possibility of thorium being on the surface of tungsten. Before I ask you that question, are you familiar with the fact that tantalum plates are rather preferred and used very extensively, on a very large scale at least, in vacuum tubes as anodes and so forth?

A. I am not familiar with that. I am familiar with the fact that we experimented with them to find whether they were useful and found they were not, and therefore we do not use them. It may be that some others use them but I do not know of any.

RXQ. 776. You were speaking of the possibility of changes in emission of a tantalum filament because of actions analogous to the action of the second patent in suit. I thought that we agreed the other day on cross-examination that the temperature at which the filament was run made it impossible there should be any layer of thorium, for example, on the surface.

A. I think I can explain that matter again, although I think I made it quite clear before. I am not even suggesting that there may have been thorium or thoria in these tantalum filaments. I simply do not know whether there was or was not. I cited, however, the well-known fact that a filament which does have in it various materials may, in the course of its operation, so re-constitute its own internal arrangement as to have more or less of these substances appear at the surface of the filament, and thereby the thermionic emissivity of the filament may be varied. As to the temperatures which you have asked me about, I think

I made it quite clear that I do not know what temperature the tantalum filaments were used at, except that they were something like the temperature of the carbon lamp, nor do I know at what temperature thoriated tungsten filaments are used. I have not refreshed my mind on those temperatures for a long time.

RXQ. 777. It is true, of course, is it not, that ion bombardment of a cathode may have a very profound effect on the emission, particularly if the cathode has something on the surface?

A. As far as I know, the only effect of ion bombardment is to warm the filament. Now, I want to make it very clear that I say ion bombardment, because "bombardment" means hitting and the only effect of hitting is to liberate energy, and the only effect that I know of liberating energy is either to warm the filament, or to erode it.

RXQ. 778. Erosion, that means the actual knocking off of something on the surface?

A. That is what I mean by erosion, yes, sir.

RXQ. 779. If the surface happened to be covered by something that had reduced the emission, the first effect of the erosion would be to knock off that particular something, would it not?

A. I cannot agree with you there.

RXQ. 780. Why not?

A. Because I am not expert enough in that art to state whether the first effect would be that or the second effect. I am not sure whether the first bombarding ion would hit it and not hit the extraneous material on the surface at all, particularly if it was only two-thirds of an atom deep on the surface.

RXQ. 781. That is, it could erode the surface without removing the atomic layer on the surface?

A. Not at the spot where the erosion occurred.

RXQ. 782. You would be prepared to admit, I think, at the spot the erosion occurred, the atomic layer would be removed, would you not?

A. I think I could go this far, Mr. Davis——

RXQ. 783. Could not you go as far as my question?

A. That if the ion on approaching the surface makes its first collision with an atom which is not one of the elemental atoms of the material itself, then that first atom may very possibly be removed, and if that atom were an atom of some extraneous substance, it may possibly be removed; I cannot go so far as to say it would positively be removed.

RXQ. 784. Can not you go so far as to say that if you have a filament covered with a thin layer of something, that if you erode that filament at the point where that thin layer is, you must remove that thin layer?

A. No, I cannot even agree with that. That is a very technical matter that you are asking me about, and I dare say that even people, very expert in it might disagree, but I can quite well picture to myself the filament getting thinner and thinner and thinner by erosion, and still there being always on its surface some impurity.

RXQ. 785. You were speaking of the tube 22, and you said, if I remember it correctly, that the possible electron emission, or the capability of electron emission was about of the order that you had in mind and desired. Did you say something of that sort this morning?

A. I think what I said was that referring to the curve, the value of about 7 milliamperes which appeared at the top of the curve, was of the order that I had in mind for the operation of a telephone repeater. I intended to imply by that, or intended to state, or I intended my statement to mean that that order of current of 7 milliamperes was about what I had estimated we would ultimately desire to be the normal electron current in a telephone repeater.

RXQ. 786. And you wanted that amount of current, as I understand it, to prevent what you called overloading the other day?

A. I think I can agree with that statement, yes.

RXQ. 787. Now, you said this morning that the— you are speaking of this 20 tube, 20.2, that it was a question of testing the pump, the procedure as to the tube itself not being in question. Had you any doubt that a Gaede Molecular Pump would pump a vacuum?

A. I had very grave doubts as to how well that pump would work. The first thing that we did with it, as I have testified before, was to put on a special sort of gauge, which did not have mercury in it, but which was capable of measuring the degree of vacuum secured in a comparatively good manner. Nevertheless, this gauge although it indicated a pretty good vacuum, left the question of the extreme goodness of the vacuum quite unsettled; in fact, I know of no way to test a high vacuum pump that is quite so good as to pump a vacuum tube on it.

RXQ. 788. You said that the tube itself was not in question?

A. I do not remember saying so; perhaps you can point out where I said that.

RXQ. 789. I have not seen the record yet. I understood you to say that this morning, Doctor.

A. No. I think what I said was that the processes of treating the tube were not in question, that is what I meant to say.

RXQ. 790. I beg your pardon, that is what I was trying to say that you said. Now, why were they not in question?

A. Because they were the same ones that we had been using, and because I was not at that time interested in those processes. They were all processes that had been described in books, and I had been taught, and I was quite familiar with them.

RXQ. 790a. Then why did you think it necessary in your specification of your patent application to devote so much space to a description of the methods of exhaust?

Mr. Haight: I object to that question. I do not know whether there was "much of space" devoted to methods of exhaust or not, and I think the witness must be shown the application and the part of it to which Mr. Davis refers.

RXQ. 791. Why did you find it necessary to say in your specification on page 14, line 2, of the Interference Record:

> "The electro-motive force of the battery 4 is, in practice, about 130 volts, and it is therefore necessary, as stated previously, so to prepare the tube that no appreciable gas ionization shall take place during evacuation at voltages considerably higher than this value. In this preparation the tube is evacuated, preferably with a molecular pump, using the precautions necessary in this kind of work, and impressing between anode and cathode a voltage about twice that used in normal operation. The effect of this is to subject the tube to more rigorous treatment than it will obtain in practice, and consequently to insure that gases remaining occluded in the walls and electrodes after this treatment will not be driven out during the practical operation of the tube. This process of pumping and aging the tube is carried on until no gas ionization can be detected."

Why did you say that?

A. In the first place, it is stated as a truth, and in the second place, the statement was prepared by the patent attorney who drew the specification, and since it was in accordance with the truth, and seemed to them best to exhibit the invention, I signed the patent application.

RXQ. 792. So that the real thing that you were testing there in April, 1913, was the molecular pump?

A. That is correct.

RXQ. 793. You were perfectly satisfied with everything else?

A. Oh, no. Mr. Davis, I do not like that word "perfectly." It is a word I very seldom use myself, and the tubes that we had then were not perfectly good tubes; they were not nearly as good as the tubes we have now.

RXQ. 794. I am speaking of the point of view of vacuum, Doctor, purely; I am speaking of the point of view of vacuum purely.

A. Did you mean to ask me if the tube we had then was perfectly good?

RXQ. 795. Perhaps not in that form. I do not want to ask you that, because no vacuum is perfect. What I mean to ask you is whether the only problem which you had to consider at that time so far as vacuum was concerned, was whether or not the Gaede pump was a good pump?

A. Well, I think I ought to explain a little bit about that, instead of just answering it yes or no. As far as removing the gas from the tubes that we were pumping was concerned, the sole question was as to the Gaede pump, and when I say that, I mean as far far as removing the gas from the space within the tube is concerned. At that time there were real problems confronting us and very serious ones that we did not solve until months, and even years afterward, as to how to prepare a vacuum proper for a Wehnelt oxide filament. So we had real vacuum problems other than that of the Gaede pump, but the only point of importance with the Gaede pump was—will it take out of the bulb the gas that is free in the bulb?—And we could take care of getting the gas into the bulb, out of the electrodes by those processes of heating the walls and the electrodes, and so on, that were well known.

RXQ. 796. So that is what you demonstrated by the test which resulted in the production of 22 was the capability of the Gaede pump to take out the gas which was free in the space in the bulb?

A. I think that was clearly demonstrated.

RXQ. 797. And that is what you demonstrated and all you certainly demonstrated?

A. We certainly demonstrated that. Pardon me —"and all we demonstrated"?

RXQ. 798. That was all you demonstrated?

A. No. I will not say that was all we demonstrated. That was the result that I was most interested in on the product of that experiment, but I had demonstrated other very interesting things.

RXQ. 799. Now, did you direct the tests of that tube?

A. I was present at the time the tube was pumped, and at the time the tests were made, which are recorded in the book showing voltages as high as 240 volts, somewhat subsequent to that, perhaps the same day, there was a talking test made of that tube——

RXQ. 800. I do not care for that, Doctor.

A. I am not sure whether I was present on that test or not.

RXQ. 801. Did you direct that the grid and plate should be connected together on these tests?

A. I do not recall whether I specifically directed that or not. It was a customary thing for us to do.

RXQ. 802. Do you know that they were connected together in that test?

A. That is the best of my belief.

RXQ. 803. You believe, but do not know?

A. I have not any documentary proof of that.

RXQ. 804. You know now, do you not, Doctor, that that is about the worst connection you could make, if you wanted to know what the properties of the tube were, from the point of view of the vacuum?

A. No, I cannot agree with you that that is the worst test I can make.

RXQ. 805. Will you suggest a worse one?

A. I am not very expert in bad tests. I think that was a pretty good test. The test was to see whether we got any evidence of ionization, any visible evidence of ionization specifically on those voltages, and I think that is a pretty good test of a vacuum tube.

RXQ. 806. It resulted in rather early saturation, did it not?

A. The saturation came at rather low voltage, but at a moderately high current, that is 7 milliamperes is a fairly high current.

RXQ. 807. Now, I thought that the use of these tubes was always on the part of the curve up to saturation; and I understood Dr. Jewett or Mr. Colpitts to explain why it was important that you should have a considerable range of voltage before you got to saturation; do you agree with this?

A. When tubes are used as telephone amplifiers, then they must work on the space charge portion of the curve.

RXQ. 808. This particular connection saturates the tube very quickly, and therefore reduces the range of voltage on the space charge part, does it not?

A. That is correct. You are referring now to the——

RXQ. 809. To the connection between the grid and plate?

A. That I used on the tube just after it had been pumped, and before the telephone tests.

RXQ. 810. Do you know whether there is any statement in the notebooks that 20.2 was so connected?

A. I do not know of any such statement, no, sir.

RXQ. 811. And 20.4 was run another way when it was tested, was it?

A. I think I made quite clear that I was not personally present at the test of 20.4, but I will look at the record and see what I think may have happened. (Perusing papers.) I have been looking at sketch E. S. 86,908 of Exhibit No. 19, and I am unable to determine from that curve what probability there is as to the connection that was used. I think I testified previously that in the process of evacuating these tubes, I would expect the heating treatment to very probably displace or deform the internal structure. Now, the curve of 20.4 is certainly different from the curve of 20.1, but whether that difference is due to a different connection, or is due to a warping of the elements in the tube on its heating the oven, I do not know.

RXQ. 812. In testing the vacuum rather, or testing the pressure produced by the Gaede Molecular Pump, you used a hot wire manometer which had been previously carefully calibrated, so that its readings could be used to give the pressure in millimeters or microns. What pressure did the gauge indicate when you were pumping with the Gaede molecular pump, if you remember?

A. These tests were made by Mr. Kendall; but I will refer to the notes and see if I can find any reference to them. (Perusing papers.) The notes which I have before me, do not specifically state what vacuum Mr. Kendall found. The figures are unintelligible to me at present.

RXQ. 813. Then, we won't trouble you, Doctor.

The Court: Are those at the top, E. S. 908, will they give the information?

The Witness: No, sir, I think not. This is the only thing here.

Mr. Richmond: What is the exhibit number?

THE WITNESS: Perhaps I should have referred to that. It is Exhibit No. 13, a page of Mr. Kendall's notebook, dated April 22, which states:

"Gauge cut off and connected to new molecular pump,"

and gives certain figures which refer to galvanometer readings, either galvanometer readings or Wheatstone Bridge settings and my recollection does not serve me as to what those figures mean.

RXQ. 814. I wonder if it would be possible if we could all of us number the pages of this book from the beginning to the end, and have a number that we can refer to. I have no doubt my friends on the other side, Mr. Richmond, can find anything in this in the dark, but the rest of us can not.

MR. RICHMOND: Mr. Davis, the exhibits are numbered, and for my convenience I wrote the exhibit numbers in red pencil on each page.

MR. DAVIS: I should think that we could [illegible] some one take all of the copies there are of this book and begin at the beginning and number the pages.

MR. RICHMOND: I think myself that the exhibit numbering is a better plan.

RXQ. 815. You spoke of the difficulties in getting the vacuum, did you not, in connection with the Wehnelt electrode?

A. Yes, I think I said we had quite a number of problems to solve.

RXQ. 816. Now, in the first place, you had to develop a Wehnelt electrode as a practical matter?

A. We had to develop a Wehnelt electrode which could be reproduced in the manufacturing sense, and which had the proper characteristics, and which could be properly activated in the audion bulb.

RXQ. 817. You do not mean by that that the Wehnelt electrode as Wehnelt disclosed in his publication, was inoperative and failed to produce emission, do you?

A. Oh, no. The Wehnelt paper which disclosed the Wehnelt oxide emission, ran to a very large number of substances placed upon platinum, most all of which resulted in increasing the emissivity of the surface.

RXQ. 818. But before you could have a filament which was satisfactory as a matter of commercial production and use, you had to go through a long series of experiments and investigations; is that correct?

A. That is correct, sir.

RXQ. 819. And you finally did arrive at something which you thought was reasonably satisfactory?

A. Well, we have now something which is exceedingly satisfactory, in fact, the best filament in the world without question; but that was not arrived at until at least ten years of very expensive experimentation.

RXQ. 820. But by the time that you were, for instance, making these tests on the transcontinental line, you had a workable Wehnelt filament, did you not?

A. Yes, sir.

RXQ. 821. Now, so much for the filament itself. Now, you have spoken of the difficulties in connection with the use of the filament. Would you state briefly what they were, the difficulty of getting the vacuum, for example, with a Wehnelt filament?

A. I am afraid I do not understand just what you mean by difficulties in the use of the thing.

RXQ. 822. I understood you—my understanding of what you said this morning, which may be far from correct, Doctor, was, that you spoke of difficulties of pumping a tube with a Wehnelt filament, being somewhat different from the difficulties of pumping a tube with a tantalum filament?

A. Yes. I may have spoke of that because that is certainly a fact.

RXQ. 323. Could you enlarge on that a little and tell us about it?

A. Yes, if one were at the time with which we are dealing, attempting to prepare a metallic filament for action as an electron emitter, then he would undoubtedly have attempted to get that filament quite clean on its surface, so that there was nothing left but the elemental material itself. Now, the principle of the Wehnelt oxide filament is to take an elementary substance such as platinum, and deposit on its surface by chemical means, or perhaps by physical means, certain things which may be considered as impurities as far as the general metallic structure of the filament is concerned. Those materials are exceedingly numerous in number, but the ones that we used for the most part were barium, calcium and strontium in various proportions, and they were applied to the filament in a great variety of ways, and I think I mentioned the use of Bank of England sealing wax, which contains some of these materials, and is in the literature, one of the historic ways of making Wehnelt's oxides. We actually used some sealing wax, and we used barium resinates and various chemical combinations, I think a number of them were new with us. Now, when one has a filament coated with such materials in a vacuum tube, and evacuates that tube, he is sometimes confronted with the difficulty that the filaments do not emit electrons. That lack of emitting of electrons from the filaments is cured by a treatment which is commonly referred to as opening-up the filament.

This is a slang term and I hardly know any other term that expresses it quite as well, but what happens briefly is this, that as the tubes are being evacuated and after they are evacuated perhaps, there is something in the chemical composition of the materials on the surface of the filament which inhibits the emission of electrons and that chemical condition on the surface can be changed by running the filament for a considerable time at its normal operating temperature or somewhat above that normal operating temperature. There are various other ways that that can be changed. As a matter of fact, the common way of opening up a Wehnelt oxid filament is to pass a discharge through the tube in the presence of blue haze and while I cannot speak as to our shop technique at the present moment, the shop technique some years ago, at the time I was more intimately connected with it, was to secure this emission in the first place by passing a blue haze discharge through the tube until the emission opened up and then frequently the blue haze would clear up by itself or frequently one would have to pump further. Does that answer your question?

Mr. Davis: Thank you, that is all.

Re-Direct Examination.

By Mr. Richmond:

RDQ. 824. One of the questions asked you, as I understood it, was if the connection of the grid to the anode was not one of the very worst ways in which to arrange for testing a vacuum tube. Now, please look at the top of page 1487 of the Interference record and tell us what it shows and see whether it refreshes your recollection and enables you to answer the question more definitely?

Mr. Davis: I rather object to the question, if your Honor please, because there was, at least by inference, the qualification in it which my brother has not stated. I was dealing there, and the witness understood it perfectly, I think, with the tube which saturated at very low voltages as shown by the curve. And the whole point was, what was that low voltage saturation in that particular tube.

The Court: Have you anything to say, Mr. Richmond?

Mr. Richmond: I do not see that that is a distinction or a limitation.

The Court: You may take your answer. If this does not meet what Mr. Davis advances, he will point it out in the brief.

A. The page that you have called to my attention shows a series of observations of pliatron No. 79, grid connected to anode in which the anode volts and the anode milliamperes are plotted in corresponding columns.

RDQ. 825. Entered instead of plotted?

A. Are entered in corresponding columns. Such an observation as this may lead to an estimate of the vacuum in the device providing the structure and so on of the device is well known. Had there been an indication in here of blue haze that would have indicated a poor vacuum, but the voltages here are not carried very high. In brief, referring to this page, I do not see just how this relates to a good test for vacuum.

RDQ. 826. What is that word pliatron that you mentioned?

A. That is a term that has been used and perhaps still is to designate certain three-element tubes made by the General Electric Company. I think it is a term invented by them.

Mr. Richmond: That is all.

Mr. Davis: That is all.

The Court: Are you through with the witness on both sides?

Mr. Davis: Yes.

(Witness excused.)

The Court: We will take a recess until 2.15.

AFTER RECESS.

THE COURT: You may call your next witness, Judge Haight.

MR. HAIGHT: Mr. Colpitts has already been sworn and I want to ask him one or two questions.*

HAROLD D. ARNOLD, resumed the stand.

RE-CROSS-EXAMINATION (Resumed).

By MR. DAVIS:

RXQ. 827. I hand you a certified copy of the file wrapper and contents of patent issued to the Western Electric Company on your application, the patent being numbered 1,297,309, issued March 18, 1919, and the application having been filed November 18, 1915. Do you recognize it?

A. This is a patent issued to me and I recognize my signature.

RXQ. 828. You recognize the signature to the petition?

A. I do recognize my signature to the petition.

RXQ. 829. Now the first claim of the application as filed was, was it not, the method of producing a high vacuum in a thermionic discharge tube which assisted in establishing an electron discharge within said tube during the process of evacuation and causing said discharge to bombard an electrode element within said tube thereby heating said electrode and driving out the gases occluded thereby?

A. That is correct.

RXQ. 830. And you regarded that as an invention when you filed that application?

A. Yes.

---

*For further examination of Mr. Colpitts, see page 802.

RXQ. 831. Although you testified that you had done exactly the same thing with a mercury tube?

A. I did not testify to that, Mr. Davis.

RXQ. 832. What did you testify?

A. I testified that in mercury arc tubes I had heated the cathodes with positive ion bombardment.

RXQ. 832a. And you regard this as an inventive step over what you did with the mercury arc?

A. I doubt that my opinion would be very valuable.

RXQ. 833. I mean your opinion when you filed the application?

A. Even at that time I doubt if my opinion would be very valuable and I do not remember what my opinion was or what I even thought the correspondence between those two matters.

RXQ. 834. Of course, you would not have filed the application unless you felt you were justified in doing so?

A. That is correct.

RXQ. 835. And unless you felt that there was some reasonable assurance that that was an invention?

A. That is correct.

RXQ. 836. So that you must have felt that at the time you filed this application?

A. Yes.

RXQ. 837. That is all I am trying to establish. It appears from this file that the application was rejected, the claims of the application were rejected on a certain British patent of 1914, and on various other patents and that on the next action dated April 23, 1917, an affidavit was filed of one Russell Trimble, as well as an affidavit—I should like to state that the effective date of the British patent was 1915—an affidavit of Dr. Arnold that he made the invention set forth in the claims in said application prior to October 1, 1915, which was probably the effective date of that English patent, and that the invention had been used extensively by himself and those assisting him in the laboratories of the Western Electric Company, Inc., prior to said date of October 1, 1915, and an affidavit of Russell Fay Trimble. That is the same Trimble who gave a statement in the Interference?

A. Yes, it is.

RXQ. 838. That he has been in charge of a large part of the work relating to the evacuation of vacuum tube devices, that prior to October 1, 1915, it was a usual and common expedient in the laboratories of the Western Electric Company, when evacuating such devices, to have one electrode, in the form of a filament, heated to incandescence—and then goes on about bombarding the second electrode. Do you remember the preparation of these affidavits?

A. No, I do not.

RXQ. 839. You have no memory of the matter at all?

A. None at all.

RXQ. 840. Do not remember the rejection or looking up the dates or anything?

A. I do not remember it at all.

RXQ. 841. Thereupon or a little later on June 8, 1918, the claims in the application, claims 1, 4 and 5 were rejected on any one of the following references, Coolidge, 1,203,495, Coolidge 1,211,091 and Coolidge 1,211,092, one of these being the Coolidge X-ray patent which we have already considered. Do you remember that?

A. No, I would not naturally have seen that, Mr. Davis, because those matters are all handled by the attorneys. I would have seen the affidavit and read it over carefully but not the patent office action.

RXQ. 842. And you do not know what happened as a result of that rejection?

A. No, I do not.

Mr. Davis: That is all.

Mr. Haight: May we reserve the right to examine Dr. Arnold until we have had a chance to look at it?

The Court: Yes.

Mr. Davis: I offer in evidence the certified file wrapper and contents.

Mr. Haight: I do not know whether it is material or not, but after having examined it I would like to reserve the right to move to strike it out.

(Received in evidence and marked "Plaintiff's Exhibit No. 170." *See Volume IV, Plaintiff's Exhibits, page 59.*)

Harold D. Arnold, resumed the stand.

Re-Cross-Examination (Continued).

By Mr. Davis:

RXQ. 843. This is you personal notebook, is it not, Doctor?

A. Yes, this is the book that I used during the years 1911 to 1915, about.

RXQ. 844. I believe that the year 1912, begins around page 114 of that book, is that correct?

A. The first 1912 record that I see here is January 3, 1912, on page 90.

RXQ. 845. Will you now look at page 136? That seems to refer to August and October, 1912?

A. Yes, it apparently does.

RXQ. 846. And without making too accurate a statement, there is a good deal in the intervening pages, that is to say, in 1912, up to October, about this mercury work that you were doing that you testified about?

A. That is right.

RXQ. 847. And at page 136 there is an entry of August 23d, an entry on August 24th, an entry on August 26th, Monday, and those are the only entries on that page, are they, Doctor?

A. No.

RXQ. 848. What other dates are they?

A. October 28th. The first part of the page is concerned with apparently a continuation of August 15th.

RXQ. 849. And is that October 28th entry finished on that page?

A. Apparently it does.

RXQ. 850. And on the next page, what is the date of the next entry?

A. December 23, 1912.

RXQ. 851. Will you please read that entry?

Mr. Haight: I object to that. It has no materiality whatsoever in the case.

The Court: How do I know?

Mr. Haight: Just an entry in the book does not prove anything. That does not mean anything whatsoever.

The Court: I think the objection is well taken, but I will hear you, Mr. Davis.

Mr. Davis: All I was trying to establish at the moment from this witness is that he did not record in his notebook during a certain period anything about this audion work except one specific thing.

The Court: On the 23d of December.

Mr. Davis: Yes, sir, 1912.

The Court: Of course you had not gotten that yet.

Mr. Davis: No, sir, I was leading up to that.

The Court: Will you put your question in another form?

By Mr. Davis:

RXQ. 852. Omitting for the moment the entry of December 23d, the next entry is on the same page and begins on February 3, 1913, and runs over several pages; is that correct?

A. Yes, that is correct.

RXQ. 853. This entry at the top of page 137, under date of December 23d, is the only entry among these entries that we have discussed that has anything to do with audions; is that correct?

A. That is correct.

RXQ. 854. Or vacuum tubes as distinguished from mercury tubes?

A. That is correct.

RXQ. 855. What is the general nature of that entry? You need not trouble to read it, but what is it about?

Mr. Haight: I object to that.

(Discussion.)

The Court: You may answer the question. The objection is overruled.

(The last question was repeated by the stenographer.)

By Mr. Davis:

RXQ. 856. Will you please read the entry?

Mr. Haight: I object.

The Court: Objection overruled.

A.

"December 23, 1912. In audion put shunt across input so that cross talk will be lessened force, since resistance of input is great at low input voltage the shunt will take a larger share of low voltage input than it will of high voltage input."

RXQ. 857. Do you recognize this book which I hand you, Doctor?

A. It appears to be from the name written inside the notebook of Mr. B. W. Kendall and so written in lead pencil on the flap.

RXQ. 858. Is that all you know about it?

A. I have seen various entries in it during the course of this case. I think there are some photostats from it that are in the record. I am not sure about that though. They may be from another Kendall book, but I do not know.

Mr. Davis: Judge Haight, I am asking whether you will state that this is one of the books which was furnished to us by you in response to our request for certain books of the Telephone Company?

Mr. Haight: Yes, I will admit it is from the files of the Telephone Company or the Western Electric.

Mr. Richmond: It has recently come from the custody of the Bell Telephone Laboratories.

Mr. Davis: The Bell Telephone Laboratories, I understand it, is a subsidiary both of the Telephone Company and of the Western Electric Company.

Mr. Richmond: Yes, that has been stated here in this case before.

By Mr. Davis:

RXQ. 859. Do you remember any tubes late in 1913, which came to be known as standard tubes? I am talking about your own people.

A. The first recollection that I have of the use of the word standard, I think was applied to a method of coating of filaments and a certain preparation of strontium hydroxide and barium resinate, but I do not recall when that term came into use, it must have been some time in 1913 or 1914.

RXQ. 860. Referring still to this book 42, certain pages of this book, for example, page 5, which was put in evidence in your behalf as Arnold Priority Exhibit 25, photostat copy of page 5 of Kendall's notebook No. 42, noting the commencement of commercial service with an audion repeater at Philadelphia on October 18, 1913, is it not?

A. Yes. The pages of this exhibit are photostats of the pages of the notebook.

RXQ. 861. Do you remember two tubes known as 162 and 163?

A. No, sir.

RXQ. 862. Were they particularly good tubes?

A. I have no recollection of them.

RXQ. 863. This book is, is it not, the original record of the experiments in Philadelphia of which you have testified made by the man who made those experiments?

A. I do not know about that. This is Mr. Kendall's book I presume and I do not know who made the entries in it. Presumably they were made by him. As for that I cannot speak.

RXQ. 864. You do not know whose notebook that is?

A. I said it says on the fly leaf it is Mr. Kendall's. I could not recognize better than that.

Mr. Davis: Is it admitted that this is the notebook of the experiments in Philadelphia?

(Discussion.)

Mr. Davis: I will withdraw my question to Judge Haight because it says in this record, as I have just read, that this was the notebook which was book 42, which was kept by Mr. Kendall and his help.

Mr. Haight: I think Dr. Arnold has already testified to that. He has identified it.

Mr. Davis: We asked——

By Mr. Davis:

RXQ. 865. This is your record, the record of your company of that work at Philadelphia, is it?

A. Why, that is Mr. Kendall's notebook as I understand it, which was kept down there in Philadelphia in part by him and perhaps in part by the others.

RXQ. 866. Have you any doubt about the accuracy of the reports?

Mr. Haight: I object.

The Court: I do not see the pertinency of that, Mr. Davis. I do not see how this witness with the association with the company which he has shown, and limited to that, can be assumed to be a proper person to verify something else. Now, if this book has already been verified, then it is the same situation, and all pages are in the condition and status as page 5, that is one thing, and if not, then we will have to turn to the principles of evidence which govern it, would we not?

Mr. Davis: May I ask a question or two?

RXQ. 867. Mr. Kendall was your assistant, Dr. Arnold?

A. He was at that time my assistant.

RXQ. 868. And doing this work under your direction?

A. The work he was doing at Philadelphia, as a matter of fact, was not done under my direction.

RXQ. 869. You were down there?

A. As you may recall, I was ill with appendicitis all during the summer and I had nothing to do whatever with his going to Philadelphia.

RXQ. 870. Did not you testify that you went down there and acted as a monitor yourself?

A. Yes, sir, I went down and visited him and visited the work. I was there for a day or so.

RXQ. 871. When was that?

A. Sometime in the fall of 1913.

RXQ. 871a. I am talking about December, 1913. You were back on the job then, were you not?

A. Is this December?

RXQ. 872. Yes.

A. I was back on the job then.

RXQ. 873. And you were in charge of this work?

A. May I see what the work is, please? I do not know what that refers to.

RXQ. 874. The work referred to in the pages of the notebook I am interested in here, is the daily log of certain tubes, at certain voltages?

A. That Mr. Kendall was reporting to me at that time, yes.

RXQ. 875. Will you look at——

A. Perhaps as my memory comes back to me, perhaps I had better qualify that statement. Mr. Kendall was working in Philadelphia, and as I recall it, at the same time another man his senior in the company, but a man who was not reporting to me, was also working in the same room, that is Mr. Shreeve; and it is my impression that as to the daily work of Kendall at that place, Shreeve was responsible, but Kendall remained on the books as reporting to me at that time.

RXQ. 876. You do not remember these tubes 162 and 163; is your recollection refreshed by looking at this book?

A. No, I do not remember those tubes at all.

(Discussion.)

Mr. Davis: If your Honor please, it has been agreed I should ask and have some questions answered by the witness to see how far his memory goes, and then we will proceed.

The Court: All right.

By Mr. Davis:

RXQ. 877. You remember this book, Dr. Arnold, book 26? It appears to be Mr. Nicolson's book.

The Court: That is a different book.

Mr. Davis: Yes, your Honor.

The Witness: What is your question?

RXQ. 878. Do you remember the book and recognize it?

A. I recognize Mr. Nicolson's signature in part.

RXQ. 879. It appears in that book that you were present at a number of tests, and so forth. For instance, look at page 58. It says: "Mr. Arnold applied" —or something, does it not?

A. Yes.

RXQ. 880. Page 63: "With Mr. Arnold." What does that mean?

A. I do not know what that means. It either means I was there when the record was taken, or else he was with me talking it over at some time.

RXQ. 881. And at page 62, April 8, here, "Took test on P-63 with Mr. Arnold at 3 P. M." That indicates that you were there, does it not?

A. That appears to be so.

RXQ. 882. Do you remember that particular test on the Fleming valve?

A. No, I do not remember.

RXQ. 883. Page 65, your name appears twice:

> "First test before Mr. Colpitts and Mr. Arnold and with Messrs. Colpitts and Arnold."

Those were at two different dates entirely, May 10th and May 9th, is that correct?

A. I see the reference to May 9th, yes, I see May 10th. One is May 9 and the other May 10.

RXQ. 884. And on page 66 it says, does it not: "Mr. Arnold said sufficiently high voltage"?

A. That is a correct reading.

RXQ. 885. And on page 79, "Burned out lamp and potentiometer (with Mr. Arnold)." Do you remember that?

A. No, I do not remember that.

RXQ. 886. It is a correct reading?

A. It is a correct reading, yes.

RXQ. 887. All this work was done under your direct supervision, was it not?

A. I would not say under my direct supervision.

RXQ. 888. Then, why did you say so in your testimony on page 593 of the record?

Mr. Haight: I object, if your Honor please.

The Court: I will hear you, Mr. Haight.

Mr. Haight: I do not think the witness has made any such sweeping testimony, or given any such sweeping testimony as that as "all this work was done under my direction." He specified what work was done under his direction.

The Court: You desire to have the witness's attention called to the specific testimony given?

Mr. Haight: Yes, I think it should be, but what is the page that you have in mind, Mr. Davis?

Mr. Davis: Page 593 (reading).

Mr. Haight: That is a very different thing from saying that all the work referred to in Nicolson's notebook was under his direction.

Mr. Davis: I did not say that. I am taking the early pages in the notebook.

Mr. Haight: You did not say that—you said all this work was done.

The Court: Do you want to reframe your question, Mr. Davis, because I think, Mr. Davis, your question is probably more general than you realized.

Mr. Davis: I have been talking to the witness about these early pages, where his presence was noted almost every day.

RXQ. 889. At that time the work was done under your direct supervision, was it not, Dr. Arnold?

A. I cannot answer your question, Mr. Davis, without seeing the dates of these references and looking over the book.

RXQ. 890-91. The work in this notebook up to and through page 27 deals, does it not, with the Von Lieben relay—up to that point?

A. Yes, it appears to.

RXQ. 892. Then it begins under what date on the next page?

A. May 15, 1913.

RXQ. 893. And begins with what, tell me what it is about?

Mr. Haight: I take it that the question is—was that done under your supervision? The witness wants to look over the book to ascertain.

Mr. Davis: All right.

RXQ. 894. And beginning on page 28, the work relates to audions, does it not, for quite a distance thereafter?

A. That would not be the way I characterize it.

RXQ. 895. How would you characterize it?

A. Mr. Nicolson was working at that time on the production of the Wehnelt oxide filaments, and I think that book relates largely to work on different coatings of the Wehnelt oxide filaments that were made up in the form of audions, some of them were, some of them were not.

RXQ. 896. Now, this page to which I called your attention, dated May 15th, 1913, but actually the Von Lieben work seems to have ended on March 25, 1913, at least that is the last record of it on page 27; and the first actual entry in the audion work is April 23, 1914, is that correct? I think you have already testified that Mr. Nicolson worked for a while on one and then went on to the other. April 14th is the beginning. There is an entry here:

> "The above will continue the tests on the R. L. S. by repeater by S. by Gray."

Indicating that the Von Lieben work was carried on by Gray, and that Nicolson directed it?

A. May I have the question?

RXQ. 897. The actual work on the audion began about April 14th, according to this notebook?

A. That is the first entry I see in the notebook, yes.

RXQ. 898. And my question is whether the work from that time until the date which is mentioned in these pages, to which I have already called your attention, the latest page is May 21, was done under your direct supervision?

A. No, I would not say under my direct supervision, I should say the work was initiated under my direct supervision, but the way the work is carried on in our laboratory, as most laboratories, is that a man of some ability is started on the job; from that time on, he is his own master as to most of the details of his work; but from time to time he has talked with his supervisor in order to become lined up. I was Mr. Nicolson's supervisor at the time this work was done.

RXQ. 899. You went in and helped to burn up the potentiometer?

A. Apparently I did, according to the record I did, but I do not remember.

RXQ. 900. Do you remember this audion N-5 shown on page 55, which seemed to have a peculiar stem construction?

A. No, I do not remember.

RXQ. 901. Do you remember these tests on the Fleming valve which are mentioned here as being at Mr. Colpitts' request?

A. I have no recollection of those except as you showed them to me a few moments ago.

RXQ. 902. I am asking you now if you remember the actual occurrence?

A. No, I do not.

By Mr. Davis:

RXQ. 903. Do you remember a report, investigation or memorandum which Mr. Nicolson wrote in this book at page 69, beginning at page 69, May 14th, in which he deals with the problems which lay before you gentlemen in the telephone group in the improvement of audions and the different expedients which were open to you in making the improvements and the different combinations that you could make?

A. No, I have no recollection of that.

RXQ. 904. Will you now look at it and looking at it see if your memory is refreshed?

A. I have no recollection of this matter at all or of having seen this matter except on these pages in this notebook.

RXQ. 905. That is, you do not remember seeing it before just now?

A. I saw that two or three days ago when the notebook passed through my hands, but I have no recollection of the occurrence at the time those things were written.

> Mr. Davis: I think, if your Honor please, that that develops a state of the witness's memory sufficient for our present purposes and I will consult with Judge Haight over the adjournment tonight and see if we can agree, and with your permission I will excuse Dr. Arnold.

Harold D. Arnold, resumes the stand for further cross-examination.

> The Court: Is there some further cross-examination of Dr. Arnold still pending, or has that been closed? I have forgotten.

Mr. Davis: The only question pending is about these notebooks and I understood that Judge Haight will take that up now.

Mr. Haight: Not now. This was to be after the other.

Mr. Davis: I thought that counsel had pretty well agreed as to what may be done with these notebooks; and it is immaterial to me whether that matter is taken up or not.

Mr. Haight: Very well, we will dispose of that matter right now.

Now, Mr. Davis yesterday stated that the only use he wished to make of any of the notebooks which we furnished him, other than the examination he had already conducted in respect to Dr. Arnold's notebook, was that we consent to offering in evidence pages 55, 59, 121, 136, 139, and 140 of the Nicolson book, and that we stipulate that those entries on those pages were the only entries in the book having reference to the exhaust of tubes.

We are willing that the pages referred to should go in evidence without any other proof than such as has already been made, but we cannot stipulate that they are the only pages in reference to the exhaust. There are two or three reasons for that, which I do not think it is necessary for me to go into now, but I am willing to stipulate this as the substitute: That the book itself may go in evidence as a physical exhibit, and may be used by Mr. Davis to support an argument, if he sees fit to make it later, that the entries that he has referred to are the only entries in reference to the exhaust of tubes, and that we shall of course have the same right to argue to the contrary, if it is deemed advisable for us to do so. In other words, the book goes in for that one specific purpose, and it seems to me that that avoids any question as to the construction to be placed upon the entries.

The Court: The specific pages enumerated by you are to go in evidence generally?

Mr. Haight: Yes, sir.

The Court: The remainder of the book to support the contention that there are no entries in the other pages touching the subject matter in question?

Mr. Haight: Yes, sir.

Mr. Davis: I do not want to be understood as making any contention. I asked my friends on the other side if they were the only ones and they said they were. I do not want to be responsible for the statement otherwise.

The Court: Then the stipulation is satisfactory.

Mr. Davis: Yes. I now offer in evidence pages 55, 59, 121, 136 and 139 and 140, of this Nicolson notebook 26, referred to in the cross-examination of Dr. Arnold.

(Received in evidence and marked "Plaintiff's Exhibit No. 216-A." *See Volume IV, Plaintiff's Exhibits, page 322.*)

Mr. Davis: With the Court's permission, I will substitute photostatic copies.

The Court: Then the remainder of the book becomes a physical exhibit to be referred to by either side if they find it useful?

Mr. Haight: For the purpose that we mentioned.

The Court: For the purpose mentioned, but the remaining pages need not be copied into the record.

(The book was received in evidence and marked "Plaintiff's Exhibit No. 216." *Not printed.*)

Mr. Davis: Now, on one of the pages, page 139, I find at the top the words, "9th August, 1913." That "August" is crossed out with a lead pencil, and the word "October" in lead pencil, with a question mark before it, and I understand defendants stipulate that should be "October" and not "August," because the preceding page 138 is October 8, and the following page, 140, October 11.

Mr. Haight: Undoubtedly that is so. Do you want to look at that, Doctor?

The Witness: I have seen that. That is undoubtedly right. The October date is undoubtedly right.

Mr. Davis: In that case, if your Honor please, I have no further cross-examination of Dr. Arnold.

Mr. Haight: We will have this photostated and they will be given one number.

The Clerk: The pages will be one number, 216-A and the book 216.

EDWIN H. COLPITTS.

Edwin H. Colpitts, was recalled as a witness on behalf of the defendants, having been previously sworn, testified as follows:

Direct Examination.

By **Mr. Haight**:

Q. 1. Mr. Colpitts, when you were on the stand last week, at page 526 of the record you made this answer: "Fixing a definite date, say January 1, 1914, there had been very few, perhaps half a dozen mechanical repeaters installed at various points in the telephone plant." Have you had occasion to examine the records of the Telephone Company and find out how many mechanical repeaters were installed in the plant as of January 1, 1914?

A. I have, and I wish to modify it to this extent. Compared to present-day figures for repeaters there were then very few mechanical repeaters, but the figure which I stated, six, was considerably in error as it should be thirty or thereabouts. I think it is thirty or thereabouts.

Q. 2. Will you please tell the Court the practice of the Telephone Company that was in effect in 1913, 1914 and so on, regarding testing in commercial use of new pieces of apparatus before the use of that apparatus generally in commercial service?

A. The general procedure and plan which was followed, except in special emergency cases, before any group or association of pieces of apparatus was put into service, was something like this. The laboratories of the Western Electric Company, that is, the Engineering Department of the Western Electric Company, developed the piece of apparatus or the association of elements and made what tests on it that they could in the laboratories. If it was thought that laboratory tests were sufficient, the next step would be to make up a sufficient number of units of the apparatus or pieces of the apparatus to give a fair trial of it in service; that is, to make a trial installation, make what was known as a trial installation of apparatus which was exactly similar to what was proposed to be furnished later on. This trial installation was largely in the hands of the A. T. & T. engineers rather than the laboratory engineers. They might co-operate with them but it would be largely in the hands of the A. T. & T. engineers.

If this trial installation was satisfactory, the apparatus was then standardized for use. We followed that practice as far as possible. Sometimes there is a third step interjected. After the laboratory tests, the laboratory engineers put this piece of apparatus or association of elements in a field trial or an extension of the laboratory test in actual telephone service. That is, broadly speaking, the procedure that was followed then and is followed at the present time.

Mr. Haight: That is all.

Mr. Davis: No cross-examination.

OTTO B. BLACKWELL.

Otto B. Blackwell, called as a witness on behalf of the defendant, being duly sworn, testified as follows:

Direct Examination.

By **Mr. Haight**:

Q. 1. Will you please state your age and residence, Mr. Blackwell?

A. Forty-two years old, residence is Plandome.

Q. 2. And what is your occupation and profession?

A. I am the transmission development engineer of the American Telephone and Telegraph Company.

Q. 3. And how long have you been connected with the engineering forces of the American Telephone and Telegraph Company?

A. Since 1906.

Q. 4. Do you recall the circumstances, not the date, of the installation in Philadelphia of the audion as a repeater on the New York-Washington-Baltimore Line?

A. I do.

Q. 5. Subsequent to the installation in Philadelphia what was the next installation of the audion as a repeater element on any circuit?

A. In commercial circuits at Brushton. That is the test station outside of Pittsburgh.

Q. 6. And on what circuit is that?

A. New York-Chicago.

Q. 7. And when was the audion first taken to Brushton for installation or when was that installation started?

A. I do not know the date of starting. It was in service early in 1914. I cannot say when it was first taken out there.

Q. 8. Was it in a commercial line?

A. Yes, it was in commercial service.

Q. 9. And was it used in that commercial line?

A. Yes.

Q. 10. Do you know the number of mechanical repeaters that were installed beginning January 1, 1914, that had been installed prior to that time?

A. The estimates which Mr. Gherardi used were made up by a man in my department.

Q. 11. And what were the numbers that he made up?

A. Prior to January 1, 1914, thirty-two.

Q. 12. During the year 1914, were a number of other mechanical repeaters, I am speaking now of two-way repeaters, put in?

A. Yes.

Q. 13. Will you please state the circumstances under which it was determined to put those repeaters in service?

A. The circumstances were these. We had underground cable installed, Boston to Washington, and we were anxious to protect our long-distance circuits between these points and the intermediate points. The cable circuits did not have as good a transmission efficiency as the open wire circuit which they were designed to protect, and so it was desired to put in installations of telephone repeaters on the cable circuits so that particularly in emergency, in conditions of storms, the cable circuits would permit us to carry out the long-distance service uninterruptedly.

Plans were made up calling for a total of eighty repeaters, made up about March, 1914. The plans called for nineteen repeaters in Providence and twenty-seven in New Haven, thirteen at Philadelphia, eight at Hartford and I believe there were two at New York and one at Narragansett Pier, and three at Milwaukee and there were a few others scattered around the plant but the big bulk were on the cable circuit between Boston and Washington.

It was planned to use at the time mechanical repeaters on all of these installations except eight at Hartford. I do not know whether I mentioned Hartford.

Q. 14. Yes, you did.

A. Eight at Hartford. The reason for choosing the mechanical repeater for the large bulk of these installations was this. At that time the mechanical repeater was in a fairly good equipment shape. I am thinking now not so much of the element itself, that is, the transmitter receiver element itself, but the associated equipment that goes with it.

On the other hand, the audion repeater was in a shape which was not nearly as convenient or compact or satisfactory for a general use in the plant as was a mechanical repeater. The device cost a good deal more, particularly in its annual charges. I think an indication of the way we looked at it at that time, even somewhat later than that time, November of that year, is pretty well brought out by a study which one of my people made of the tube prices, in which he figured that the annual charges on the vacuum tube set would vary between twice that of the mechanical set to something like three and a half times as much.

Q. 15. May I interrupt there? What was the difference in cost due to?

A. The difference in annual charges was partly due to greater first cost—of course it was not the vacuum tube itself, the cost of the tube itself was a very small item, I think perhaps $12 for a tube, I forget what the prices were, whereas the whole cost of the vacuum tube installation would be seven or eight hundred dollars. I have more exact figures if you want them.

Q. 16. That is all right. That is close enough.

A. Then the annual charges were due partly to the fact that the audion device cost more in first cost and partly due to the fact that it cost much more to maintain it. The mechanical repeater, the elements, could be connected across 24-volt batteries, which was the usual battery available at our central offices. For the audion devices we were using a separate storage battery for the filaments and for the plate batteries separate sets of dry cells. In this study it was assumed 100 dry cells, two strings of 100 dry cells each for initial installation and if the set was used continuously they would need to be changed four times a year, which ran into considerable expense.

Q. 17. What was the voltage of these cells?

A. The battery voltage then would be about 150 volts. The audion itself was estimated at that time to have a life of about 500 hours on a continuous operation basis that would need replacement every three weeks. Ordinarily we would not operate it continuously, so that in practice not more than once every six weeks.

Another factor that was important in this decision was the fact that the mechanical repeater, being of somewhat simpler circuit, and more nearly a standardized proposition could be obtained in a shorter time. The plans were for eighty sets of which only eight were to be on the audion type, at Hartford. The plans went ahead to the point where the twenty-seven in New Haven were installed and the nineteen at Providence were installed, six were put in at Philadelphia and one at Narragansett Pier.

Later in the year, in September, because of a retrenchment policy on the long lines, they decided to give up the remaining installations so that the total number put in in connection with this original plan of eighty was fifty-three, I believe. The table shows forty-nine going in, the three which had been in previously came out, so that the total number that went in out of the eighty was fifty-three.

Q. 18. I take it then from what you have said that the eight which were scheduled to go in at Hartford were not actually installed because of the retrenchment policy that was put into effect in September or thereabouts. Were there any audion repeater elements put in during the year 1914, other than the one near Pittsburgh which you have mentioned?

A. Yes, installations were put in on transcontinental circuit to San Francisco.

Q. 19. And how many?

A. A total of eleven two-way.

Q. 20. I am speaking of two-way?

A. Yes.

Q. 21. And why did you use them on the transcontinental line?

A. Well, in conditions of that kind where we needed at least three points in series, and where the expense, of course, was not any part of the factor, in our development we considered the audion type the best type we could possibly put in.

Q. 22. Were they put in for private use by any of the officials in regular lines, I mean that use?

A. Well, the actual opening of the transcontinental circuit occurred next year, as I remember, in

January, 1915. During 1914, I think what we considered our opening from the development standpoint, when our president was given a demonstration of a circuit, it was in July, 1914.

Q. 23. What I was referring to particularly was this, were the audions used as repeater elements for the private use of any of the officials of the company?

A. My answer to that is yes, they were.

Q. 24. Just state will you for whom and where?

A. After the circuit, the transcontinental circuit in July was set up for Mr. Vail to talk to the Pacific Coast. After that there was on various occasions the circuit was used by the officials and also there was an installation I believe in connection with reaching Mr. Vail both at his home in Vermont and also in connection with his summer home at Jeckyll Island.

Q. 25. You mean winter home?

A. Yes, winter home. We put in one at Richmond in connection with reaching him at that point.

Q. 26. The audion was used as the repeater element of those lines?

A. Yes.

Q. 27. Now, during the year 1914, did you put any more mechanical repeaters in?

A. Yes, we put in a small number.

Q. 28. How many?

A. Well, the table shows eight going in. There was an increase of eight net. I am not sure whether that may not have possible been ten going in, and one or two coming out.

Q. 29. And how about the audions that year?

A. That year there were thirty-two put in.

Q. 30. And the following year, how many mechanical repeaters, new ones?

A. In 1916?—I am not sure.

Q. 31. During the year 1916, you are quite right.

A. I think there was one put in in 1916.

Q. 32. And how many audions?

A. During 1916, the number increased by about 100.

Q. 33. And after that, what happened?

A. After that, the audion device came into general use with us.

Q. 34. And then what happened to the mechanical repeater?

A. They gradually filtered out of the plant. Some of them were left in for some time.

Q. 35. I do not know whether you told us why you used the audion on the transcontinental line, did you? If you did, you need not repeat it.

A. Well, I think I did. The fact that we had three points in series and we wanted the very best device we had, and expense on that structure was not of course an important factor.

Mr. Davis: No cross-examination.

(Witness excused.)

Mr. Richmond: Now, Dr. Kelly.

MERVIN J. KELLY.

Mervin J. Kelly, was called as a witness on behalf of the defendant, and having been duly sworn, testified as follows:

Mr. Richmond: Your Honor, this tube that I have in my hand was Exhibit No. 30 in the Interference record. It bears the Number 64 in black paint, and also No. 91 in red. It has often been referred to as No. 64.

The Court: It is a different tube than the 7 and these others?

Mr. Richmond: Yes, it is one that has not been mentioned in this case, so far.

The Court: I see.

Mr. Richmond: As I remember, I do not think it has. I thought you asked if it was a different tube from 7-A.

The Court: Yes, I did. I assumed it was.

Direct Examination.

By Mr. Richmond:

Q. 1. Please state your name, age, residence and occupation, Dr. Kelly.

A. I have stated my name. My age is thirty-two, and I live at Short Hills, New Jersey. I am a research engineer, employed by the Bell Telephone Laboratories.

Q. 2. When did you go with that organization?

A. About January 1, 1918.

Q. 3. What had been your training and experience in the line of physics leading to vacuum tube work before you went with that organization?

A. I have the B. S. degree, the bachelor of science degree from the University of Missouri in 1913, and I specialized as major in chemistry and physics. I then went to the University of Kentucky, taking graduate work that was available there during the next two school years, as instructor the first year and assistant professor the second year and received at the end of the second year the degree of master of science. I took the courses in physics and mathematics while I was teaching there and in the summer between those two years I attended the summer quarter of the University of Chicago. At the end of the second year, that would be in June, 1915, I went to the University of Chicago, first on fellowship and later as assistant to Dr. Millikan and pursued work in physics and mathematics and completed the work in December, 1917, the work for doctor of philosophy. However, the degree was not conferred until one or two years later, because the last part of the year I was there was the war year, and I was engaged in some work for Professor Millikan on submarine detection and did not get around to my examination before the convocation in December, but took it after convocation, and did not get that to a convocation for my degree until one or two years later, until after the war.

Q. 4. Will you tell us again when you went to the Western Electric?

A. I went right from there to the Western Electric, January 1, 1918, and was with the Western Electric Company in the Research Laboratories from that time until those laboratories were changed to the Bell Telephone Laboratories, and I have been with that organization since. I have actually been at the same place all of the time. I think that has been explained before.

Q. 5. Please run over briefly the positions you have occupied from that time to the present with the Western Electric, succeeded by the Bell Telephone Laboratories.

A. When I first went there, I was assigned to Dr. Arnold's organization, and was immediately put on vacuum tube work relating to manufacturing developments for tubes that we were then manufacturing for the Army and Navy, and was engaged in that manufacturing development work until after the close of the war. I then continued in development work of a much more purely development nature for the next few years, and have been connected continuously with the vacuum tube development and manufacturing work of that organization. At the present time I have immediate charge of all the vacuum tube development and vacuum tube manufacture of that organization.

Q. 6. I hand you Exhibit No. 30 in the Arnold priority record of the Interference record, and ask you whether you have measured the pressure in that; I ask you to first state what the object is, describe the object, and what it is supposed to be?

A. This is a three-element vacuum tube of the audion type.

Q. 7. Have you measured the pressure in this audion?

A. I have.

Q. 8. What result did you get?

A. I got a result of 1.5 times 10 to the minus fifth millimeters of mercury. In the language of this case that is .015 microns.

Q. 9. One and a half hundredths of a micron?

A. That is right.

Q. 10. How is that pressure for such a tube, good or bad?

A. That is a very good pressure; that is a very good vacuum.

Q. 11. What is the present condition of this tube with regard to operativeness?

A. Well, if it is as I left it after making the tests for pressure, it still has a pressure of .015 microns plus or minus a few points in the next place, I suppose. It has a filament that I suppose was coated throughout its whole surface at one time with oxide coating of the Wehnelt type. Much of that coating has now disappeared from the surface of the filament and instead of having the thick regular coat which it possibly initially had, it is now bare in a number of spots, and thin where there is coating material it is thin.

Q. 12. Please tell us in a simple way how you arrived at the result that you have just stated for the measurement of its vacuum.

A. Stated briefly, and in our language, I counted the gas ions. That was the method that has been referred to previously here, first, by Dr. Millikan, I believe. Since I have made the measurement, I might go into more detail about it than has been done. I might say that I first became familiar with this method of measurement of pressures of this order in the year 1917 at the laboratory at Chicago. At that time we had in the laboratory some three-element tubes, not differing greatly from this, with Wehnelt oxide coatings which Professor Millikan, I understood from him, had obtained from the Western Electric Research Laboratory. In any apparatus when we were interested in pressures of the sort which this device is unique for measuring, we used it, and I became familiar with its use and the method of using it in that way at that time. When I came on to the Western Electric Laboratories, I found it in general use there, in fact in most general use there, and I might say that at the present time, all of our high vacuum systems that are used for pumping what we call power tubes, have one such tube at each exhaust position for the measuring of pressures and also that practically every exhaust position in the laboratory where we are making vacuum studies has one such tube for measuring pressures. We also supply a small number of those to educational institutions that are interested in having them for such measurements.

Q. 13. You spoke of these tubes that you supply to the educational institutions; what do you call them?

A. We call them ionization manometers, I think that is the name, along with the code number. Every piece of apparatus has a code number, and those manometers have such a code number. The name "ionization manometer" is put with the code number in their description in our files.

Q. 14. Go on with your description.

A. Now, in the use of this device, as a measure of pressure, an electron current is taken from the cathode to one of the two other electrodes as a collector, and that electrode will of course be at a positive potential with respect to the cathode, in order to draw the electrons across, and the third electrode is maintained at some negative potential with respect to the cathode, so that all gas ions that are formed by the collisions of the electrons with the molecules of the gas will be collected to this third electrode and the current to that third electrode is measured. Now, having measured that current, one has to ascertain other things in order to know to what pressure it corresponds, in whatever units the pressure is given.

Now, it is a fact that in a device of a given geometry, and by a given geometry I mean the configuration of the elements, that over a considerable range of pressures the number of positives that are produced by a given electron stream is linearly proportional to the number of electrons going to the anode. That factor of proportionality is a factor depending on the structure of the device and if one does not know for a given three-element tube what that factor of proportionality is the reading obtained cannot be converted into the pressure units.

What was done initially, of course, was to calibrate, in the first use of such device, such a tube as a pressure measuring device against some other pressure measuring device in order to get the constant of the geometry, and then having that you can calibrate any other devices having a different geometry, as desired.

In this particular ionization manometer tube that I speak of we have carefully determined that proportionality factor by such calibration methods so that when one reads the current to the positive ion collector keeping of course the number of electrons going to the anode at a fixed value, then one knows the pressure that is in that device or in the apparatus that the device is connected to.

Now, in order to get the pressure in this bulb and not knowing the geometry factor or the proportionality factor, it was necessary, if it was wanted to be done as exactly as possible, and that is quite exact, to construct a tube similar to it. Since a tube similar was not available, that was done. So we looked into it and made measurements without cutting into it, leaving the bulb intact and from those measurements made a duplicate tube, an approximate duplicate tube. A tube as nearly duplicate as possible from such measurements.

This is the tube. Here it has two numbers on it, X9452 and X9450. We still have the practice in the laboratory that they had in the early days that if we cut out a tube and reseal it in we give it another number and the first time that this was sealed in, something happened to the filament. The filament is at one end while the plate and grid structure is entirely on the other, so that you take that mount and seal it into a bulb. Something happened to that filament unit when it had its first number X9450 and it was cut out and repaired and a new filament put in and resealed in and given the number X9452. That tube (X9452) is as nearly a duplicate of Exhibit 30 as is possible to make now.

Of course, the grid of Exhibit 30 is slightly bent, probably from heating during exhaust. It was warped, and we could not duplicate that, but those differences would make a negligible difference in the constant of the device.

Mr. Richmond: I will now interrupt Dr. Kelly to offer the substantial duplicate that he has referred to. I would like to have it called Kelly's approximate duplicate of Arnold's priority record Exhibit 30.

(Received in evidence and marked "Defendant's Exhibit No. 47.")

A. (Continued.) Now, having the manometer, the tube which you are going to use as a manometer, we sealed it on to an exhaust position with one of our standard manometers which I said we were using in the laboratory.

Q. 15. Let me interrupt you, please. Why didn't you seal Exhibit 30 on?

A. I would have been distributing its vacuum if I had. If I opened it it would never have the same vacuum again. Or if I had first made the measurements and then opened it, I do not know in the first place whether I could have done that because of its being an exhibit, but even if I should have done that I could not have taken the steps necessary to make a proper calibration because of the condition of that filament. So I did not do it for two reasons, because of the condition of the filament and because it was an exhibit and I was told not to disturb it. The thing that I did was just as good, practically as good to all intents and purposes for the final result.

Q. 16. You said you sealed the duplicate?

A. I sealed this duplicate tube and manometer tube both on to the exhaust position and made a calibration to determine its constant by first exhausting both this approximate duplicate and the manometer tube of our standard practice to a high vacuum, denuding, freeing the electrodes of gas completely (of course by electron bombardment) and initial activation of the filament before doing that, which that is still a necessity with the Wehnelt oxid types of filament. Having both tubes well exhausted and electrodes freed of gas we admitted nitrogen into the exhaust position. The exhaust position was so arranged that that was possible. We admitted small amounts. After having admitted small amounts a certain short aging process was gone through to get equilibrium conditions and as nearly simultaneously as was possible the currents that are needed to be recorded were recorded on both the approximate duplicate and the other tube.

Q. 17. The other tube being the manometer?

A. More currents being the gas ion current and the electron current. Then more nitrogen was admitted to get a slightly higher pressure and the operation was repeated over quite a range, because doing it over quite a range the small inaccuracy of any particular measurement was ironed out and a good average value of the constant was thus determined. So much for getting the constant.

Having gotten the constant—that is, not the sequence of events, as a matter of fact. Before we did this calibration work, because that took time in making up the tube and so on, I had already made a manometer measurement on the Arnold Exhibit 30. That is, I had put it into a circuit and taken electron current to one of the electrodes as an anode and picked up the positives on the other electrode which was held at a negative potential with respect to the cathode and then after I had the manometer constant by the experiments that I have just detailed I determined what that positive ion current that I had measured previously meant in pressure units. I might just say that I have not stated what electrodes were used. When a three-element tube is used as an ionization manometer, the electrical connections so far as voltages are concerned are different from where it is used as an amplifier. We take the electron stream, the electron current to the grid rather than to the plate, as the grid is made positive with respect to the filament, in this case by 100 volts and the plate is made negative, plate or anode is made negative with respect to the negative end of the filament by 10 volts. That is the voltage condition on this test. Then electron current is taken to the grid and the positive current is taken to the anode.

I might say further in regard to that experiment that of course in using any device as a manometer for pressure measurement of a system, it is obviously necessary that that device shall not contribute gas to the system, because if it does it will change the pressure of the system. So always in the use of a three-element tube as a manometer for measuring the pressure in a system, the tube is previously exhausted, pumped, given a high vacuum exhaust and the electrodes freed of gas for energy levels sufficienly above the energy level at which the measurements are made that one has great certainty from their background that there will be no gas contributed by the manometer. These tubes that were sent to universities were always exhausted, very well initially, and in putting them on to the apparatus it is necessary to open them to air to seal them on. So a second exhaust is necessary, but that can be much more abbreviated because of the initial exhaust.

How does that apply here? It applies in this way that the experiment that I have recounted with this bulb was to determine the pressure in the bulb, the pressure in the space. If gas had been liberated by the electrodes in the making of the measurements, the pressure would have changed, it would have been different from what it was as the bulb was initially handed to me so that I tried to take full care of that in the method that I made the measurement. I went up to the conditions, for making the measurement, of voltage and current in the filament as rapidly as I could, at the same time proceeding carefully enough that I did not destroy it in making the experiment.

Having gotten there I made the readings of electron current and positive current to the anode. Then I let everything go on with time. I waited two minutes and took readings again, and then two minutes more and took readings again, and then I took readings at the end of eight minutes. The pressure readings that I got at zero time, two minutes, four minutes and eight minutes were as follows: .0144 zero time, .0148 at two minutes, .0141 at four minutes and .0146 at eight minutes.

I can state from a general experience in this line that that would be called substantially constant. It varies from .0141 to .0148, which is a small variation and is not necessarily due, especially in this case is not necessarily due to variations in pressure, and I would like to go into that.

In order to do that I will have to go back just a little bit. The gas currents that were measured are very small, that is, they are of the order, that is, they are measured in microamperes or fractions of a microampere, depending on the pressure and on the number of electrons you are taking.

In the tubes which we make just for manometer purposes we insure by the arrangement of the way that the leads come out through the glass that we will have a very good insulation between the plate lead to which positives go and all other leads, so that there will not be any electrical leaks.

This tube was not built for a manometer and the grid—I should not say that because—the grid and plate leads come out through the same press here quite close together and it was found in making this measurement that there was an electrical leak between the grid and plate lead and there was that added current to the gas current.

In order to separate that electrical leak current at each of the measurements at the zero time, two minutes, four minutes and eight minutes time, we took the three currents and then keeping the filament at the temperature at which it had been running for the measurements, keeping the grid voltage at 100 volts, we decreased the electron current to the anode by the grid action of the plate by increasing the voltage, so that the electron current decreased.

It was measured until it was substantially zero. That would then remove all of the electrons from the space, and the only current that would be left would be the current across the glass, that is the leak current and that leak current was read, and the difference recorded, and that difference then taken as the gas ion current.

I may say that that leak was quite small and to all intents and purposes could be neglected; if you took all of the current as gas ion current, the pressure would not have been double, that is, it would have still been less than three-one-hundredths of a micron, which is a sufficiently high vacuum for a pure electron discharge.

Q. 18. Now, let us see if this is a correct although incomplete summary of the procedure; you made your substantial duplicate and put it up beside a standard manometer or measuring instrument and pumped them both alike, and you knew by the standard the pressure you had in both of them so that you could determine your currents in the duplicate that corresponded to those particular pressures, is that right?

A. Will you please read it?

Mr. Davis: Let the witness state his own summary.

Mr. Richmond: I will withdraw the question if it is objected to.

Q. 19. Will you please try to summarize the procedure distinguishing the different elements of apparatus sharply and giving the thing in the order of time in your procedure?

A. The first thing that was done was to measure the pressure in this device——

By The Court:

Q. 20. Referring now to what device?

A. To measure the pressure in Arnold Exhibit No. 30 by a manometer method. Not knowing the geometry constant of the device we could not transfer that into pressure readings. In order to transfer that into pressure readings we made up this in Kelly substantial duplicate of Exhibit 30 and put that on to an exhaust position with a manometer whose constant we knew and by a comparison of readings of those two tubes at different pressures I determined the constant of this approximate duplicate and since it was made exactly like or as nearly like this Exhibit 30 as possible, I took that constant to convert my meter readings over to pressures.

By Mr. Richmond:

Q. 21. And the further procedure that you told about you call a load test, do you?

A. Yes.

Q. 22. Will you summarize that in the same way?

A. The measurement that I have just given is a manometer measurement but the tube as I pointed out in making that manometer measurement, the grid was used as the anode and the electrons were taken to the grid. In a tube as used the electrons are taken to the plate or anode. Now, it is practice in the measurement of the vacuum of operating devices to make a measurement equivalent to a manometer measurement that I have described, except that the electrons are taken to the anode and the positives are taken to the grid, that is done by making the grid the most negative element and by making the plate the most positive element. And such load tests are made with loads that are somewhat greater than the loads for operation of the device and the positive current is observed with time and the steadiness of that current is taken as a measure or as an indication of the vacuum condition of the device under its operating conditions. So that that kind of measurement was made on Arnold Exhibit 30.

There I started out with a plate voltage of 150 volts and increased that fairly rapidly and noting readings up to 180 volts and held the currents to the anode at three-tenths of a milliampere by varying the grid potential. The grid potential was always negative with respect to the negative end of the filament, and when I got to 180 volts with three-tenths of a milliampere to the anode, I considered that that was as high an energy level as I needed to go from knowledge of about where the device was supposed to have been capable of operating, and I observed the gas ion current that time at two minutes, four minutes and six minutes, and that gas ion current stayed substantially constant, after six minutes the change was negligible.

Q. 23. These tests that you have been telling about, how do they compare with standard practice; how do they compare with Army and Navy requirements?

The Court: Before he answers that question may I make sure that I get that former test by the duplicate? Is the testimony of the witness as you understand it that the constant of the duplicate was assumed to be the constant of the original?

Mr. Richmond: Yes, your Honor.

The Court: I do not know whether variations beyond in the constant of the duplicate would cause it to go on terms of the original, or whether the duplicate was assumed for that purpose.

Mr. Richmond: It was so assumed, I understand.

The Court: Read the present question, Mr. Smart. (Question repeated.)

A. The load test that I made is the type of test that is made in determining the vacuum condition under load of all of the types of three-element devices for the Army and Navy with which I am familiar, and I believe that I am familiar with all of their standard devices. The practice is to take electron current to the anode and have the grid negative with respect to the filament and observe with time the gas ion current, and then place on the different types of device a certain limit for the value of that current, and in some cases a specification as to the way that it may change that time is given. I may say that the load conditions that I put on to this tube, Arnold 30, is a load test, would compare with load conditions for tubes that would be used at upwards of 100 volts, or from 100 to 130 or 140 volts, and with a space current of at least three-tenths of a milliampere.

Q. 24. Are you familiar with that variant of the so-called 3/2 power law, which is referred to as the 2/3 law, and if so, will you please refer to some standard source for it?

A. Well, the 2/3 law is nothing more than the inverse of the 3/2 power law; and the 3/2 power law states that the plate electron current varies as the 3/2 power of the voltage. What I think you have reference to, is, I think, that the 2/3 power of the current varies as the plate voltage, that is the equivalent thing.

Q. 25. And can you refer to some authority for that?

A. Yes, I can. What you have reference to is a statement in the patent in suit No. 1,558,436, and that states as follows—do I need to give the section where it is?

Q. 26. Just give the line in the patent and read it.

A. Line 28, on page 2, says:

> "In most simple devices embodying my invention, these conditions are so well fulfilled that the current does vary in proportion to the 3/2 power of the voltage over wide ranges of voltage above the ionizing voltages. This means that if the logarithm of the current is plotted against the logarithm of the voltage, the resulting plot is a straight line whose slope is 3/2. Or, in many cases

it is more convenient to make use of the equivalent relation, that the 2/3 power of the current plotted as ordinates against the anode voltages as abscissæ gives a straight line."

Q. 27. Well, now, what did you find was the best exponent for this Exhibit 30 that we have been talking about?

A. Well, now, Arnold Exhibit 30, as I stated, has a filament that is quite imperfect as it is. That imperfection did not affect at all the kind of measurement that we made in making those pressure measurements, and after making this and getting the information desired, I took a plate voltage, plate current, characteristic of the tube advancing the filament current to as high a value as I felt that I dared, with the condition of the filament, and tried to get as near as possible the filament into complete temperature saturation, and took that data and examined it to determine the relation existing between the plate current and the plate voltage and the plot of that data I have made here.

The Court: Is that logarithmic?

The Witness: No, that is not logarithmic. I will explain that in just a minute, your Honor. This paper is linear co-ordinate paper, and I have plotted the one over two point twenty-five power of the plate current against the plate voltage and have drawn a straight line through that data, the crosses representing the plate current readings at the different plate voltages. I may say, your Honor, that this corresponds exactly to the alternative method of plotting the data suggested in the patent here, if instead of using 1 over 2.25, I use one over 1.5.

Q. 28. So that instead of the exponent 3/2, you get an exponent of 2¼?

A. Oh, yes, instead of getting an exponent of 3/2, I get an exponent 2.25, that is the exponent I may say which best fits the data for the relation that the plate current is equal to some constant times the plate voltage to some power. Then the best power, the best exponent, the exponent which best fits the data for the whole range, I found to be 2.25.

Q. 29. In view of the work you have done with this tube, Arnold priority Exhibit No. 30, what is your opinion of it?

A. There is no question whatever in my mind but what this tube as given to me, is a tube that would operate to voltages of upwards of 100 volts, with a pure electron discharge, with a space current of at least three-tenths milliamperes.

Q. 30. Is there anything the matter with it, and if so, what?

A. The only thing that is the matter with it is the imperfect filament.

Q. 31. Can you explain how that originated?

A. Well, from present experience, I would say that assuming that that filament was coated completely at one time, of course, I have no knowledge that was so, that with the operation of the filament, with the coating of such a nature, that with time, it did not adhere, and it either vaporized or may be mechanically separated, and has fallen off in spots, so that a small portion of probably the initial material is now there.

Mr. Richmond: The blueprint just produced by the witness is offered in evidence as Kelly Diagram for Arnold Priority Exhibit 30.

(Received in evidence and marked "Defendant's Exhibit No. 48." *See Volume V, Defendant's Exhibits, page 629.*)

Mr. Richmond: Your Honor, I have here another audion, which was Exhibit 32 in the interference transcript.

The Court: Do you mind telling me before you go into that, what, from your point of view, I am to understand from this last blueprint? I mean briefly, because I am not sure that I quite understand what the conclusion is that you draw from the exponent which was obtained by the witness. Do I understand that this harmonizes with the 3/2 power law or as inversely stated, the 2/3 power? I missed that.

Mr. Richmond: Your Honor, it is my view that it does not harmonize with the 3/2 power law. This tube is so far from the 3/2 law, that it should be 2¼.

The Court: Then it is a fact that I passed, because I thought you were trying to reconcile it as tube 30.

Mr. Richmond: Tube 30 was one of the tubes used at Philadelphia in the installation that has been testified about at length, and happens to have been saved, and is an exhibit in the case.

The Court: I think I had better save my difficulties for a later time.

Mr. Richmond: And your Honor, I have something further in view with this witness that I think will clear that up.

The Court: I thought you were trying to reconcile that, too, and I wondered how you did it.

Mr. Richmond: I was trying to keep my argument out of it.

Mr. Davis: I say the same thing, your Honor. I do not want to argue the case now.

The Court: I thought I had missed even more than I have.

Q. 32. You have just called attention to the high value of 2.25 as the exponent for this Arnold priority Exhibit 32 audion. Are such high values as 2.25 within your knowledge in high vacuum tubes, and if so, will you please direct our attention to other examples?

A. Yes, such high values of the relation between the plate current and the plate voltage are within my knowledge, and I have some examples here. I have plotted in the same way the relation between the plate currents and the plate voltage of a standard 102-D Western Electric Company vacuum tube with the grid at zero, which was the condition of the other measurement, the grid tied to the negative side of the filament, and that plot I think shows that over the range of voltages there shown, which is up and well through the operating range of the tube when the points fall well on that straight line, which indicates that the relation Ib is equal to K times E to the 2.25 power.

Mr. Richmond: The blueprint just referred to by the witness for the 102-D tube is offered in evidence as Kelly Diagram for Western Electric Standard 102-D Vacuum Tube.

(Received in evidence and marked "Defendant's Exhibit No. 49." *See Volume V, Defendant's Exhibits, page 630.*)

Q. 33. Dr. Kelly——

A. Just a minute. I had not finished.

Q. 34. All right. Go ahead.

A. You asked for exhibits. I have here another, which is for a U. V. 201-A tube with E. C. equal zero, and this data has been taken from data given in an article in the proceedings of the Institute of Radio Engineers, December, 1923. Those were the two that I have as examples.

Mr. Richmond: The last blueprint produced by the witness is offered in evidence as Kelly Diagram for Tube 201-A.

(Received in evidence and marked "Defendant's Exhibit No. 50." *See Volume V, Defendant's Exhibits, page 631.*)

Q. 35. Where did you get the data for this last diagram?

A. I got it from an article in the proceedings of the Institute of Radio Engineers, December, 1923. I should say the article is by Mr. J. C. Warner, and the data is taken from a plot on page 591, called Figure 4.

Q. 36. Who is the author of this article?

A. Mr. J. M. Warner.

THE COURT: Who? J. C. who?

THE WITNESS: J. C. Warner.

Q. 37. Can you identify him?

A. Yes. He is, it says here, in the research laboratory of the General Electric Company, Schenectady, New York.

Q. 38. Does the article state whether that is a General Electric tube?

A. I do not know that the article states it is the General Electric tube, but the designation "U. V. 201-A," stamps it, to the best of my knowledge, as a tube of the Radio Corporation of America. I will have to read it. I do not see that the writer does say it is the General Electric Company tube, but the type U. V. tubes are tubes that are marketed by the Radio Corporation of America, which are manufactured by the General Electric Company and the Westinghouse Electric & Manufacturing Company, I believe.

Q. 39. Now, Dr. Kelly, referring to these last three blueprints that you have put in, please state what the different slopes on them mean; I mean the actual slopes of the lines on these three blueprints?

A. The slope of a line on this method of plotting is the constant of proportionality between the plate current and plate voltage. As that constant of proportionality varies, the angle that this line makes with the plate voltage axis will vary.

Q. 40. Then that slope is not to be confused with what is sometimes called the 3/2 slope, is it?

A. Oh, no. If one were plotting logarithms that is so; but the slope of this plot is the constant of proportionality between the plate current and the plate voltage, to whatever power you have there, and on the logarithmic plot, the slope of the line may or may not be 3/2.

Q. 41. And it is the straightness of the lines that indicates the conformity to the 2.25 component?

A. It is the straightness of the line that indicates the conformity of the data to the relation that the plate current is equal to some constant times the plate voltage to the 2.25 power.

Q. 42. Now, I direct your attention to Arnold priority Exhibit 32, which I mentioned a few minutes ago, and ask you to state briefly what that appears to be?

A. This again is a three-element vacuum tube of the audion type.

Q. 43. Have you measured its pressure, and if so, what result did you get?

A. I have measured its pressure and I do not think that it is necessary for me to go into the details of the measurement other than to say that I did it in precisely the same way as with the Arnold Exhibit No. 30, with the result that I found a pressure of .011 microns initially, and we took readings of this tube (32) at two minutes, five minutes and ten minutes. These readings were as follows: The zero time reading was .011. At two minutes, it was .011 plus. That is, it was slightly more than that, but the last digit was less than 2. And at five minutes, it was .012, and at ten minutes, it was .011 plus. In other words, its pressure was constant. That variation is the variation that we get in all such measurements, and I would say that the pressure was constant throughout the ten minutes. I might say this of this particular tube, the filament is very much better than the filament in Arnold Exhibit No. 30, and that the coating is not removed, and the whole surface is pretty well coated. That, your Honor will see, if you put that in the light. You see you will get the metallic surface on the filament if the light flashes on it.

THE COURT: That is No. 30?

A. Yes. That is the one that I said had a filament pretty well lost. Now, this is the 32 tube, and if you notice that filament throughout, is dull, you get no metallic sheen. That filament is well covered, practically completely covered with the oxide coating and emissive, as the examination of it we made showed over much more of its surface than the other filament, because it was so emissive at 100 volts on the collecting electrode without going to a higher voltage than 100 volts on the collecting electrode, and with filament currents that we were free to use, I could go up to 2.03 milliamperes of electron current, and did so, and the only difference in this measurement and the other one was that I used a larger electron current than in the other, which would mean that for the same pressure I would get a proportionately greater number of positive ions. I also made on this tube the load test, which is similar to the load test which I made on the first tube, and here I went up quite rapidly to 180 volts on the plate holding the plate current here to four-tenths milliamperes which was one-tenth more than in the previous tube. Holding the grid negative with respect to the filament, and varying that negative value to keep the plate current at exactly four-tenths milliamperes, and observe with time the current to the grid. That current remains substantially constant throughout the period of time. I do not know whether I stated the period of time. It was in this case fourteen minutes, and I took readings at two minutes, at six, and at ten minutes, and at fourteen minutes.

Those readings of gas current are as follows: zero reading was 1.36; two minutes, 1.40; six minutes, 1.43; ten minutes, 1.38; and fourteen minutes, 1.37. That is, it stays substantially constant, and I would say from my experience in readings and making such experiments on tubes that that tube was steady under such load and that the test indicated that it would operate as a good high vacuum tube in pure electron discharge with anode voltages of 100 volts or more, 100 up to 140, with a space current of .4 milliamperes.

Just here, Mr. Richmond, I would like to make one statement. When I was describing on the previous tubes the method of correcting for my leak current, I find the method I outlined here, contrary to the method used. With my initial slight nervousness on being on the stand I stated the method of making the correction incorrectly and I would like to make the correction now.

There are two methods of doing that, and I had looked at the two methods and did not state what I actually did. The two methods of determining that leak current are substantially the same. It is necessary in order to determine it to have the electron space current absent so that you do not get the gas current. You can either do that by making the electron space current zero, by either the grid action of the collecting electrode making it more and more negative so that you block off electron current, or you can cut the filament current down to such a low value that it has no emission.

The method that I used was the one of cutting the filament current down rather than of increasing the collector electrode voltage negatively as I stated, and the reason I used the method of cutting the filament current down rather than the other is this, that as you increase that collector voltage you actually increase the voltage difference between the two electrodes where the leak occurs and that would increase the value and therefore you would give it undue value, that is, you would make it greater than it was with the actual voltage that was there.

I did not use that method, but I used the method of lowering the filament until there was no electron emission and that actually leaving the voltages as they were, where there was electron emission, and that worked in the other direction; that is, that made the leak actually less because the bulb would cool some and as the bulb was cooled the leak would become less.

I am sorry to have made that mistake, but as a matter of fact it is of small moment, because even taking the whole current, not correcting for the leak at all, the pressures obtained are still pressures where you would get a pure electron discharge.

(After a short recess.)

Q. 44. Dr. Kelly, I understand that you proceeded with Arnold priority Exhibit No. 32 in the same way substantially that you proceeded with Arnold priority Exhibit 30. Did you make a substantial duplicate of Arnold priority Exhibit 32?

A. Yes, I made a substantial duplicate of Arnold priority Exhibit 32.

Q. 45. Please produce it.

A. Yes, sir.

Mr. Richmond: I offer in evidence the tube that the witness has produced, called approximate duplicate of Arnold priority Exhibit No. 32.

(Received in evidence and marked "Defendant's Exhibit No. 51." *See Volume V, Defendant's Exhibits, page 632.*)

Q. 46. Did you examine the data for this tube to find whether they conformed to the 3/2 power law and if not what was the best exponent instead of 3/2?

A. I took data on this tube and examined the exponent of plate voltage which would best conform with the data and I find that to be 2.25. This line is the approximate duplicate to 32, I_B with exponent 1 over 2.25 plotted against E_B, and this line is a plot of the Arnold Exhibit No. 32.

THE COURT: The last line referred to being nearer the right-hand lower corner and the first one referred to being the one nearer the left-hand upper corner.

Q. 47. Please explain about that legend 105.

A. With regard to audion 100, later No. 105, Arnold Priority Exhibit 32, there are so many names that I put the 105 on that.

MR. RICHMOND: The blueprint last produced by the witness is offered in evidence as Kelly diagram for Arnold Priority Exhibit 32 and the approximate duplicate tube.

(Received in evidence and marked "Defendant's Exhibit No. 52." *See Volume V, Defendant's Exhibits, page 633.*)

A. (Continued): I may say that the approximate duplicate of the exhibit was, after it was made up, exhausted to a very, very good vacuum and is a high vacuum tube prior to the taking of this data, and its pressure was determined by a manometer method to insure that it was a good high vacuum tube, and it was. It was a tube with such a pressure that the discharge was a pure electron discharge.

Q. 48. On this last blueprint that you have referred to, what does the difference in location and slope of the two lines mean?

A. You will note that we called it an approximate duplicate. If it were an exact duplicate, the two lines would have been coincident, but it is not possible by measuring the dimensions of the grid wires and so on with the micrometer to make it identical. Further, the constant of proportionality there was, aside from slight differences in mechanical structure, different due to the filaments not being of exactly the same area and the ribbon of filament which I have in the approximate duplicate may not have exactly the same area as the ribbon of filament in the tube 105 and I have no way of determining what that was, but the tube was as close to the Exhibit 32 as it was possible to make it.

Q. 49. And what does the straightness or approximate straightness of the lines on that blueprint mean?

A. The lines are straight. Straight lines have been drawn through the points and the straight line fitting the points as well as it does indicates that the data conforms with the relation given that the plate current varies as the 2.25 power of the plate voltage.

Q. 50. Please state in brief summary your opinion of this tube, Arnold Priority Exhibit 32?

A. Again, Arnold Priority Exhibit No. 32 is a tube of a very good high vacuum, such that it would operate with a pure electron discharge as an amplifier at plate voltages of upwards of 100 volts, I have said from 100 to 140 volts, I believe, with an electron space current of at least .4 of a milliampere.

Q. 51. I direct your attention to Arnold Priority Exhibit 34, which consists of two notebook pages and a curve sheet following, relating to a tube that was designated 9.111.

A. Yes.

Q. 52. Have you made an analysis and study of the data there presented?

A. Yes, sir, I have.

Q. 53. Do those data enable you to ascertain the best fitting exponent corresponding to the 3/2 power law?

A. They do.

Q. 54. Please give us your result.

A. I find that the exponent best fitted to the result was 2.25.

Q. 55. Have you prepared something——

A. I have prepared a plot showing the data with the grid at zero on a sheet with Arnold Exhibit 32, which is again repeated. This grid connected with the negative side of the filament in both cases.

Mr. Richmond: The blueprint last referred to by the witness is offered in evidence as Kelly diagram for Arnold Priority Exhibit 32 and Arnold audion 9.111.

(Received in evidence and marked "Defendant's Exhibit No. 53." *See Volume V, Defendant's Exhibits, page 634.*)

Q. 56. Here again I understand that the approximate straightness of the lines means that 2.25 is the best fitting exponent.

A. That is correct.

Q. 57. And that the different slopes of the lines on the diagram correspond to different factors of proportionality between the voltage and current?

A. That is correct.

Q. 58. Have you made any examination of these same data in Arnold Priority Exhibit 34 with regard to the constancy of the vacuum in the tube from which they are taken?

A. All that is here available to examine is the data. This tube was not available and I have studied the data carefully. The data being the plate voltage, plate current relation with the grid marked at zero and with three other grid voltages which were values close to the filament potential.

Q. 59. Have you plotted the data?

A. Yes, I have.

Q. 60. If so, produce the plots.

A. I plotted the data for all four sets of characteristics. The characteristics were taken with the grid at zero, with the grid at 1.5 volts positive and 2.6 volts positive and four volts positive.

Q. 61. What kind of plots are these?

A. These plots are similar to the previous ones, where the plate voltage is plotted against one over 2.25 power of the plate current. In fact, the lower right-hand line is a duplicate of the line on the last plot. The fact that the points lay along the straight line as drawn through them is indicative that the data follows the relation.

Q. 62. And for this tube 9.111, according to these data you find that the best fitting exponent is 2.25 instead of 3/2; do you?

A. I find that 2.25 is the best fitting exponent for the whole range of the data, of any exponent that I could find, yes.

Mr. Richmond: The diagram last referred to by the witness is offered in evidence as Kelly diagram for data of audion 9.111 in Arnold Priority Exhibit 34.

(Received in evidence and marked "Defendant's Exhibit No. 54." *See Volume VI, Defendant's Exhibits, page 635.*)

Q. 63. Referring to this last-mentioned exhibit, I notice that on the left-hand line some of the points at the top seem to be getting away from it. What about that?

A. Yes. The upper values of plate current when the grid was at four volts positive are found to lie below, and increasingly below the straight line which I have drawn through the points. The explanation of that is that the filament, as we saw it, was getting out of saturation; that is, there was no sufficient emission for the larger current so that the current to the plate was not as large as it would have been if there had been more emission.

Q. 64. At what voltage was that?

A. It is on the plot with the grid at plus 4 and departures begin to take place at the plate potential of

100 and from there on up to the plate potential of 125. Those points lie below the line which is indicative of paucity of electron emission.

Q. 65. Do you see any other divergent points to call attention to on that diagram?

A. There is one that is specially notable and that is the first point, the lowest point with the grid at zero which is the point for plate potential of twenty-seven volts. That is found to lie considerably above the straight line drawn. I might say in explanation of the divergence of the upper points from the line, that is, the points on the plus 4 volt grid plot, the divergence of this point at a voltage of twenty-seven volts with the grid at zero lies above the line, and the only explanation seems to me to be an error in either recording the observed plate current or in recording the observed plate voltage. The type of departure that is there noted could not be explained consistent with all the rest of the data in any other reasonable way so far as I can see.

Q. 66. Can you produce advertising circulars issued by the General Electric Company for their gassy tubes?

A. Yes.

Q. 67. Please just run over these and point out the allusions and explain them.

A. These are photostats from catalogues of the Radio Corporation of America of a tube called radiotron UV200 and there is considerable descriptive matter in regard to the tube that is referred to as a gas content detector on one of these sheets, and the price is given.

Then on a further sheet of this catalogue in a paragraph where it gives the important facts concerning radiotron UV200, it is stated that the Radio Corporation radiotron UV200 is in itself an excellent tone frequency amplifier, it does also give the power amplification obtainable by the corporation's special amplifier tube UV201.

The UV200 tube is referred to as a gas content tube for use as a detector or tone frequency amplifier. On one sheet there is shown the diagram of a train of tubes in a receiving system showing this tube used as a detector and as a two-stage amplifier.

Q. 68. Is this what you call a high vacuum tube?

A. No. Its description is of a gas content tube and it is also called a vacuum tube detector and amplifier.

Q. 69. Who makes these tubes?

A. The General Electric Company was making them at this time. I do not know whether the Westinghouse Company are making them now.

Q. 70. How long have they been on the market?

A. Since around the first of 1920, or the latter part of 1919. I am not just certain as to the exact time they came out on the market, but it might have been even later in 1920, but it was around 1920. That is about as near as I can fix it.

Mr. Richmond: The circulars produced by the witness are offered in evidence as circulars for gas content tube UV200.

Mr. Davis: I suppose that my brother has the right to call these exhibits anything he pleases, but I do not think the description is very descriptive, because it includes the 201 which is not a gas tube at all but a high vacuum tube.

The Court: I did not quite hear what you said, Mr. Davis.

Mr. Davis: The offer of these circulars is as circulars of low vacuum or gas tubes. The 200 tube is a gas type of tube for special purposes. The 201 is a high vacuum tube which we have already shown you, your Honor.

Mr. Richmond: All right. Circulars of General Electric tubes including tube UV200.

(Received in evidence and marked "Defendant's Exhibit No. 55." *See Volume VI, Defendant's Exhibits, page 637.*)

Q. 71. You are aware of the theory with respect to the 3/2 power law when the emitting surface is shown to be equi-potential and perhaps with other simplifying assumptions. Will you discuss the application of this law to practical audions?

A. In reply to the first question, I am aware of the law and am familiar with it, and in respect to the second, I may say that the law does not apply because the commercial devices do not come within the limiting conditions or boundary conditions that are set up for the derivation of the formula and because that there are in practical devices in their operating range considerable departures from the theoretical relation for the equi-potential emitting surface we have discussed.

I might mention a number of the conditions in the practical device that are not covered or included in the theoretical derivation, but I shall not go into them in great detail, because it is my understanding that they are covered in the record, but I would like to mention a number of them.

The first departure is in the way the electrons themselves come out of the emitting surface. The formula as derived supposes zero velocity of emission. They do not come out of the thermionic filaments or cathodes in that way. They have a distribution of velocities which follows a law, and the velocities are considerable.

The second point of departure is that the cathode is filamentary rather than being a plane surface and equi-potential. A current is passed through and there is a voltage drop along the cathode so that the cathode differs from the ideal case in two respects. It is not a plane and it is not equi-potential.

The third thing is that there is in three-electrode devices at least one electrode which is placed between the emitting surface and the anode which is called a grid and that modifies the applicability.

The fourth is that the derivation of the law presupposes complete temperature saturation. That is in many cases not true with practical devices. The cathode, as I have stated, has a filament and is heated by a current that is passed through it and that cathode is connected to the outside by leads which in general are of considerably lower temperature than that of the cathode, and they conduct heat away from the cathode and even if we suppose for the moment that on the particular data that we are looking that the middle of the filament is sufficiently hot that complete saturation is obtained, the ends of the filament will be operating or may be operating somewhat different, the degree varying in each particular case, some so that a portion of the filament will be in complete saturation and a portion of it out, and I may say that that is especially important in higher temperature filaments of the tungsten type.

Some minor points that are of importance in particular instances, are the fact that whatever the effect of the grid element between the filament and plate is, it is not the same for all electron currents. That is due to the fact that the constant that we call amplification is not truly a constant; that is, it varies with the electron current and varies in value as much as 10 per cent. commonly in many cases and there are cases where it is twice that or 20 per cent. over a considerable range of current.

Then there are effects of contact potential between the filament and grid and the variation of that contact potential in the taking of the data and there are other minor things that come in that assume different degrees of importance in particular cases. The result of the effect of these different conditions that I have named is that when you plot for a particular practical device any data before you the I_B, 2/3 E_B, or plot on log paper, the plate voltage and plate current, you get divergence from the 3/2 power law and the 2/3 power law and the only way in general to get closer adherence to the relation is to attempt to take care by estimating the effect of these various factors.

And the result of all of this is that the use as a criterion of vacuum condition of whether or whether or not a practical device is following the 3/2 or the 2/3 law, is, in my estimation, practically of no value.

Q. 72. To your knowledge, to what extent is the law used or relied on?

A. I should like to say in that connection that I have been now for almost nine years, nine years the first of the year, working intimately with the development of two- and three-element thermionic devices for use in communication with wires and wireless, and operating at plate voltages of from twenty volts to 25,000 volts, and to the best of my knowledge I have never used the plot of the plate voltage against the plate current or any power of the plate voltage against the plate current as an indication of the vacuum condition of the device. Further, I may say that for almost six years of that time I have been intimately connected with the manufacture of such devices and the development of specifications to be used in determining whether the manufactured product is sufficiently exhausted to operate under its condition of operation as a pure electron discharge device, and never have we used in such specifications any plate voltage, plate current plot, or any possible obeyance of that plot to any power law as an indication of the vacuum condition of a manufactured tube.

I may say further that throughout this time I have been in very close touch with the specifications that the U. S. Government departments have as acceptance tests at the factories of manufacturers of such devices, and to the best of my knowledge such a test—that is, I mean the use of plate voltage plate current relation or the following of powers of a plate voltage and plate current as an indication of the vacuum condition of such devices—has not been used.

On the other hand, I may say that the gas ion count method which I have explained as having used to determine the vacuum condition, that is the gas ion count method, which I call the load test, is the method that we have employed in all of our developments and as a measure in the manufactured product of the degree of vacuum in the final specification of the manufactured product. To my knowledge there has been no use at all of a 3/2 power method of determining the vacuum condition of the tubes in current use; and in fact, I must say that the only place where I have definite knowledge of its use or the proposal for its use, is in connection with the present patent litigation. I would like to say further in that regard that the plots which I have here shown of the Is data to the one over 2.25 power of these different tubes has not been shown as an indication of the possible degree of vacuum of the tubes. It simply has been to show that tubes whose vacuum condition that we know without any question have slopes of this value of as high as 2.25, that is, have a relation between that current and plate voltage of as high as 2.25.

Q. 73. On the other hand, if a tube has a slope of 1.5 or an exponent of 1.5, does that prove that it is a high vacuum tube?

A. No, indeed, it does not.

Q. 74. Can you give some examples to illustrate your answer?

A. Yes, I can. I have here the data and the 2/3 plot of a tube, which, according to the legend is "Helium filled type 718 G. tube X 7408." The grid zero, that means the grid connected to the negative side of the filament, and there is given here a plot of the plate voltage against the plate current. I have two sets of coordinates of this paper. The coordinates here are the actual plate current, and this is the plot of the plate and the curve to the right is the plot of the plate current. The curve to the left is the plot of the plate current to the 2/3 power against the plate voltage.

It will be noticed that there is a very good straight line relation over a portion of the characteristic; that is, about thirty volts on as far as the characteristic is taken, to about 120. It just happens that the characteristic, that the geometry characteristics of this particular tube are such that the departures from a 2/3 relation, due to geometry, do not take it over a wide range, and that great care was taken that the filament was at temperature saturation and it is a filament so dull and tempered that the cooling of the lead-in wires has a small effect, so that these departures in a high vacuum tube as being of varying degree, dependent upon the particular type of device for operating to effect the characteristic to about the minimum amount which you could get in a practical device. There is a good straight line showing of the 2/3 power. It will be noted that it says up there:

> "Initial pressure three times ten to the minus three millimeters of mercury."

That is three microns; and the final pressure 3.9 times 10 with the exponent —3, that is about four microns. Those pressures I might say were determined in the tube before this run was made, this particular run, and after the run was made by the ionization manometer method. Those pressures are so high that this tube is certainly not a high vacuum tube, and yet a 2/3 plot is there well shown over a portion of the characteristic.

Mr. Richmond: The tube produced by the witness is offered in evidence as Kelly Helium Filled Tube.

(Received in evidence and marked "Defendant's Exhibit No. 56." *See Volume VI, Defendant's Exhibits, page 650.*)

Mr. Richmond: The plot referred to by the witness in this connection is offered in evidence as Kelly Diagram for Helium filled Tube.

(Received in evidence and marked "Defendant's Exhibit No. 57." *See Volume VI, Defendant's Exhibits, page 651.*)

Q. 75. Go ahead, Dr. Kelly. I thought you were through.

A. I have a second example of this where the data has been taken at different pressures with the same tube. That meant of course that the tube had to be the part of a larger system in order to vary its pressure, so that that tube in the system could not be transported; and I have taken the Es, Is data and put Es against Is to the 2/3 for this tube as a high vacuum tube, and where the pressure was 2 times 10 to the minus 5 or [illegible] that is .02, two-hundredths microns, and at sixty-four-hundredths microns, and at 1.2 microns, substantially operating with a pure electron discharge.

Mr. Richmond: The three blueprints just produced by the witness are offered in evidence as Kelly 3 Diagrams for Helium Filled Tube at—

The Witness: Just a moment. This tube was not filled with helium, but was filled with nitrogen. The gas is not the same in the two cases. I beg your pardon.

Mr. Richmond: I offer it as Kelly 3 Diagrams for Nitrogen Filled Tube at Different Pressures.

(Received in evidence and marked respectively "Defendant's Exhibit Nos. 58, 58-A and 58-B." *See Volume VI, Defendant's Exhibits, pages 652, 653 and 654.*)

Q. 76. Explain to us about that, Dr. Kelly. I supposed it was the same tube.

A. This tube was sealed to an exhaust system similar to the one that I described in which we made the manometer calibrations and the tube was first exhausted to a given vacuum and the electrodes properly denuded of gas and characteristics were taken on the tube first at a pressure of one-tenth, that of a plot that I have shown, and then that would be at a pressure of .002 microns, and the tube properly aged, and then nitrogen was admitted, and the pressure of .02 was obtained and characteristics were taken. I may say that the data obtained for .02 microns and .002 microns, were identical. That is the test of high vacuum that Dr. Millikan referred to, at one reading at 120 volts on the plate and zero on the grid. The electron current is 17.65 milliamperes for .002 microns and 17.67 milliamperes for .02 microns, which is identical, if you will look at the data. You will find at another place that the current read at 70 volts is 6.5 milliamperes for the .002 and 6.48 for the .02. That is just a variation of readings from time to time to the other. The tube had been pumped down beyond the place where there is no effect. The currents were substantially the same; and then after having taken the characteristics at .02 microns, further gas was admitted and proper aging routine performed, and the characteristics again taken, and those are the characteristics; that is, the pressure there was .6 microns and there the pressure was sufficiently high for the 120-volt that the space current had increased from the 17.65 milliamperes to 22.3 milliamperes. That was due to the partial neutralization of the space charge by the gas ions formed; and then at 1.2 microns, gas was further admitted after taking the characteristics at .6 microns, and the tube was aged properly and a pressure of 1.2 microns obtained, and the characteristics taken, and at 120 volts—I am reading just one point, the electron current to the place was 28.4 milliamperes, still a further increase due to still further partial neutralization of the space charge; so that from the pure electron discharge current to the last one, there is an increase of 17.65, up to 28.4 milliamperes, and yet the plots from one to the other show over a considerable range of the plot of I_B to 2/3 against E_B that the plots fall on a straight line; and as a matter of fact, if you take the plot for the 1.2 microns and do not have the legend on there, you certainly could not differentiate that plot from other plots of tubes operating a pure electron discharge. I certainly could not.

Q. 77. What is the phenomenon called singing?

A. The phenomenon called singing in this general telephone radio field is a sustained tone of some frequency that generally is in the audio range. It was manifested on hearing as the audio range.

Q. 78. Where is it familiar?

A. Singing as a general term is very familiar to all of us that are working with three-element high vacuum tubes, in most any of their applications.

Q. 79. Does it occur in connection with the two-way repeaters using vacuum tubes?

A. Yes, it does.

Q. 80. Can you tell about that?

A. Yes, I will, and I have prepared a diagram which I think will make the explanation possibly more clear. This diagram is a two-way repeater shown diagrammatically. I am a little confused how to talk from the diagram and be sure that the record is understandable.

Mr. Richmond: I will try to get hold of a colored pencil for you.

Mr. Darby: Here is a blue and red.

Mr. Richmond: Put your reference letters on freely, and we will mark up the other copies in the same way.

The Witness: Shall I mark this?

The Court: Maybe Mr. Davis would like to have his marked with the reference letters.

The Witness: Referring to the diagram of two-way telephone repeater, the two lines marked 1, represent an incoming pair of telephone wires to a two-way repeater, the box marked 2 is what we call a hybrid transformer. The box marked 3 is the balancing network for the line, which I have called 1. That is the line extending back in the direction 1. The box which I have called 4 is the amplifier for amplifying the incoming speech from direction 1. The box marked 5 is the hybrid transformer for the incoming speech from the opposite direction, or from the outgoing speech from direction 1, and the box called 6 is the balancing network for the line coming in from the opposite direction of 1. I shall call that 8.

The Court: Then the pair of lines on the right are marked 8?

The Witness: And the box 7 is the amplifier for the amplification of the speech from direction 8.

Now, I have assumed that we have an incoming telephone current of the magnitude 2_{I1}, coming in on line 1 into hybrid transformer 2, that current will divide approximately half of it which I call $_{I1}$, going into amplifier which I have marked 4. That current will be amplified an amount which I have called A_1, and the outgoing current will be A_1, I_1, and that current will go into transformer 5, and about one-half of that current $\frac{1}{2}A_1i_1$ will go out at line 8.

Now, due to the fact that the circuit made up of network 6, line 8, transformer 5 is not in complete balance, let us assume it is not in complete balance, there will be what we might call a leakage of current down into the pair of leads going into input on amplifier No. 7, and I have said that we shall designate that leakage by a letter u_1. That u_1 represents a percentage of A_1i_1 that leaks out hybrid transformer 5 into the pair of wires leading into amplifier 7. Therefore, the current going into amplifier 7 will be $u_1A_1i_1$ and after it goes through amplifier 7, if we call its amplifica- A_2, the current will be $u_1A_1A_2i_1$, and that current will go up through that pair of lines up through the transformer 2, and if there were no unbalance there, it would divide a portion of it going out to line 1, and the remainder going out to network 3; but we will assume some unbalance in that system, and call that unbalance u_2, so that the current going into the input amplifier 4 from this source will be $u_1u_2A_1A_2i_1$, as the percentage of unbalance in the transformer 2. Now then, when $u_1u_2A_1A_2i_2$ is equal to or is greater than the incoming I_1, the repeater will sing, that is, when ui, u_2, A_1, A_2 is equal to or greater than 1.

Mr. Richmond: I offer in evidence Kelly diagram of two-way telephone repeater.

(Received in evidence and marked "Defendant's Exhibit No. 59." *See Volume VI, Defendant's Exhibits, page 655.*)

The Court: Adjourn court until ten tomorrow.

(Whereupon, at 5.15, adjournment was taken until Thursday, October 28, 1926, at ten o'clock A. M.)

United States District Court,
Wilmington, Delaware,
Thursday, October 28, 1926,
10 o'clock A. M.

ELEVENTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mervin J. Kelly, resumes the stand.

Direct Examination (Continued).

By Mr. Richmond:

Mr. Richmond: Your Honor, with your permission, I should like to make a very brief statement to point out where this testimony of this witness fits into the case. The two tubes to which he has referred, Exhibit 30 and Exhibit 32 in the interference record were tubes used at Philadelphia in the toll lines in the latter part of 1913. It has been urged against Arnold that those tubes were low vacuum tubes and the principal ground for that allegation was that they had steep characteristics, that is, a slope greater than the 3/2 slope. Indeed, they did have such a higher slope, and this witness has testified to the effect that they are high vacuum tubes, notwithstanding their steep slopes, and he shows that other tubes that are high vacuum tubes have steep slopes, so that they classify with admittedly good tubes.

Mr. Davis: I will not now reply except to the extent of stating that I am not interested in the second of the two tubes because it was made about a month after Dr. Arnold attended Dr. Langmuir's lecture, and the other points we will take up at the proper time.

The Court: Yes, the statement of Mr. Richmond being only to keep me advised as to what he is attempting to establish.

Q. 81. Dr. Kelly, you have mentioned to me that you found a couple of slight errors in your numerical work, on which your testimony was based. Will you please tell about those?

A. Yes. Dr. Langmuir and his associates, some of his associates last night, asked for more detailed data upon which some of the exhibits that I made, or some statements that I made, were based, and last night, in the preparation of this information for Dr. Langmuir, I ran on to a couple of mechanical errors, which did not change the purport of the testimony at all; but for exactness and accuracy, I wish to state what they are here, and I advised Dr. Langmuir's associates of those two errors. The first one was in the calculation of the pressure in the ionization manometer measurement of Arnold Exhibit No. 32, that is the second of the tubes. A factor of proportionality of two was overlooked in this calculation, and the pressure should have been about one-half as stated. The other error——

Q. 82. Excuse me, Dr. Kelly, you mean that the vacuum was better or worse than you have stated?

A. It was better. The pressure was approximately one-half what I stated yesterday. The other error was in connection with the plots on Exhibit No. 54.

The plot of the one over 2.25 power of the current against the plate voltage for grid current at zero, its slope is in error due to the fact that in going down a column of figures in making the plot the finger of the person making it wandered into the adjacent column and while that shifted the slope of this line it did not alter, when the corrected data was used, the straightness of the line which is an indication of the fact that the data follows the I_B equals E_B to the 2.25 power. I want to substitute the corrected line for the other one, which was in error.

The Court: The original one had better stay in, Mr. Davis, the original of Exhibit 54.

Mr. Davis: I do not know whether a new one is submitted.

The Court: Yes.

The Witness: There is other data on 54 which is not in error.

Mr. Davis: Then I understand that the error applies to one of the lines.

The Witness: Yes, only the lower line.

The Court: Let this be 54-A, then.

Mr. Richmond: I offer in evidence the tracing just now produced by the witness as Kelly diagram showing correction for lowermost line of Exhibit 54.

(Received in evidence and marked "Defendant's Exhibit 54-A." *See Volume VI, Defendant's Exhibits, page 636.*)

Q. 83. Referring to the diagram Exhibit 50, which you produced yesterday, showing a 2.25 relation for the tube 201-A, I get this relation from the diagram itself, but I do not see that you have mentioned it in your testimony.

A. Yes, sir.

Q. 84. Will you please refer to the matter?

A. In Exhibit 50 we have plotted the plate voltage against the one over 2.25 power of the plate current and found that the relation is linear. We find that a straight line can be drawn through such points, which indicates, which means, that the tube follows the relation, over this range of data, I_B equal E_B to the 2.25 power.

Q. 85. Does singing occur in repeaters using high vacuum audions?

A. Oh, yes, indeed, it does.

Q. 86. How can such singing be remedied?

A. It is remedied by decreasing the gain of the repeater to the point where singing does not occur.

Q. 87. And how may that decrease of gain be effected?

A. It is effected by decreasing the amplification in the repeating elements. That may be done in a number of ways. A very effective way is decreasing the plate voltage.

Q. 88. You have testified about a number of tubes which have the exponent 2.25 instead of 1.5. Is there any generality in this exponent 2.25 as compared with 3/2?

A. No, there is not.

Q. 89. What is the range of such exponents in practical tubes?

A. In practical tubes over their operating range of plate voltages the exponent which best fits does vary from 1.5 approximately to 2.5 approximately.

The Court: Will you please read the preceding question and answer?

(Q. 88. was repeated by the stenographer.)

The Court: What I was wondering there and what constituted the basis of my inquiry yesterday, was the fact that the 2.25 or 9/4 seems to be the square of 3/2 and I was wondering whether you were trying to bring that out from the previous question.

Mr. Richmond: It has absolutely no significance. It is just an accident.

By Mr. Richmond:

Q. 90. Dr. Kelly, can you refer to some example to illustrate a variety in these exponents?

A. We have shown a number with an exponent of 2.25 and we believe, or I know that on this plot of data for three tubes which was introduced in evidence yesterday——

Q. 91. I think that was not introduced, Dr. Kelly.

A. I beg your pardon.

Q. 92. You can say it was referred to.

A. Which was referred to yesterday the relation for one of those tubes, UV-201-A was found and that was given on Exhibit 50, and the 2.25 was the exponent there. The other two tubes that were given are the UV-199 and the UV-201. Obviously from the data they have a different slope than that of the UV-201-A. I know that the exponent of E_B that best fits the data for the UV-199 given there, is approximately 1.75 and for the UV-201 as given there, it is approximately 1.5.

Mr. Richmond: The diagram referred to by the witness is offered in evidence as page 591 of Warner article in the proceedings of Radio Engineers, showing curves for UV-199, 201, and 201-A.

(Received in evidence and marked "Defendant's Exhibit No. 60." *See Volume VI, Defendant's Exhibits, page 656.)*

Mr. Richmond: Let me add that the publication in which this diagram appears is the number of the Proceedings dated December, 1923, Volume 11, page 6.

The Court: Of what, Mr. Richmond?

Mr. Richmond: Of the Proceedings of the Institute of Radio Engineers.

Q. 93. Now, you have shown that the best fit is obtained for certain tubes by plotting them to the exponent 2.25. Can you show us any examples to show

how the same data would appear in an attempt to fit them to the exponent 3/2?

A. Yes, I can. I have selected the tube given in Exhibit No. 52; that is, tube X-9399, which was approximate duplicate of Arnold Exhibit No. 32 and have plotted for the same data on which the plot Exhibit 52 was made, the plate voltage against the plate current to the 2/3 power. Here they are (indicating). I think, your Honor, in looking at that, that I might call your attention to the Exhibit No. 52, which is the one over 2.25 power of the current against the voltage, this being a plot of the same data in both cases, but to a different exponent. You will note on the plot the departure from the straight line on both tubes in the case of 2/3 over approximately one-half the voltage range, while over the entire voltage range of the plot on Exhibit 52, the linear relation is exhibited.

Mr. Richmond: The blueprint just produced by the witness is offered in evidence as "Kelly Diagram for Arnold Priority Exhibit No. 32 and the approximate duplicate tube plotted for the exponent 3/2, or its inverse."

The Court: If it is at all important, Mr. Richmond, I am sorry not to be able to follow without help, but I am lost here, so that if that does not make any difference, do not stop.

Mr. Richmond: No, I am glad to have you ask, Judge.

The Court: I have gotten away from these charts which we had three weeks ago and I have lost it already in a way. I am not sure that I appreciate the significance of the departure from the straight line of the beginning of the circular markings, that is, with respect to tube L-9399 and the square markings of tube 105.

Mr. Richmond: That departure in so far as it is a departure, shows a departure from the 3/2 power law, because of this——

The Court: Does the straight line here indicate the operation of the 3/2 law?

Mr. Richmond: It does.

The Court: All the way to the base line?

Mr. Richmond: Yes.

The Court: Then I understand.

Mr. Richmond: And if you compare that with Exhibit 52, you will see there is no such departure there, and that makes the conformity to the other exponent quite clear.

The Court: I think my memory is now refreshed vaguely.

Mr. Richmond: You understand, your Honor, that it is the straightness of the line that proves the condition.

The Court: Yes, I think I have that, but I lost sight of that fact you have just mentioned.

(Received in evidence and marked "Defendant's Exhibit No. 61." *See Volume VI, Defendant's Exhibit, page 657.*)

Q. 94. From your experience, is the existence of the 3/2 power relation between plate current and plate voltage in a vacuum device a reliable proof that the tube is operating as a pure electron device?

A. It is not. In fact, I have shown here tubes with considerable gas pressure, I mean data of tubes with considerable gas pressure, in which the 3/2 power relation is followed.

Q. 95. From your experience is the existence of a relation substantially different from 3/2 power a reliable proof that there is gas ionization present in a tube?

A. Indeed it is not.

Q. 96. What is the significance of absence of blue haze or presence of blue haze in a Wehnelt oxid coated filament tube after it has been in service?

A. If a tube with the Wehnelt type of filament does not develop blue haze in its operation that is very good evidence that occluded gases from the filament, the glass bulb and from the metal parts have been well gotten out by a high temperature treatment. On the other hand, if a vacuum tube with a Wehnelt oxid type of filament develops blue haze in its operation that is not an indication that the tube had not been exhausted in such a way as to free the glass, the filament and the metal parts from gas by proper treatment.

Q. 97. Can you give a reason for the last statement that the presence of gas is not an indication of the failure to give the tube proper treatment?

A. The reason for that statement is that gases may appear during the operation due to chemical changes in the filament which gases were not occluded in the filament. These gases so liberated may or may not be cleaned up in the further operation of the tube. If they are cleaned up blue haze will not develop. If they are not cleaned up the presure in the bulb will increase and blue haze may result.

Mr. Richmond: Direct examination closed.

CROSS-EXAMINATION.

By Mr. Davis:

XQ. 98. You have testified to considerable experience with the ionization manometer?

A. Yes, sir, I did.

XQ. 99. Is your experience with that manometer that it is reliable and accurate?

A. It is.

XQ. 100. I suppose that you have made a study of the various probable sources of error?

A. I am familiar with the sources of error and I have seen data dealing with that. I must say that I myself have not made a detailed study directly of the sources of error that are involved.

XQ. 101. Such study has been made?

A. Oh, yes, in many places.

XQ. 102. And you are familiar with the results in a general way?

A. In a general way I am familiar with the results, yes, sir.

XQ. 103. What if any error exists in this device due to recombination in the tube?

A. If recombination occurred it would of course decrease the number of gas ions that were formed by the process of ionization. However, in the pressure range in which the device was used in this particular evidence here, the chances of recombination are very small and the errors resulting would be very small.

XQ. 104. That was the basis for the statement you made yesterday that all ions formed will be collected?

A. That was the basis, of course. By all I meant substantially all or nearly enough all, that the device was usable for the purpose that I used it.

XQ. 105. You mean that while recombination might theoretically occur it was negligible on the circumstances of your test?

A. Yes, sir.

XQ. 106. Will you please explain to his Honor what recombination is so that we may have the matter clear?

A. The molecule of gas is ionized, an electron is liberated from it and there is formed a positive ion with that molecule or ion having a unit of positive charge. If it should happen before that ionized atom or molecule is picked up and counted that it collides with another electron it then becomes a neutral atom all over again and would not be counted.

By The Court:

Q. 107. It is the restoration to balance that you call recombination?

A. Yes, that is it.

The Court: Is there any such thing as a negative ion by reason of an extra electron becoming attached to it?

Mr. Davis: I understand there is. I was just coming to that.

The Court: Do not let me anticipate that.

Mr. Davis: I was going to ask the witness whether that phenomenon ever occurred in the tube, the formation of negative carriers due to a combination of electrons with neutral molecules, for example.

The Witness: Oh, yes, that is a well-known phenomenon in the electron physics realm.

By Mr. Davis:

XQ. 108. Is that a source of error?

A. Not of any moment for the purpose for which it was made.

XQ. 109. And these considerations we are discussing are rather the theoretical than the practical?

A. At the pressures at which they were made, yes. In so far as they affected the results and being off 10 per cent. or 15 per cent. or any figure of that order, and if they were off by that amount it would have no bearing on the value of the pressures indicated.

XQ. 110. Now, this test with the manometer when it is applied to a tube which is already sealed up and of which the characteristics are not definitely known, has the disadvantage that you should reproduce that tube?

A. That is correct when you want to get the pressure, when you are using it as a manometer, your statement is correct when you are using the tube as a manometer in order to determine the pressure in some pressure unit.

XQ. 111. The ordinary use of this manometer, as I understand it, is to connect it to the air pump, carefully calibrate it, and leave it there and in that way you get accurate results; is that right?

A. One connects it to the apparatus whose pressure they desire to follow and throughout the experiment it is left attached to the apparatus.

XQ. 112. And it was calibrated in the first instance by reference to the McLeod gauge or some other known gauge?

A. Yes, that is done. I believe that the first, as well as I remember the article now, the first calibration in the literature of such a tube for manometer measurement were made against a Knudsen gauge. But I am not certain that that is there, at least you have to do that at some time.

XQ. 113. Do you agree with this statement, and I will tell you that it was made by Dr. Millikan on page 848 of the Interference record which would be page 380 of Arnold's rebuttal testimony on motion:

> "I should agree with Dr. Langmuir, and with everyone else who has testified in this case, that an abnormally rapid rise in the volt ampere characteristic in the space charge region is an indication of positive ions. On a logarithmic volt ampere curve, such a rise will appear as an increase in slope. It is quite justifiable therefore, to infer from Exhibit 17 that in this case a considerable amount of positive ionization was occurring in the region above 15 or 20 volts, and this wholly independently of whether the curve was following the 3/2 power below 20 volts or not."

A. Where is Exhibit 17?

XQ. 114. I am looking for it, Doctor.

A. Pardon me.

XQ. 115. Exhibit 17 is on page 1123 of the same record, being page 117 of Langmuir's record on motion.

A. Well, I only partially agree with him. I would like to go into that just a bit. With the background that I have for a basis of judgment, and that is all that one can have for a basis of judgment, I know so many things that can affect a particular volt ampere characteristic, given a particular volt ampere characteristic and nothing else, that I would not lay great stress or great value to the opinion that I have based on an analysis of that, that is, I would not be willing to say that any one factor was the one which was doing it and the others were not. That is why I said yesterday that I did not use at all such information to tell me about the vacuum condition of a device.

XQ. 116. Will you tell me what other factors might in your judgment cause the departure which is shown on this Exhibit 17?

A. Of course, Mr. Davis, I would need to know a good deal more than this plot, but just looking on this plot I see that you have anode volts against anode milliamperes on a log scale, and seeing that it departs somewhere—I should say that one of the causes of that particular departure could well be ionization and that in this particular case the departure is so pronounced whether one looks at the lower part or the linear part that it might well be gas, but I would not lay great weight on my opinion about it, because I do not think that you can give opinions that are worth a great deal from just this information.

XQ. 117. On the next page is plotted not the log plot but the direct plot of volts against amperes, is it not?

A. Yes.

XQ. 118. That also shows a rise?

A. Yes, one of them showed a rise and if you have it in one, you have it in the other, and you have it at any power that you might plot those two relations on.

XQ. 119. That is a typical gas rise, is it not?

A. That is the kind of a rise that might be due to gas, yes.

XQ. 120. Do you agree with the statement which I understand Dr. Millikan to make in this record, that one good test is to measure the current, and then increase the vacuum and see whether the current changes?

A. I think that is a splendid test, when it can be applied. When the person who is applying it takes care of all of the other conditions. If there is no other variable present than the decreasing pressure, the data that is obtained, is fine for the purpose.

XQ. 121. You have no suggestion of any other cause, to go back for a moment to this Langmuir plot we were discussing a moment ago—you have not any suggestion of any other thing that would make that particular kind of a rise, except the gas, have you?

A. Well, I would want to look at it a good while to give a very confirmed opinion, as low as that voltage is, and the magnitude that is shown, I would say that for this particular tube, if I was forced to hazard on it, I would hazard that it was more likely due to gas than any one of the other things from the amount that I have looked at.

XQ. 122. Then, is not perhaps this a correct statement, Doctor, that you agree with Dr. Millikan's statement as I read it to you with the reservation that to your mind all these things are very complex and unexpected factors met in there at some time, and that no generality is perhaps absolutely true?

A. I would prefer to put it this way: That there are a number of factors which contribute to the exact shape of the volt ampere characteristic, and I believe when I attempt to hazard an opinion about what it is due to, simply having the volt ampere characteristic before me, that it is speculation of questionable value.

XQ. 123. I would like to go back a moment to this plot, which was Langmuir 17 in the Interference record, on page 1123 of the record. Now, if you wish to study the characteristics of a tube as they would be in the absence of ionization, and do not know whether or not ionization can take place in the tube in substantial quantity, that is, you do not know whether there is gas in the tube in substantial quantity, there is one part of the characteristic of the tube which you nevertheless can study, without ionization, is there not, namely, the part of the tube below ionization voltages?

A. Oh, that is correct if you keep your voltage below ionization voltage; there is no ionization.

XQ. 124-25. So that referring again to this plot, the points on the curve which are taken at two volts, at three volts, and four volts, and five volts, and six volts, and so on up, to say ten volts, are points which were determined in the absence of ionization, it does not matter how much gas there was in the tube within reason, is not that true?

A. Yes, that is certainly true, below ionization voltage.

XQ. 126. Now then, let us go to twenty volts for a moment. You notice that the line, whether or not there is a reason for it, you notice that the line obtained above plots from zero, plots to ten volts, is a straight line, is it not?

A. Yes, that is a straight line, that looks as if it is a straight line.

XQ. 127. And the points are fairly on that line?

A. Yes.

XQ. 128. Now then, if we indulge the assumption that in the absence of ionization that line would continue to be straight a little longer, let us say up to twenty volts, and if we read the current off that straight line at twenty volts, what figure do we get?

A. At twenty volts, that is about—the current on the line is about 8.2 milliamperes, I should say.

XQ. 129. Then, what is the actual current as shown by the line drawn through these actually observed points?

A. It is twenty milliamperes.

XQ. 130. And the difference——

A. It is approximately twelve.

XQ. 131. Call it twelve milliamperes difference?

A. Yes.

XQ. 131a. Having obtained that reading on this particular tube of twenty milliamperes, and knowing that if the tube had followed the straight line determined by the lower points, it would have been eight milliamperes, we conclude, do we not, with some justification, that if we should take all the gas out of that tube, that twenty milliamperes reading would drop to eight?

A. If that increase were due to gas in this particular case, I think from looking at the data, and seeing the statement that there was mercury vapor in it on the plot, and I think it was due to gas, you would certainly get around eight milliamperes when you pumped out, if no other condition had been changed than the vacuum condition, if the only thing you had done was to pump out the mercury vapor.

XQ. 132. Of course, if in pumping it out we disturb the relation part of the tube, or something of that sort?

A. Or the activity of the filament or contact potential relation between elements or any of the other things that vary the volt ampere characteristics.

XQ. 133. I am assuming we could pump it out without doing those things, because if we do not make that assumption, I do not see what Dr. Millikan's test is good for, do you?

A. Of course, I did not read the whole thing. I am not confining myself to that——

Mr. Richmond: I object to that. It seems to me we are going more deeply into the analysis of Dr. Millikan's testimony than this witness has done.

Mr. Davis: The witness has approved one of Dr. Millikan's tests as the best possible test when it could be applied. I have a right to cross-examine on that.

The Court: I do not quite see the impropriety of the question, Mr. Richmond. If the witness is unable to answer, or has not had the experience which enables him to answer, that is one thing, and he may say that at any time, of course, but I do not see that it is an unfair method of obtaining the facts by making the reference to Dr. Millikan, made by Mr. Davis.

Mr. Richmond: May I ask to have the question read again?

(XQ. 133 repeated as recorded.)

The Witness: Cancel that answer up to there. Surely Dr. Millikan's statement that that was a good test was undoubtedly presupposed on the fact that we only had one variable present, and that was the amount of gas there; but the point I am trying to make, Mr. Davis, is, when you do not know that the conditions of the experiment are such that there has only been that one variable there, that in making any speculation about it, I want to take care of such factors in the special relation.

XQ. 134. You have not answered a previous question of mine because we diverted ourselves on to this other discussion.

A. Right.

XQ. 135. Then really we have succeeded in performing Dr. Millikan's test without opening the tube, have we not?

A. No. I do not see that we have.

XQ. 136. You do not think so?

A. No. I agree that in a very gross case like this, and with the statement as to all the conditions surrounding it, that a very good inference, if all the information here was available, and apparently the correct one was that that rise was due to gas, but I should not want to generalize from that.

XQ. 137. In using this ionization manometer you said the anode was plus 100 volts and the plate at minus ten?

A. That is correct.

XQ. 138. What was the electron current to the grid?

A. When we were working with Arnold Exhibit 30, the electron current to the grid was 1.6 milliamperes for the readings on which we made computations of pressure.

XQ. 139. What would be the positive current, the ion current flowing to the plate for a pressure of one micron?

A. I would have to figure that out for you. Let me see—oh, approximately 10 micro amperes, if I have not made any error in computation.

XQ. 140. What would the figure be if you used the standard ionization manometer?

A. Our standard ionization manometer, as we use it for convenience, we have an electron current of 20 milliamperes, and for a pressure of one-hundredth of a micron, the pressure of one-hundredth of a micron we have two micro amperes, so for a pressure for 100 times that——

XQ. 141. Two micro amperes?

A. Two micro amperes, yes. A pressure of 100 times that would be 200 micro amperes, would it not?

XQ. 142. In using the duplicate of Exhibit 30, that is the tube which you made up resembling Exhibit 30, you used 100 volts on the grid and ten volts negative on the plate?

A. That is correct.

XQ. 143. And what was the electron current to grid?

A. When?

XQ. 144. Give it to me at some reasonably useful point on the curve. Say at 100 volts.

A. I would like to say that in the calibration of this approximate duplicate, as I have called it, we first found the manometer constant for the approximate duplicate with a twenty milliampere electron current just as we had twenty milliampere electron current in our standard manometer, over quite a range of pressure in order to get a good average value for the constant. That was done more as a matter of convenience than necessity and that made it necessary to do the calibration in two steps, and having the constant for the approximate duplicate at twenty milliampere current, the next problem was to get its constant at 1.6 milliampere current, because as is well known, the relation between electron current and gas current in a given manometer at a given pressure over a wide range of electron currents is not necessarily linear so that the second step in the experiment was to hold the pressure constant at some value and that pressure was checked during the experiment with a standard ionization manometer and to vary the electron flow in the approximate duplicate from twenty milliamperes down to a current considerably less than 1.6 milliamperes to get a plot of that relation and thus be able to convert the constant for the approximate duplicate of twenty milliamperes to its constant of 1.6 milliamperes or for any other current. I may say that that is all experimental and based on nothing else than the facts that are before you and I may say also that the shape of these curves that we obtained were in conformity with relations that are generally known to hold.

XQ. 145. What was the figure of the first constant that you thus obtained?

A. With twenty milliamperes in the approximate duplicate tube the constant is .010. Of course we have to say some more about that and I will do that; that is, when the pressure is to be measured in microns and when the gas current is measured in microamperes, if you multiply the .010 by the gas current in microamperes you will get the pressure in microns.

XQ. 146. That was the factor in the first case. Now, what is the second factor?

A. The second factor for 1.6 milliamperes, the factor is of the same sort as .10.

XQ. 147. .10?

A. Yes, the relation is not exactly linear over that wide range. If it were linear the constant would be about 20 or 30 per cent. different.

XQ. 148. Which end of the filament was connected to the B-battery?

A. The negative end.

XQ. 149. Looking now at Defendant's Exhibit 48, what do these figures mean along the bottom, are those volts?

A. The figures along the bottom are the plate potential measured from the negative end of the filament in volts.

XQ. 150. And the figures in the vertical row on the left-hand side up to 12 are currents to the 1 over 2.25 power but in what units?

A. I will have to go back to my original work to tell you that and that is the reason that I gave the initial data to Dr. Langmuir. I varied the units in order to handle logarithms conveniently. In order to get the 1 over 2.25 power you divide the logarithm of each of these currents by 2.25 and that takes the 2.25 root and then you look that up and in order to handle my logarithms most easily I shifted my decimal place for a given lot of data but shifted it the same amount for the entire lot, so that I could not say from what we have here just what the unit is. It is quite a laborious job to do all of this, and I did them in as convenient a way as I could find.

XQ. 151. In one or two of these sheets you speak, for instance, of 53, you say Arnold A-911. That is intended to be 9.111, is it not?

A. That is an error. There should be an additional one there. I am sorry. Yes, the data that that was taken from had that designation in the exhibit book as it was given to me, in copying it one of the ones was omitted. It was omitted on plot 53, and not on plot 54.

XQ. 152. When were these manometer tests made on Exhibits 30 and 32?

A. They were made some time in September, latter part of September of this year.

XQ. 153. You were speaking of your reproduction of 30 and you called attention to the fact that the plate of 30 was somewhat warped and said that that difference due to the warping was negligible or unimportant; is that right?

A. As I remember it, I emphasized more the warping of the grid than the plate on that exhibit.

XQ. 154. Very likely it was the grid.

A. What I said was that it was warped, or what I meant to say was that it was warped and that we could not follow its undulations exactly but that we did attempt to make the grid plate spacing the average of the plate and the grid in Exhibit 30.

XQ. 155. Now, I call your attention to some curves which are in evidence here in Arnold Priority Exhibit curve E. S. 86,907 and 86,908, and state to you that all of these curves on these two sheets are said to be curves taken on the same tube but at different exhausts. Do you think that the differences in those curves, and I am speaking only of the rising straight part of the curves, are such as could be explained by an accidental warping of the plate during the exhaust assuming that they were exhausted between those readings?

A. All of the curves on each of the sheets——

Mr. Richmond: May I have the question read?

(XQ. 155 was repeated by the stenographer.)

Mr. Richmond: The statement of the question is not correct.

Mr. Davis: In what respect?

Mr. Richmond: There is at least one other tube——

The Court: Is it 19?

Mr. Davis: I beg your pardon. I would like to correct the question.

XQ. 156. Will you please disregard the curve of D-19 of 86,907?

Mr. Richmond: Then I think he ought to disregard the one at the bottom.

Mr. Davis: All right.

XQ. 157. Please make the comparison between the curve of audion 20 which actually is 20.2 on E. S. 86,907, the lower curve also marked audion 20 on the same curve and E. S. 86,908, the curve of the audion 20.3, which is the curve that goes up the straightest, then the curve of 20.3, which is that dotted line collection of curves in the middle. It is all one exhaust. At the moment I do not know what that lower curve is, so please disregard it. You have that curve in three different exhausts.

A. Now, as I understand it, this is in 908 that this dotted curve is the same tube as that one.

XQ. 158. Yes.

By The Court:

Q. 159. That is the same tube as this one, you mean the one which is charted on the near left-hand margin?

A. Yes, the one charted on the near left-hand margin.

By Mr. Davis:

XQ. 160. But at different exhausts and different vacuum conditions. You will note that the one on the left-hand is exhausted on a mercury pump and the one to the right, the dotted one is exhausted on a molecular pump.

A. While I have difficulty in expressing an opinion between the two tubes, when there is as big a divergence as there is in the data of two different runs on the substantially same tube, I do not know what the records are as to how these tests were made, but I would have difficulty in reconciling this test, that is, the test with the dotted lines on E.S. 86,908, with the test with the solid lines.

XQ. 161. Which is the one on the mercury pump?

A. Yes, as the conditions under which the two tests were made ought to be known to me before I can make any sort of an analysis of what I think has happened. It looks as if the one on the left-hand side saturated at quite a low voltage and the one on the right saturated at a considerably higher voltage. That difference might be explained by a difference in electrical connection. If it was the identical tube the curve to the left might be with the grid and plate together because the tube has a very much lower impedance, when the grid and plate are connected together than when the grid is tied to the filament. That might be an explanation. Is anything known as to the conditions of the two experiments?

XQ. 162. Nothing is known to me.

A. I may say that I do not know anything about these curves at all and I have not even looked at them. I heard a bit of this in Dr. Arnold's testimony but I did not follow it because I did not have the sheets at hand.

XQ. 163. I want to make one or two things very clear. May we each of us take a piece of paper and write down a few simple things. I wonder if I could ask his Honor, Judge Morris, to do the same.

The Court: I will be glad to do so.

XQ. 164. Write down $I=KE^{3/2}$.

A. Yes, sir.

XQ. 165. I just want you to show the Court how that is transformed into the 2/3 power law. The first thing to do is to take the cube root of it.

A. I would say take the 2/3 root of it.

XQ. 166. Let us go a little slower than that.

A. All right. You can first take the cube root.

XQ. 167. Then we will have I to the 1/3 power, which is the cube root of I is equal to K times E to the ½ power, or $I^{1/3}=KE^{1/2}$.

A. You will either have to invent a new K——

XQ. 168. We will put a K^1 there to show that it is a different constant.

A. That is all right if you put a prime.

XQ. 169. A constant is a constant and you can take all the roots you please as long as you assign a new name to the constant.

A. That is right.

XQ. 170. Now we will square both sides of this equation.

A. Yes.

XQ. 171. We have I to the 2/3 power, which is equal to K double prime times E, or $I^{2/3}=K^{11}E$.

A. That is correct.

XQ. 172. And that is the derivation of this 2/3 power law which you spoke of in your testimony?

A. That is the transformation that was referred to in the patent in issue and I spoke of it.

XQ. 173. And in your view it is equivalent?

A. It is equivalent mathematically, yes, and every other way, I suppose.

XQ. 174. Let us go back to I is equal to K and we will put a parenthesis there, and we say E with a little b under it plus nEg and that is the end of the parenthesis and we put a 3/2 power outside of the parenthesis. $I=K(E_b+nEg)^{3/2}$. That is, it is the same thing that we had before, excepting that in place of E in our first equation we put in this more complex expression E_b plus nEg?

A. That is correct.

XQ. 175. That is because there are two currents flowing in the tube?

A. No.

XQ. 176. Or may be?

A. No.

XQ. 177. Why is it, what is the explanation of the substitution of E_b plus nEg for E?

A. Without additional knowledge of the equation, I would say that it indicates that there are two electrodes other than the cathode in the device in question.

XQ. 178. That is the form which the equation takes if you wish to consider a three-electrode tube, is that right?

A. It takes that form and you may put the exponent 3/2 there if you choose.

XQ. 179. Let us not at the moment quarrel about exponents. Let us put N in place of 3/2.

A. All right. N is a general thing and we can agree on that.

XQ. 180. What I am trying to make perfectly clear, and I think it is outrageous to ask the Court to follow these mathematical formulæ, but this last expression I equals K E_B plus nEg to the Nth power, $I=K(E_B+nEg)n$ is the form which the first equation takes when we are dealing with the three-electrode tube, is that right?

A. That is right, when you properly define your Eg and your N.

XQ. 181. I was coming to that. Your E_b is what?

A. That is the potential between the anode or plate and some point on the filament, and it is pretty generally accepted now that we use the negative end of the filament.

XQ. 182. It is the first approximation of the voltage between the plate and filament?

A. Speaking roughly, that is true.

XQ. 183. And E_g is the voltage between the plate and the grid?

A. It is the total voltage——

XQ. 184. I beg your pardon, between the cathode and the grid?

A. Between some point on the cathode and the grid.

XQ. 185. And if you were for the moment assuming that the cathode is all at the same voltage then we could say simply is the voltage between the cathode?

A. Yes.

XQ. 186. This n is what?

A. That n is a factor which has been called the amplification factor and as a matter of fact as stated most simply it is a number expressing the relative effect of a volt on the grid and a volt on the plate.

XQ. 187. The grid is nearer to the cathode than the plate is, is it not?

A. Yes.

XQ. 188. And that n has something to do with that?

A. That is right, and I may say that in your simple relations here you are using that n as a constant, Mr. Davis, and as a matter of fact, it is not a constant.

XQ. 189. You explained that yesterday, Doctor——

A. Being very simple for the time being, we will talk about it as a constant, yes.

XQ. 190. Because we must begin somewhere, must we not?

A. That is right.

XQ. 191. As a practical matter, this equation that I have read to you is an awkward thing to handle on account of this E_b and nEg being inside parentheses with an exponent to them, so in order to work with it, you have transformed it in just the same way into this simple equation, which was the first transformed this morning, and you get I_B is equal to $K(E_B)$ plus U E_g—I beg your pardon, that is what we started with—I do not find that you carried that through, Doctor, but if you do carry it through, it would be I to the 1 over the Nth power, to use your general expression is equal to K(E_B plus nEg), is that right? Or $I^{\frac{1}{n}}=K(E_b+nEg)$.

A. I_B, yes, the K being a new K again.

XQ. 191a. I suppose the K is a new K. And that is the basis exclusively, or implicitly, of these plots which you made, is it not?

A. That is correct.

XQ. 192. It is simply putting the more complex equation of the three-electrode tube into a form where it can be more readily handled, as I understand it. Now, in that equation, if we assume that E_g is equal to zero, we then get I to some power?

A. I^N one over N.

XQ. 193. Which is equal to K times E sub b, do we not? $I^N = KE_b$.

A. That is correct.

XQ. 194. That is the term nEg vanishes?

A. That vanishes because we are still talking of an equi-potential cathode.

XQ. 195. Yes, we must, I think, for simplicity, but it is clear to your Honor why that term vanishes?

THE COURT: I think so.

XQ. 196. So that now in such an equation as that, if we assume that the electromotive force E_b is zero, what does the current I become?

A. It becomes zero.

XQ. 197. Then, whenever you plot a curve of this character, as far as your mathematics go, the curve must pass through the origin of co-ordinates, must it not, so far as these mathematics are concerned?

A. Yes, so far as these mathematics are concerned, if E_b is zero, I_B has to be zero.

XQ. 198. Will you be kind enough to look at your Exhibit 53, which is the plot of the tube 9.111?

A. Yes.

MR. DAVIS: Will you show that to the Court?

XQ. 199. This curve, the more upright of the two, the curve of the tube 9.111, does pass through zero, does it, as you have drawn it?

A. No, it does not.

XQ. 200. Where would zero be on this plot?

A. The zero of E_b would be two of the larger squares to the left of 10, and zero of I_B would be two points down from the intersection of those two lines, in other words, the zero zero of these co-ordinates.

XQ. 201. Is it not one point down?

A. Well, two of the large squares, see.

XQ. 202. The zero so far as the horizontal location is concerned, would be on the very lowest line of the plot, would it not?

A. The zero, so far as volts are concerned, could be anywhere in this line.

THE COURT: In the vertical line?

THE WITNESS: Yes, that is this line here, specifies the condition that E_b is equal to the zero.

XQ. 203. The horizontal black line?

A. The vertical white line specifies the condition of E_b equals zero.

XQ. 204. What is the condition with the current equal to zero?

A. The current I_B equals to zero is specified by the two squares below the intersection of the two white lines.

XQ. 205. That is to say, if we should draw that line, the vertical white line, and continue it down to the bottom of the markings on the curve sheet, the bottom of the little squares, the last one as shown at that point of intersection, would be the zero, would it not?

A. That is correct.

XQ. 206. So that the condition which mathematically appears to be specified in this tube, would call for the characteristic curve of the tube passing through that point?

A. If this tube was the kind of a device you have been talking about, that is correct.

XQ. 207. Now then, if you should draw a curve from that point, the zero point, and it should pass through the first of the points shown by the dotted circles, and to the second one, it would be a fairly straight line, would it not?

A. Yes, that would be a reasonably good straight line.

XQ. 208. Then what is the basis for your statement made yesterday, that you had no theory on which you could account for the position of that lower dotted circle, except the theory that a mistake had been made in the reading of an instrument?

The Court: Except what——

Mr. Davis: That a mistake had been made in the reading of an instrument.

A. Mr. Davis, you have gone a long way in trying to draw that line through the origin from the simple mathematics that we have been doing together.

XQ. 209. Your mathematics lead directly to the proposition that the line must pass through the origin?

A. It does not in this particular device. I agreed in these mathematics that we would say the filament was equi-potential, and as I intended to state yesterday, that is not true, so far as I know, in any present commercial device.

XQ. 210. It is your own formula, Doctor. If you take the formula of this Exhibit 53 just as you have written it, and let E_c equal zero, you get exactly the same result; you get an equation which is only satisfied if I is zero and E is zero; is not that true?

A. That is true, and I wish to say although that is true, that has not any bearing at all on this point.

(After a short recess.)

XQ. 211. I suppose as a matter of fact, Doctor, that in order to be complete, you would have to have one more little term in that equation, would not you?

A. Well, if we go any further than the distance that I want with that equation, taking that factor as it was, after you have taken the N through, that is a good factor as a constant, then we have to go into the thing pretty deeply, and when we have the inference—I do not want to say something I should not, but the question that you asked me as to the straight line that can be drawn between the origin and the first two points, as I see it, has not any bearing.

XQ. 212. If the cathode is an equi-potential surface, if there is no contact voltage, and no other disturbing factor than the curve will pass through the origin?

A. The curve will pass through the origin only with the boundary conditions of derivation, yes, and among these are the ones you mention. Another is no initial velocity. With initial velocities, the current will flow to the anode.

XQ. 213. You might make that clear that the electrons boil out of the cathode, just as molecules of water boil out of a tea-kettle, when you have it on a stove; is that right?

A. That is frequently used as a picture, and I think it is a good one.

XQ. 214. And of course if they boil out, they must have a certain velocity as they come out?

The Court: I thought you were going into the other phase. One of the things I wanted to ask is this, eliminating your A battery entirely, and put a voltage of say 135 volts on your plate, do you get any current from the cathode?

XQ. 215. How is that, Doctor, cold filament, you have 135 volts B battery with no voltage on the filament; do you get any current at all?

A. Not unless there is leakage across the electrodes that is, across the insulator, the glass between the electrodes.

The Court: The outside voltage. Won't you read me the previous part, Mr. Smart?

(Previous part of record repeated by the stenographer.)

The Witness: Without the B battery—if there were initial velocities.

The Court: I understand.

The Witness: With the plate voltage at zero, if the electrons had initial velocities, the current would not be zero, and you understand when we speak of the plate voltage being zero, we do not mean that the plate is disconnected from some point of the filament, but there is no battery in the circuit if the current is to flow there must be a metallic——

The Court: I misunderstood your previous answer. I thought you were saying electrons would flow, even though the filament were at room temperature.

The Witness: No.

The Court: If the voltage on the plate were sufficient.

The Witness: If the voltage on the plate is zero, and electrons coming out with initial velocities, there would be some flow of current to the plate.

Mr. Davis: I think perhaps your Honor's recollection may be refreshed if I show you this plot of a very low current from Richardson's deposition, page 44. This was a photo-electric tube. This tube was saturated with zero voltage and that was on account of the initial velocity, was it not?

The Witness: I do not know of that experiment. I should have to look at it.

Mr. Davis: If that statement is wrong, it can be corrected later.

XQ. 216. That is to say, Doctor, if these electrons come out, the only thing that lets them come out is the fact they have a velocity, is it not?

A. I think that is the reasonable statement of it, yes. Yes, at a certain amount of energy, it can get across a certain boundary condition because of that energy.

XQ. 217. And some will have perhaps enough to come out and drop dead, and some will have a little more; is that it?

A. That is right.

XQ. 218. So that if there were no other factor present, a small current would flow in the tube with no B-battery whatever; that is right, is it, Doctor?

A. Yes, that is right.

XQ. 219. But if you have no A-battery then you are so far down on Richardson's emission curve that as a practical matter, you get no current at all; is that correct?

A. That is correct.

THE COURT: Regardless of the strength of the B-battery?

XQ. 219a. Regardless of the strength of the B-battery?

A. That is correct.

XQ. 220. Now, to take the mathematics of it in order that the line, whether it be a 3/2 power or any other line, may pass through to the right or the left of the origin, there must be a third term in that equation, must not there, at least?

A. Oh, yes, there is a constant term which gives the intercept on that line.

XQ. 221. A constant term which gives the intercept and by intercept I understand you to mean the distance from the axis or from the point of origin at which those lines intercept the axis?

A. Yes.

XQ. 222. So that we have an equation like this: I to the 1 over N power is equal to K parenthesis E_b plus nEg plus D, which D represents some voltage somewhere in that circuit.

$$I^{\frac{1}{n}} = K\,(E_b + nEg + D)$$

D may not be a simple thing, but I mean that would give us an expression which would allow that line to miss the origin; is that right?

A. You will have to insert that D in that equation if you are going to erase the nEg in order to get the intercept; that is correct.

XQ. 223. You say in general, I understand you to say in general that there is an intercept?

A. Yes.

XQ. 224. Do you agree with me to this extent, that considering the pure phenomena there is no intercept, the intercept only comes when you come to talk about modifying the phenomena?

A. The intercept only comes when you begin to talk about things that differ from the original conditions of the derivation.

XQ. 225. And when you do have an intercept you are obliged to account for it, are you not?

A. Oh, yes.

XQ. 226. For instance, in the case which we have been discussing on Exhibit 53, the curve of A-9:111, the intercept is thirty volts, is it not?

A. Well, the intercept is actually about twenty-five, is it not, because that white horizontal line is not the real axis.

XQ. 227. I beg your pardon. It is somewhere a little above twenty-five, is it not?

A. Yes. I would have to lay a straight line on that. It is around twenty-five.

XQ. 228. Now, you have spoken of contact potentials. I do not want to go into the cause of contact potentials, because I understand it is very obscure, but will you tell us how a contact potential acts in the tube? Is it true that it acts as though there was little voltage on the grid that you have been looking at?

A. The contact potential when spoken of has to be specified between two things, and if we are speaking about a contact potential between the filament and grid then it is an inherent potential, which is present that acts like a battery that might be interposed outside of the tube of equal value.

XQ. 229. It acts like a C battery?

A. That is correct.

XQ. 230. And that is due to some chemical action that we need not trouble about here; is that correct?

A. I do not see that we need to know if we recognize that it is there and also that it is not a constant.

XQ. 231. Now, I would like to discuss for a moment this 3/2 power law and the law I equals Ke to the 2.25 power which law I understand, this latter law, I understand you prefer. What is the rational basis——

A. If I can comment on your remarks, I would like to say that the statement that I prefer that law is not correct.

XQ. 232. What is your attitude toward it?

A. My attitude is that over the operating range of plate voltage of the practical thermionic devices, that the relation between the plate current and the plate voltage is expressible as I_B equals some constant times the plate voltage to some power. For any particular device, the value of that power may lie between 1.5 and 2.5 approximately and that is for very good and well known reasons.

XQ. 233. You do not take the position then that in general on practical tubes the law I equals Ke to the 2.25 power is a better and more representative law than I equals Ke to the 3/2 power?

A. Indeed I do not. I do not want it to be the impression that I think there is anything unique about 2.25. I would like to state that I have taken certain devices that were exhibits here and found that the best exponents for showing the relation between the plate voltage and plate current is the 2.25 power. I have also measured by an unquestionably sound method the vacuum condition for the operation of the tube over this range of operation and found them to be high vacuum devices. I have also made up a tube as nearly like them as possible——

XQ. 234. Please let us talk about the law at the moment. We are not talking about the vacuum of these tubes.

A. I am trying to state just that I have exhibited a certain group of tubes with the 2.25 power.

XQ. 235. I understood you this morning to give the impression that the 2.25 power line was a better line to represent practical tubes than the 3/2 power line. Was I mistaken?

A. I am sorry. I did not intend to give that impression. In fact, I intended to say that the 2.25 was in no way unique.

XQ. 236. There is no rational theoretical basis for a 2.25 power line, is there?

A. Not for exactly 2.25, no, but the reasons why in practical devices that the exponent is not a constant when you try to find the exponent that fits the data over the complete range, the reasons for that are many, but they are well known and taken logically can be made to account for the variation in that exponent.

XQ. 237. Do you agree with the statement which Richardson makes in his book, "The emission of electricity from hot bodies"? Edition of 1916, page 64:

> "In fact Langmuir has shown from a consideration of the dimensions of the equations that, whatever may be the geometrical relation between the emitting and receiving electrode, the current under these circumstances will be equal to V 3/2 multiplied by a factor depending on E_1/m and the geometry of the system."

A. I believe that I remember this dimensional argument and in so far as I know it is sound, but I do not see that this statement applies to our discussion.

XQ. 238. It takes care of those boundary conditions you spoke of yesterday, does it not?

A. If you could consider each electron or any small group of electrons coming from a particular point on the filament and knew the actual voltage that was effective between the place where the electrons were emitted and anode I agree that for that infinitesimal part the 3/2 relation would be true.

XQ. 239. Let us take the history of the thing. Child first—I will not say first, because I do not want to get into controversial matters—but at least Child published a law which he derived mathematically from a consideration of the conditions existing in two small areas between very large parallel plates, did he not?

A. It is a long time since I have read Dr. Child's article and I do not want to be explicit as to his conditions of derivation, but I know in a general way what his derivation was.

XQ. 240. It has been testified in this case that Child derived that law as a law for the simplest case which could possibly be imagined, a small area between two large parallel plates, and it was the 3/2 power law. It has also been testified that one of Dr. Arnold's assistants and also that Dr. Langmuir derived that law as a law for the somewhat more practical case of a very long cylinder, having a filament down in the middle of it.

Mr. Richmond: I object to the question. I do not think it contains an accurate statement of the testimony referring to Dr. Arnold's assistants.

Mr. Davis: What is the fact?

Mr. Richmond Dr. Arnold derived it.

Mr. Davis: I thought it was one of his assistants. It makes no difference.

XQ. 241. Let us assume that Dr. Arnold and Dr. Langmuir also derived the law for a very long cylinder having a filament down the middle of it. That approaches more closely to a practical condition, does it not?

A. I suppose it is somewhat nearer, yes. In their derivation the wire is an emitting surface.

XQ. 242. Oh, yes, we are still on equi-potential surfaces?

A. Yes.

XQ. 243. Then Dr. Langmuir published this argument from dimensional equations which I hope we will not have to discuss, which is referred to in Richardson's article, did he not?

A. I know that that was published and I was familiar with it a number of years ago.

XQ. 244. It showed that that law was to a very large extent independent of the form of the electrodes?

A. Still with an equi-potential surface.

XQ. 245. Yes, let us consider that equi-potential surface until we talk about something else.

A. I always want to be sure it is there because it is one of the vital things.

XQ. 246. So that we are as far as this, that the 3/2 power relation holds from an equi-potential surface in the absence of disturbing factors, that is, when you are considering merely a mutual repulsion of the electrons. Of course, the assumption is that there should be all the electrons there that you want. That is one of the assumptions. Now you have suggested that there are certain factors which prevent that law from being an accurate law which modify it or distort it. I would like to think of those one at a time if we may. The first one is the initial velocity of the electrons which you say was considerable. Now, Dr. Millikan has testified that while it was there it was an effect which could be neglected. Would you like to hear his exact language rather than my paraphrase of it? I want to know if you agree. My note is wrong and I am sorry. You agree that this effect can be neglected in dealing with most ordinary tubes?

A. No, I do not agree with that.

XQ. 247. The effect is small, is it not?

A. I do not agree with that. The determination of the magnitude of the effect is apparently so difficult a mathematical operation or so tedious that no one so far as I know considered the problem mathematically of the effect of the distribution of velocities until about 1920 or 1921. Dr. T. C. Fry of Western Electric Engineering Department at that time did publish an article in the *Physical Review* in which he took into account in this ideal derivation the effect of the initial distribution of velocities for the simple case of the derivation. His only added factor to that derivation was the consideration of the fact that there was a distribution of velocities and he assumed that that is what is called the Maxwellian distribution, and there is experimental evidence that that is the distribution, I believe, and from his mathematical analysis he concluded, as I remember, that it was not negligible, that is, the effect of the distribution of velocities was not negligible and could cause considerable error even in this simple device of two elements to voltages as high as forty or fifty volts, that is, to voltages on the collecting electrode on the anode, of forty to fifty volts.

2 XQ. 248. You know, do you not, that Richardson published a paper in which he based his work on the assumption that these velocities could be neglected although he was dealing with volts very much lower than forty volts?

A. I do not know that.

XQ. 249. Richardson published a paper with some Italian whose name I forget.

A. That was a number of years—if you mean the Richardson-Bassoni, that paper I remember faintly, but that is a long time prior to this exact mathematical analysis of Dr. Fry.

XQ. 250. The next factor I would like to consider are these contact potentials. They modify the operation of the 3/2 power law, do they not?

A. That is one of the factors, yes.

XQ. 251. What is the order of magnitude of the contact potentials?

A. In the Wehnelt oxid type of filament vacuum device, contact potentials between the grid and filament vary from the contact potentials of approximately one volt positive, the grid being one volt positive to the filament to being as much as two volts negative to the filament, that is, over a range of at least three volts. There are some cases where the difference in contact potential between the filament and grid is as high as two volts and the range for the family of devices is appproximately three volts.

XQ. 252. The third point I would like to consider is that the cathode is not in general in an equi-potential surface.

A. Just one second.

XQ. 253. I beg your pardon.

A. I would like to say that those contact potentials are extremely difficult to measure in a fundamental way and the values that I have given there are based on a method of measurement which gives an approximate value. I am not stating those as precision measurements.

XQ. 254. What was the method to which you refer? Is it published?

A. No, it is not published. It is a practical thing that we use as an indication of the magnitude of the contact potential in the course of our development work. Let us first take the case where the grid has such a contact potential that it is positive with respect to the filament. Then if you connect a wire from the grid to the negative side of the filament electrons will flow to the grid due to that contact potential from some portion of the filament. Now then, what we do is to insert a variable battery in that connection between the filament and the grid and also a meter for measuring the current and apply outside the tube a retarding voltage, that is, a negative voltage, a voltage that makes the grid negative with respect to the cathode by whatever amount that voltage may be, and vary that until the current of the flow of electrons to the grid is zero.

Then we draw the conclusion, that again is for practical purposes, that the retarding voltage outside is equal to the accelerating voltage inside and therefore, whatever that voltage is, that it is the positive contact potential of the grid. Now, then, if the grid has a negative contact potential with respect to the filament that means that it retards the flow of electrons from the filament if you connected a wire from the negative end of the filament to the grid and no current would flow because of the presence of that retarding potential.

In this case we reverse the polarity of the outside battery and make it an accelerating battery and we have the voltage variable in very small increments by suitable methods and we increase that voltage until we get a small current to the grid, as small as you please. We arbitrarily make it one microampere because that is the smallest current we can read conveniently with the type of meters that are used in the general laboratory work. And then we say that we have just more than equiliberated the contact potential inside to the voltage outside and for the purposes of our development argument and studies we call that outside voltage as measured the negative contact potential of the grid with respect to the filament. And while I recognize that that is not a precision method of doing it, it exhibits the practical application of this voltage there and handles its effect in the way that it actually occurs in the operation of tubes.

XQ. 255. In the case of a two-electrode tube is contact potential a factor?

A. I should say that in operating devices that it is not a practical factor. I may say that when the tube is operating as an amplifier that this contact potential effect is multiplied by the amplification factor in the tube the same as grid battery voltage outside is multiplied by the amplification factor of a tube.

XQ. 256. You have spoken of the fact that the cathode is not an equi-potential surface. I think that has been explained.

THE COURT: Oh, yes, I understand that.

XQ. 257. So that in a practical tube, for instance, take your VT detecting tube, what is the drop in the filament?

A. I do not know what you refer to by our VT tube.

XQ. 258. The peanut tube.

A. The peanut tube has a voltage drop of 1 to 1.1 volts.

XQ. 259. And in the 201-A of which you spoke yesterday, do you know what the drop is?

A. Approximately five volts.

XQ. 260. And the plate voltage on these tubes as used these days is 150 volts ordinarily?

A. You are placing rather an upper limit, I think the 201-A tube and also our peanut tube so-called operate more generally at voltages of 100 than above.

XQ. 261. Eighty is about common?

A. It is now sixty to ninety. It is gradually climbing upwards in receiving sets.

XQ. 262. In either case the 1.6, if you said 1.6 or the five volts is rather a small proportion of the sixty or eighty or ninety?

A. That voltage itself is small, Mr. Davis, but its effect is not small for this reason that when we connect the grid to the filament we connect it at just one point, and there is voltage drop along the filament from that common point of the filament and grid throughout its length. If you connect the grid to the negative side of the filament, only that one point, only that negative end, is at the same potential except for contact potentials as the grid and the other end of the filament is at a voltage away from the grid by an amount equal to the drop in potential in the filament plus or minus the contact potential and that summation of voltage acts like a grid battery so that you have to consider the grid action on the voltage drop, and that multiplies the effect of this drop by a factor that is of the order of the amplification factor of the tube.

AFTER RECESS.

MR. DAVIS: I would like to state, if your Honor please, that this morning I was unable to give a reference to a statement by Dr. Millikan. The statement is contained on page 453 of the typewritten record in the present case; it is part of the answer to Q. 30.

XQ. 263. If we have a cathode which is not an equi-potential surface, and consider a short length of that cathode, a length so short that we may think of that length as an equi-potential surface, the emission from that length would follow the 3/2 power law, except as it is influenced by some of these modifying factors we have discussed, one of the modifying factors being that the rest of the cathode may act as grid; is that correct?

A. I did not get the first part of the question.

(Question repeated as recorded.)

XQ. 264. And I would like to add that I meant to say a space current rather than emission.

A. Yes—well, with the reservation that all the limiting factors may be present in the particular case, that is true, they take an element so small that it can be considered to all intents as equi-potential surface, the space current from that element, except for other conditions, varies as the 3/2 power law.

XQ. 265. And as a practical matter, by taking the potential of the middle of the cathode instead of at the end, and making the calculations on that basis, you very largely eliminate the difficulty, do you not?

A. If one does what you suggest, he compensates to a certain extent for the one factor, that is, the drop of potential along the length of the filament.

XQ. 266. And if we take the curve with the rotating commutator so arranged as to get out the heating current of the cathode, while the space current is being measured, we eliminate that factor entirely, don't we?

A. If the experiment is well performed so that the electrons are only drawn from the cathode during the time that no current is flowing, it should assimilate very closely an equi-potential condition.

XQ. 267. Now, you spoke also, Doctor, of the effect due to the fact that the filament is not all at the same temperature, with particular reference to the ends of the filament. Of course, the points at which the filament of an incandescent lamp, or the filamentary cathode of the vacuum tube, are fastened to the supporting and leading-in wires, are naturally cold points, because the heat is carried away very rapidly by the supporting wires, so that between the points of actual contact with the wire and a point removed some short distance from it, there will be a gradual rise of temperature called the end effect or the lead effect; that is correct, is it not, Doctor?

A. I do not know just how much I am to say is correct. I think you had better read that from the beginning. (Previous question repeated as recorded.) That is a good statement, reasonably exact, of the cooling effect of the ends in so far as it affects the temperature of the filament.

XQ. 268. Now, that temperature effect will have some effect on the space current in the tube, will it not, under certain conditions?

A. It would.

XQ. 269. And that is one of the causes of what is called the transition portion of the curve, is it not?

A. Well, I do not know just what is called the transition portion of the curve.

XQ. 270. As the language has been used in this case, Doctor, we have divided the characteristic volt ampere curve of a tube into two various portions, the first portion being the portion which was said to be limited by space charge, and the final portion being the saturation portion. Now, it is generally true, is it, that those two portions do not sharply pass from one to the other in a high vacuum tube, but are connected by a curved portion of the characteristic?

A. Well, one goes, of course, in any such characteristic—one may go from a region of complete space charge, to one of voltage saturation. I do not know what that is called in the language of this case.

XQ. 271. We called it the saturation curve here, Doctor, meaning that all of the electrons——

A. Are being pulled across.

XQ. 272. Are being pulled across?

A. Then one has over the whole volt-ampere characteristic, if taken over a wide enough range, from a region where you are, what you call the other part of the curve in temperature saturation.

XQ. 273. I have here page 48——

A. Well, I am going to finish. I want the term.

XQ. 274. This is the curve on page 48 of Langmuir's record on motion, (Interference record, page 1052). The copy I have here does not give the transcript number, but in this curve you will notice a part marked D, from A to around D, which has been called the space charge region and the part marked F, which has been called the saturation region, and the part marked E, has been called the transition in some of the testimony?

A. If you will cancel out all I started to say after his question, and read the question, I will start over again. (Previous record repeated as recorded.) It would play a part in that portion of the curve, yes.

XQ. 275. It was all very thoroughly analyzed and discussed by Dr. Langmuir in his testimony on the motion, was it not?

A. I cannot answer that. I have read none of the history, practically none of the history of this case.

XQ. 276. Now, if we are dealing with the two-electrode tube instead of the three-electrode tube, the situation becomes a little simpler, does it not?

A. Yes, it is simplified.

XQ. 277. As for example, the contact potential cannot be multiplied by a grid amplification factor?

A. That is correct.

XQ. 278. Now, when you come to deal with three-electrode tubes you said there were two other factors, one the presence of the grid itself which may have a potential that is taken care of in the computations as you made them by the use of that double expression, that is, the use of the expression E_b plus nEg instead of the expression E?

A. The expression that I had on those curves is not entirely a complete expression because it does not have a term in there taking care of the grid action of the filament drop along the filament.

XQ. 279. That would introduce another term?

A. That would introduce another term in addition to the voltage between the negative point of the filament and the grid itself.

XQ. 280. And you also spoke of changes in the amplification constant?

A. Yes, sir.

XQ. 281. That also is something which is limited to a three-electrode tube?

A. Yes.

XQ. 282. And to express that very roughly, if you had a grid which had a hole in the middle of it, for example, or a part in the middle where the spacing was very wide, you would at low voltages across the tube get most of your current through that hole and as your voltages across the tube became higher you would also begin to pull current through the finer spaced part of the grid; is that an explanation of that factor?

A. No, I do not think that is a very good explanation.

XQ. 283. Then suppose you give one.

A. This amplification factor of a tube is the relation between the effect of one volt applied to the grid to its effect applied to the plate. That is, if we say in changing the space current, in changing the space current to the anode——

XQ. 284. That is because the grid is nearer?

A. Yes, that is to say, let us say the amplification factor is six. That means, in general, that if you apply one volt to the grid it has the same effect in changing the space current to the plate as applying six volts to the plate.

By The Court:

Q. 285. In accordance with the distance that the electrodes are separated?

A. The distance which the electrodes are separated is one of the factors which determines what that constant is. In commercial devices, three-electrode devices, the amplification factor ranges over values from very close to two up to values of thirty or more and the exact value is a function of what I call the geometry.

That statement that I have made has not included the modifying statement that as the electron current to the plate assumes different values due to changes in the grid and plate voltages that the effective ratio of grid and plate voltages does not remain constant. I think I stated yesterday that it changed 10 per cent. to more than 10 per cent. in practical operating devices from very small space current up to space currents of the value of the space current range in which the tube is used in its operation.

For example, if the amplification factor of a tube were six, for the average space current of its range, the amplification factor would vary from 6.3 to 5.7 over the operating range of the current if the statement that there was a 10 per cent. variation were the case with the particular tube.

By Mr. Davis:

XQ. 286. All these factors are factors which influence or modify or distort the fundamental 3/2 power law of Child, is that true?

A. They are all factors which make the behavior of the device as it works or as you are testing it not conform to the 3/2 power law.

XQ. 287. For example, you are familiar with Boyle's Law, I suppose?

A. Yes.

XQ. 288. Pressure times volume is equal to constant times the temperature of a gas?

A. When you add the temperature you give the law to another man. I believe that Boyle only said that pressure times volume was a constant.

XQ. 289. That that form then. Pressure times volume is constant in a gas?

A. Yes.

XQ. 290. That is of course the fundamental law of gases, is it not?

A. Yes, that is quite true.

XQ. 291. And there is no gas that ever follows that law accurately?

A. That is about right, yes.

XQ. 292. It is a law of a perfect gas, is it not?

A. Yes.

XQ. 293. You say that the reasons that the exponent in the tubes you have described is higher than 1.5 are well known and that such an exponent as 2.25 in an individual case can be explained or derived in terms of these known effects. I would like to have you take your Exhibit 48 if you will and tell us what these effects are that are thus referred to?

A. The effects that I referred to are the effects that I have enumerated.

XQ. 294. And what do you consider the relative importance of these factors?

A. The relative importance altogether depends upon the particular device that you are looking at.

XQ. 295. I am looking at this tube, Defendant's Exhibit 48, which you tested?

A, That is quite difficult to separate in the case of this particular tube, because of the fact that all of the information in regard to its constants are not known, that is, I do not know what the amplification factor of this particular tube is. In a discussion of that kind one needs to know the magnitude of all of the various factors and I did not mean to state, and if I did so state I did not state my exact position. I did not mean that one can separate out in every case or even in any case completely the different modifying effects, the different effects that change it.

XQ. 296. Look at your Exhibit 53, please.

A. Yes, sir.

XQ. 297. That has a tube 105?

A. Yes, sir.

XQ. 298. You are familiar with the constants of that tube, are you?

A. Yes, approximately.

XQ. 299. What do you consider the principal reason why the intercept of the curve of that tube is somewhere around twenty-five volts instead of zero?

A. The reason for that is—the principal reason for the intercept being off from zero is the grid action of the filament drop plus any possible contact potential that may be there which may add or subtract to the grid action to give a resultant intercept.

XQ. 300. Do you know what the amplification of that tube was?

A. I will give my best recollection. I could give it if the data were here on the stand, but as I remember it it was approximately 20. That may be possibly plus or minus three or four.

XQ. 301. On page 819, Doctor, you spoke of sealing the manometer into the apparatus after it had been shipped to the university which was going to use it and you said you had to break the vacuum to do it. You also said that a second exhaust was necessary but that can be much more abbreviated because of initial exhaust. What did you mean by that?

A. I meant that the initial exhaust of the device did two things, it removed the occluded gases from the glass, the metal parts and the filament to a sufficient degree and that so long as it remained sealed in a vacuum that the manometer would operate under the energy conditions of its use without contributing any gas, without any gas coming out into the space. The other thing, and which was very important in the case of the Wehnelt oxid filament, the filament is activated by that exhaust process.

XQ. 302. And stayed activated?

A. And stayed activated so long as it was in the vacuum.

Now, then, if one takes that sealed off device, it has a long tube extending above the bulb, and opens it and immediately puts it on to the apparatus there is a certain amount of gases absorbed. That amount is not as great as the amounts that were there before the initial exhaust; also, if one does not leave the Wehnelt oxid coated filament in the air too great a length of time the activation process is simpler in the second case than in the first, although some bombardment and activation will be required for the purpose of activating the filament as well as for cleaning out the occluded gases before the tube could be used.

XQ. 303. But where a tube has been well exhausted and the gases have been properly removed from the walls of the tube in the anodes, and it is necessary for any reason to open it, and re-exhaust it, the second exhaust can be a very much simpler and shorter performance, can it not?

A. That is generally true, yes; if a tube is immediately put under vacuum after it is opened, and if it does not go through some cycle of operations in the interim, which introduces additional amounts of gas, the second exhaust is a more simple proposition than the first one.

XQ. 304. Now, on Defendant's Exhibit No. 52, which is based on the data from audion 100, you gave also the curve of tube L 9399, which I understood to be the approximate reproduction?

A. Yes. It was the one that was our attempt at reproduction.

XQ. 305. I am using Mr. Richard's term.

A. That is correct.

XQ. 306. Now, you did not give the curve of the approximate reproduction on Defendant's Exhibit 48, did you, which was audion 64?

A. That is correct.

XQ. 307. Was there any reason for not giving it, Doctor?

A. Well, both reason and sequence of events, I will be glad to explain that. In the tube 105, as I have stated, it had a very good filament, a very rugged filament relative to the filament in the tube of Exhibit 30, so that we could take in addition to making mechanical measurements through the glass on it, we could take electrical characteristics with reasonable safety, and not destroy the filament in order to help in the determination of the characteristics of the tube. As I originally planned, and had originally talked over with counsel on the work that I was going to do, because of the extreme fragility of the filament in the tube on Exhibit 30, and because of just looking at it, it appeared that a great portion of the filament, of the active material on the filament was not present, and it was agreed that we would only make vacuum measurement on the Exhibit 30, and that was what was initially done, and some days later it occurred to me to see what the condition of the filament was, and I made this run, venturing up a little at a time in temperature, until I got the filament as hot as I thought was at all safe, without possibly burning it out, and was surprised, and it is surprising that we got the emission that we did, because the filament is quite bare, and this is all the data, other than the pressure data, which I have given, that was taken on this tube. I do not know the other constants and amplification factor, or any other factors about the tube at all. I used it as little as possible as not to burn it out, and I plotted the data taken and found that it followed the approximate exponent of the other tubes of this general type. I showed it to counsel, and he advised its use.

XQ. 308. Does that mean that you did not take a similar curve of the approximate reproduction, which I think is Exhibit 47?

A. That is correct. Exhibit 47, after it was made, was put on to this system with nitrogen for the pressure calibration, and after those calibrations which I have detailed this morning were given, that tube was sealed off with some degree of vacuum. I do not know what the degree of vacuum is, and that tube was made only as a duplicate in geometry, to make a pressure measurement where the measurements have no bearing on whether you operate in space charge or not; and for that reason I was not interested in taking other data, so that I never sealed the tube off as a high vacuum tube.

XQ. 309. I will now refer, please, to the helium tube, which I understand is Defendant's Exhibit No. 57. That is the 57 I understand is the plot of some of its characteristics?

A. This is the tube here (indicating).

XQ. 310. Now, you say in your answer to Q. 74. on page 844?

> "I have here the data and the 2/3 plot of a tube, which according to the legend is 'helium filled type 718G'——"

and so forth. Why did you say "according to the legend," Doctor; is there any reason?

A. That was just an expression. It is not only according to the legend, but is actually filled with helium.

XQ. 311. That is, you were speaking of your own knowledge and not about something your assistant had told you?

A. Oh, yes.

XQ. 312. That tube has not been put in evidence, has it?

A. It is my understanding it is in evidence.

Mr. Davis: I beg your pardon. You are quite right, it has been put in evidence.

XQ. 313. What was this tube originally designed for, Doctor? I am speaking now of Defendant's Exhibit No. 56?

A. That tube was made in the course of development studies in our laboratory on the operation of tubes containing gas, part of general studies of gas-filled tubes.

XQ. 314. What are its peculiarities of design?

A. It is a three-electrode tube.

XQ. 315. Have you a drawing of the tube, giving dimensions?

A. No, I have not.

XQ. 316. How does it differ?

A. I have not that information with me.

XQ. 317. Do such drawings exist?

A. That I do not know, because it is not a standard tube. There is undoubtedly laboratory information concerning its construction. That may not be in the form of drawings.

XQ. 318. Now, why did you use this special type of tube for this experiment, rather than a standard type of tube?

A. That tube is one of a series of studies on the effects of both gas pressure and geometry on the performance of gas content tubes as three-element thermionic devices.

XQ. 319. What is the shape of the filament?

A. I will have to look. I think it is an M. Some were made with M's and others V's (inspecting).

Yes, the filament is in the shape of what we call an M filament.

XQ. 320. And the width of the M is the distance between the two central vertical leaves at the top; is that correct?

A. The top of the M is at the top of the bulb, and it may be a W, I do not just know how you draw an M or a W. It is the distance between the two center supports at the top of the M which is less than the distance between the two outside legs at the base of the M.

XQ. 321. Now, the grid is exceedingly near to the plate of this tube, is it not?

A. The grid is close to the plate.

XQ. 322. How were these tubes prepared before they were filled with helium at the pressure which you mentioned; what kind of an exhaust did they have?

A. They were given an exhaust which is equivalent to the exhaust for a high vacuum device.

XQ. 323. That is the modern, full modern exhaust of a high vacuum tube, is that right?

A. That I can not state without looking at the record. It is the exhaust for that tube, and I do not know that the records would show that, but when the exhaust was done, it was done according to the practice of our laboratory for getting a good high vacuum tube of that general size.

XQ. 324. So that there was not going to be any gas coming out of the anode or any other part of the tube to interfere with the experiment; is that true?

A. That is correct. As much gas was removed as was removed from the high vacuum device.

XQ. 325. Then you introduced helium to the amount of about one micron?

A. To the amount of about three microns.

XQ. 326. Three microns?

A. Yes.

XQ. 327. Now, you know, do you not, that helium is the least ionizable of all gases?

A. Its ionization potential is near the top. It is in the upper limit of ionization potential. Without having a table before me, I would not say it is the highest, but it is high.

XQ. 328. The quantity of ionization of the helium under given voltage is less than that of any other gas, is it not?

A. That is in general true.

XQ. 329. I have here a paper, what purports to be a paper by K. T. Compton and C. C. Van Voorhis. Do you know Compton by reputation?

A. Yes.

XQ. 330. He is a well known physicist who has worked in this line, has he not?

A. Yes, indeed.

XQ. 331. On page 449 of that paper he gives curves showing a number of positive ions in different gases under certain circumstances, does he not?

A. Yes, that is the purport of this curve, as I understand it, from the legend beneath it. I have not looked further than that.

XQ. 332. You do not happen to be familiar with that paper?

A. Yes, I have a knowledge of it. I have not read it for some time and when I did read it, I looked at it as I look at many papers that are not of most vital interest to me. That is, I looked at it at the time when it was published in the *Physical Review.*

XQ. 333. These curves with different symbols marked against them, read, do they not, the number of positive ions formed in the different gases under the same circumstances?

A. Yes, under the same circumstances.

Mr. Davis: I will be glad if the Court will just glance at the diagram, and ask to have it marked.

I call attention to the fact that the lowest of all the lines are the helium lines. I ask to have this paper marked for identification.

(Received and marked "Plaintiff's Exhibit C" for Identification.)

By Mr. Davis:

XQ. 334. How did you happen to use helium in this experiment, Doctor?

A. I cannot answer to that particular one. I will say in general in these studies we were studying the geometrical configurations and the gas effects in these devices in the course of our general development work. Helium was one of the gases used. Other gases were used too.

XQ. 335. How did you happen to pick this out to bring down here?

A. I not only picked that one, but I also picked a tube containing nitrogen. It happens I picked a tube containing nitrogen because that data was taken on a station where you could vary the pressure to show the variation in pressure. This was a sealed off tube and one that illustrated a point very well, so I brought it.

XQ. 336. In any other tubes of that series was the grid any closer to the plate than it is in this one?

A. I cannot say that there was any with the grid any closer, although there may have been. I might say that that particular tube is an extremely low impedance tube with a low amplification factor and that is one of the factors that affected this geometry. The tube 7510 tube in which the nitrogen data was taken is not in evidence now, was a tube of practically identical construction with one of our standard high vacuum tubes.

XQ. 337. And was the grid therefore very much nearer to the cathode?

A. The grid was nearer in proportion, as I remember it.

XQ. 338. That is to say, you are talking now of what tube?

A. Of a 7510. I say that the grid of the 7510 tube is nearer the cathode to the best of my recollection than the tube in question, the tube of Exhibit 57.

XQ. 339. You know, do you not that the nearer the grid is to the plate, other things being equal, the more accurately the tube would follow the 3/2 power law?

A. For the moment I do not follow that statement in so general a form. I will say that the lower the amplification factor of the tube the more nearly, so far as that factor is concerned, will it follow the 3/2 power law and over a greater range of its characteristic.

XQ. 340. Is not this true that the nearer the grid is to the plate and the further it is from the cathode, the more the three-element tube acts like a two-element tube, other things being equal?

A. With the grid potential at a value near to that of the filament rather than that of the plate, I cannot say that that is true.

XQ. 341. Our people skilled in such matters want certain information about this tube. Will it be possible to get that information for us and give it to us later, the information is the distance from the filament to the grid, the distance from the filament to the plate, the diameter of the grid wires and the spacing of the grid wires?

A. It is my impression that all such information is available and I do not know what the rule is in such matters.

The Court: I suppose you can address your request to counsel.

Mr. Davis: I really meant to address it to counsel. I also include the amplification constant which this tube would have in a high vacuum. Is counsel willing that the witness should furnish this?

Mr. Richmond: I will look into that and try to get you the information, Mr. Davis.

Mr. Davis: I would also like, if it is possible similar information for the other tubes, all the tubes on which tests have been made so far as information exists and testified to by this witness.

Mr. Richmond: I make the same answer.

By Mr. Davis:

XQ. 342. How did you measure the pressure of helium in this tube 56 after you had taken the curve?

A. That was by a manometer method. Without referring to the data I cannot go into detail on it, but that is the method of measurement both before and after it was run.

XQ. 343. Treating the tube itself as a manometer?

A. That is correct, yes, sir. And the particular tube had of course been previously calibrated and there was calibration information on it.

Mr. Davis: I wonder then if we could also be given the positive ion currents before and after and the calibration factor.

Mr. Richmond: I make the same answer to that.

By Mr. Davis:

XQ. 344. Now, these other tubes, for example, 7510, which is not in evidence but which has its characteristics under certain conditions of Exhibit 58, is it true that this tube 7510 was exhausted in the same way, that is, given a thorough modern exhaust before the gas was introduced?

A. Yes, that is correct.

XQ. 345. And then the tube was sealed off?

A. No, that is not correct in this case. You see

I have given the data here at different pressures and this data was taken on a modified exhaust position in which the gas, in this case nitrogen, could be admitted.

XQ. 346. How was this pressure measured?

A. This pressure was measured—the actual values that are here without going to the records, I cannot say. Our practice on this work, we have both the manometer on the station and a McLeod gauge outside of the liquid air trap, and I am not certain without going to the records which measurement was used. I feel very certain that for the .02 micron measurement it would have been a manometer measurement. Whether it was for the others or not I do not know.

XQ. 347. How was the pressure kept constant during the taking of these characteristics?

A. What are you referring to?

XQ. 348. Take type 7510 and Exhibit 58 which is headed pressure equals .02 of a micron, as I understand it.

A. That is done in the method of preparation of the tubes after they had vacuum exhaust as I stated yesterday and aging treatment in the particular gas is given and an aging treatment, depending upon the interest of the experiment is prolonged a sufficient amount, that the pressure changes during the experiment would be small.

XQ. 349. I am afraid I do not quite understand yet. The tube is connected to a manometer tube, is it?

A. No, in this case 7510 it is connected to an exhaust system into which the gas in question can be admitted and this tube under investigation such as type 7510 is on that exhaust position in general with a manometer.

XQ. 350. And you simply get this two times ten to the minus fifth by pumping until the manometer shows that?

A. For two times ten to the minus fifth we go further than that. This is gotten by the admission of the same nitrogen in excess of two times ten to the minus fifth and then an aging process carried on such that the manometer measurement during the experiment would remain essentially constant. I may say that I am stating our general practice in connection with these types of studies and in a case of this particular data I would have to refresh my recollection as to whether there was any departure at all from what I am stating.

XQ. 351. I still do not understand You left some nitrogen in and then seal it off?

A. After you have left your nitrogen in then you have a system containing the ionization manometer of the type 7510 and whatever additional apparatus there is sealed off from the pumping system.

XQ. 352. Then you run it until by clean-up or otherwise, you get down to your .02 microns?

A. We run it if we are interested in pressure of .02 microns until the pressure changed with time is low enough if there is change, that the data can be taken with pressure substantially constant.

XQ. 353. How do you get the next curve which is 58-A?

A. A further amount of nitrogen is admitted and that would in general be more than to have a pressure of .64 microns and then the system is trapped off from the pump and further aging process is carried on and when the aging has been carried to the degree that the pressure change with time is sufficiently small for whatever is desired, then the data is taken.

XQ. 354. And the same is true of 58-B where the pressure is 1.2 times 10 to the minus 3?

A. That is true, the general practice.

XQ. 355. But you do not know whether this was done in this particular case or not?

A. I do not know at the present time, no. This work has been going on for quite some time and I have been in on various types of modifications of it and without going to the records of this particular tube I cannot say whether there was any departure from what I have stated but I think it will be found that the departure would not be substantial.

Mr. Davis: There was a question of some data which the Doctor was kind enough to let us have last night and I would like to ask that these sheets which are the sheets that he gave us be marked for identification.

The Court: Let them be marked.

Mr. Davis: I will ask the witness one question if I may.

By Mr. Davis:

XQ. 356. Is this letter of October 28th signed by you and beginning, "Dear Mr. Hogan," a letter that you did write and whether these sheets attached to it are the sheets which you attached?

A. Yes.

XQ. 357. And they are correct data as they purport to be?

A. They are copied from information that I have here, and to the best of my knowledge they are correct copies. I tried to make them correct.

(Received and marked "Plaintiff's Exhibit D for Identification.")

Mr. Davis: That is all, Doctor.

Re-Direct Examination.

By Mr. Richmond:

RDQ. 358. Please refer to Exhibit 54 which shows your diagram for the tube designated 9.111. You were cross-examined about the point in the lower part of the diagram represented by a cross or a plus sign and in that connection its departure from the line was discussed. I think that on the direct examination you said something about thinking that point might be erroneously plotted.

Mr. Davis: I think that in the cross-examination the actual reference was to 53. They are, however, the same thing.

Mr. Richmond: All right. I will add that the same point is shown by the circle in the lower part of Exhibit 53. I would like to direct attention to Exhibit 54, where the point is shown by the cross.

RDQ. 359. Now, when you said something about thinking that that point might be erroneously plotted, can you give any reasons that you had for making such a conjecture?

A. It was based on the data on the three additional curves there which in order of time were taken afterwards and there is no evidence of those three plots or on those three sets of data of such departure.

Mr. Richmond: That is all.

(Witness excused.)

Mr. Darby: I would like to offer in evidence a certified copy of the file wrapper and contents of Langmuir Patent No. 1,558,436, being patent No. 1 of the patents in suit. I understand, if your Honor please, that the file wrapper and contents of the patent in suit up to the time of the Interference procedure is part of the Interference record, and it had been contemplated to put in the remainder of the papers subsequent to the successful outcome of the Interference; but for my purposes, I would prefer to put in a complete document right up to the date of issuance, rather than have it piecemeal.

The Court: That is, consolidated?

Mr. Darby: Consolidated, yes.

(Received in evidence and marked "Defendant's Exhibit No. 62." *See Volume VI, Defendant's Exhibits, page 659*).

Mr. Darby: I offer in evidence a certified copy of the file wrapper and contents of Langmuir Patent No. 1,244,216, being patent No. 2 in suit.

(Received in evidence and marked "Defendant's Exhibit No. 63." *See Volume VI, Defendant's Exhibits, page 786.*)

Mr. Darby: I offer in evidence certified copy of file wrapper and contents of Langmuir Patent No. 1,244,217, being patent No. 3 in suit.

(Received in evidence and marked "Defendant's Exhibit No. 64." *See Volume VI, Defendant's Exhibits, page 824.*)

Mr. Darby: I offer in evidence certified copy of the file wrapper and contents of Langmuir Patent No. 1,529,597, being patent No. 4 in suit.

(Received in evidence and marked "Defendant's Exhibit No. 65." *See Volume VI, Defendant's Exhibits, page 852.*)

Mr. Darby: I ask opposing counsel if they will stipulate that the article entitled "A powerful Roentgen Ray Tube with a Pure Electron Discharge" by W. D. Coolidge was published in the *Physical Review* of December, 1913, and that the "W. D. Coolidge, Esq.," is William D. Coolidge of the General Electric Company?

Mr. Davis: Yes. I think that the paper was in evidence in the Interference, but not printed.

Mr. Darby: I offer in evidence a photostat copy of the Coolidge article in the *Physical Review* of December, 1913, entitled: "A Powerful Roentgen Ray Tube with a Pure Electron Discharge." I will have to supply an unmarked copy of this.

(Received in evidence and marked "Defendant's Exhibit No. 66." *See Volume VI, Defendant's Exhibits, page 919.*)

Mr. Darby: Your Honor, reference has been made to the Coolidge patent for the X-ray tube. Your Honor will recall in the opening statement of Mr. Davis, that the statement was made that that was a specific embodiment of the broader Langmuir invention of the patent No. 1, and although it has been referred to, I do not believe that it has been offered in evidence, and I would like to offer in evidence a certified copy of the file wrapper and contents of Coolidge Patent No. 1,203,495, granted October 31, 1916, on an application filed May 9, 1913.

The Court: That being——

Mr. Darby: The Coolidge X-ray, the High Vacuum X-ray Tube.

(Received in evidence and marked "Defendant's Exhibit No. 67." *See Volume VI, Defendant's Exhibits, page 941.*)

Mr. Darby: I would ask opposing counsel if they will stipulate that the Coolidge X-ray patent, which forms part of the file wrapper of Defendant's Exhibit 67, as well as the White Patent No. 1,159,307, Defendant's Exhibit 42, were filed by and prosecuted by the General Electric Company as assignee of both Coolidge and White; that is to say, that the inventions were assigned to the General Electric Company prior to the actual filing of the papers in Washington?

Mr. Davis: I have no doubt, your Honor, that that is the case, and it is our ordinary practice, I will stipulate it, with the right to make a correction later, if I find I am wrong.

MR. DARBY: I ask opposing counsel to further stipulate that the assignment from White and Coolidge, respectively, was of the entire right, title and interest, in and to the invention and application and letters patent.

MR. DAVIS: I agree to that.

(Discussion.)

MR. DARBY: I gave notice at a prior time of my intention to make application to your Honor for leave to set up the defense of double-patenting and I have prepared my amendment, one specifying the particular claims of the White patent with respect to patents Nos. 3 and 4 in suit, and the other setting up and specifying the particular claims of the Coolidge patent with respect to patent No. 1 in suit and I now make formal request to have my answer amended.

THE COURT: Do I understand that there is no objection?

MR. DAVIS: We would like to look at the papers.

THE COURT: Suppose we take the afternoon recess now.

(After a short recess.)

MR. DAVIS: No objection to the amendment.

THE COURT: Let the amendment to the answer be filed.

MR. DARBY: And I think that Mr. Davis is willing to admit that the Coolidge tungsten patent, the drawn tungsten patent, may be considered as prior art in this case.

MR. DAVIS: Yes, Dr. Coolidge invented the drawn tungsten to the extent shown in his patent before Dr. Langmuir's date of invention.

The Court: There is no date of invention given for the first patent back of the filing date.

Mr. Darby: That the Coolidge patent involved in the Coolidge suit may be considered prior art to Patent No. 2 in this case.

Mr. Davis: That is the thoriated filament patent. The filament was in use at the time Dr. Langmuir made that invention.

Mr. Darby: And the Coolidge patent is Defendant's Exhibit 38 in this case.

The Court: I see.

Mr. Darby: Reference has been made to the testimony that was taken by deposition in California, and I would like to——

The Court: Those depositions were filed?

Mr. Darby: I might explain why they are in my possession. The depositions were taken in connection with the suits that were brought in Brooklyn and we stipulated to withdraw and placing them in my custody for use here in connection with all the patents in suit.

The Court: So you now file them?

Mr. Darby: Yes, sir.

Mr. Davis: To which we object as immaterial and having no relation to any issue in the case.

The Court: I will overrule that objection without prejudice, saving discussion at this time.

(Discussion.)

Mr. Darby: I would like to offer in evidence the drawing to scale of the pump used by Lamont and which was Defendant's Exhibit I, pump drawing, in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 68." *See Volume VI, Defendant's Exhibits, page 1031.*)

Mr. Darby: I would like to offer in evidence the drawing to scale of the jet device enlarged which was marked L in the previous drawing and which was marked Exhibit J in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 69." *See Volume VI, Defendant's Exhibits, page 1033.*)

Mr. Darby: I offer in evidence a photograph of the initial pumping device which was Exhibit B, Lamont parallel pump, in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 70." *See Volume VI, Defendant's Exhibits, page 1034.*)

Mr. Darby: I offer in evidence a photograph of the Lamont pump which was Defendant's Exhibit A, Lamont mercury pump, in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 71." *See Volume VI, Defendant's Exhibits, page 1035.*)

Mr. Darby: During the testimony of one of the witnesses named Hewlett, he made a drawing, a schematic drawing of the Lamont pump, which was offered in evidence as Defendant's Exhibit G, Hewlett pump, in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 72." *See Volume VI, Defendant's Exhibits, page 1036.*)

Mr. Darby: During the testimony of a witness by the name of Clark, he drew from recollection a pump of Lamont and it was offered in evidence as Defendant's Exhibit H, Clark pump sketch, in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 73." *See Volume VI, Defendant's Exhibits, page 1037.*)

(Discussion)

Mr. Darby: I also offer in evidence photographs of certain sheets of the account book which was in evidence as Defendant's Exhibit C in the depositions, Lamont account book, cash, consisting of five sheets bound together.

(Received in evidence and marked "Defendant's Exhibit No. 74." *See Volume VI, Defendant's Exhibits, page 1038.*)

Mr. Darby: This showed the actual dates and the charges for this re-exhaust work in connection with audions, who it was done for and, as I recall it, what was done.

Mr. Darby: I was trying to find one illustrative entry. I cannot find it today, though it is in there. Likewise a photostatic copy of the three sheets of the Lamont account book order, which we constituted Defendant's Exhibit D in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 75." *See Volume VI, Defendant's Exhibits, page 1048.*)

Mr. Darby: For example, on that sheet there is an order of September 4:

"Professor Yahnka, 2 audion receivers $15. work done September 4, 1909."

(Discussion)

Mr. Darby: In that connection we obtained from the original files of the Federal Telegraph Company, cards, one card, the original card is in evidence, on Defendant's Exhibit L:

"Shop card amplifiers (three-stage)" of the Federal Telegraph Company.

It is labelled "Audion Amplifier 3-in-one box."

November 29th, is the first item, showing a charge against the laboratory for the apparatus without the audion bulb, and in 1913, April 29th, putting in for the audion bulb, and shipped to San Francisco Beach.

I might say that one of the stations, as commercial stations of the Federal Telegraph Company in California, was known as the Beach Station.

I offer in evidence this card.

(Received in evidence and marked "Defendant's Exhibit No. 76." *See Volume VI, Defendant's Exhibits, page 1054.*)

Mr. Darby: The second card was Defendant's Exhibit K "Shop card amplifier tubes." This card says "Audion lamps (detector bulbs)," and on the same card appears, "Amplifier bulbs," the purpose being to show the distinction in the laboratory of the Federal Telegraph Company between the detector and amplifier.

I offer in evidence the Defendant's Exhibit K in the deposition, shop card and amplifier tube.

(Received in evidence and marked "Defendant's Exhibit No. 77." *See Volume VI, Defendant's Exhibits, page 1055.*)

(Discussion)

Mr. Darby: I offer in evidence the letter from McCandless to the Federal Company, photostats of them at least, which were marked Defendant's Exhibits P-1, P-2, P-3, and P-4, in the deposition and are attached together.

(Received in evidence and marked "Defendant's Exhibits Nos. 78, 78-A, 78-B and 78-C" respectively. *See Volume VI, Defendant's Exhibits, pages 1056-1059.*)

Mr. Darby: And I offer in evidence the photostat copies of letters from the Federal Company to McCandless and Lamont, which were in the deposition as Defendant's Exhibits Q-1, Q-2, Q-3 and Q-4, being attached together.

(Received in evidence and marked "Defendant's Exhibits Nos. 79, 79-A, 79-B and 79-C" respectively. *See Volume VI, Defendant's Exhibits, pages 1060-1063.*)

(Discussion)

Mr. Darby: I offer in evidence the photograph of the three stage amplifier which was Defendant's Exhibit O, Watkin's photograph, in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 80." *See Volume VI, Defendant's Exhibits, page 1064.*)

(Discussion)

Mr. Darby: I do not recall which engineer of the Federal Company the blueprint was offered in evidence by, but I offer it in evidence in this case, the same being Defendant's Exhibit M, drawing 88, Federal Telegraph Company, in the deposition.

(Received in evidence and marked "Defendant's Exhibit No. 81." *See Volume VI, Defendant's Exhibits, page 1065.*)

Mr. Darby: Likewise the blueprint No. 229 of the Federal Telegraph Company dated February 4, 1913, showing the audion amplifier box and the actual equipment in use at the station. This exhibit was Defendant's Exhibit N in the deposition in California, and I offer it in evidence in this case.

(Received in evidence and marked "Defendant's Exhibit No. 82." *See Volume VI, Defendant's Exhibits, page 1067.*)

Mr. Darby: The operators of this Beach Station with these vacuum tubes testified to the voltage that they employed on the B-battery of the cascade amplifiers and that was from 40 to 70 or 80 volts. I do not find the exact reference now.

Mr. Edmonds: Are you putting in all of the exhibits?

Mr. Darby: Yes, it was my intention to put them all in. If I have omitted any I will put them in later.

Mr. Edmonds: You can offer those tubes as if they were here.

Mr. Darby: I offer in evidence what was known as Exhibit E in the California deposition, defendant's audion structure, which, as I recall it, was illustrative of the type of audion tubes which Lamont pumped and I believe it is identical in appearance with the audion tube No. 7-A in the Arnold-Langmuir Interference.

The Court: That one you have not here, but will produce later.

Mr. Darby: Yes, sir, it is in the custody of the clerk in Brooklyn.

(Received in evidence and considered marked "Defendant's Exhibit No. 83." [Note: This exhibit afterwards withdrawn.]

Mr. Darby: I offer in evidence what was known as Exhibit F in the California deposition, Jahnke tube, which is a particular type of structure, and I would not go so far as to call it an audion construction, which this Dr. Jahnke had Lamont build for him.

(Received in evidence and considered marked "Defendant's Exhibit No. 84." [Note: This exhibit afterwards withdrawn.]

(Discussion)

Mr. Darby: I ask opposing counsel to stipulate that the testimony given by Mr. Frank N. Waterman in a cause pending in the United States District Court for the Southern District of New

York, wherein Marconi Wireless Telegraph Company of America was plaintiff and DeForest Radio Telegraph & Telephone Company was defendant, may be considered as evidence in this case with the same force and effect as if Mr. Waterman had actually been called as a witness in this case and testified, and I might further state, at least give Mr. Davis notice that if he does not so stipulate, I ask your Honor for permission to take the deposition of Mr. Waterman before the defense closes its case.

Mr. Davis: I see no reason why I should so stipulate. I have never read the evidence and I do not know what it is or what it is about and there is no connection between Mr. Waterman and any party to this case, or between the parties to that case and any parties to this case which makes it anything more than something that happened between strangers. The fact that the Radio Corporation of America purchased the assets of the American Marconi Company in the year 1919, does not seem to me to establish such a connection.

The Court: If I understand you, you decline so to stipulate for reasons which you deem adequate?

Mr. Darby: Before your Honor passes on my application, may I likewise ask opposing counsel to stipulate that the testimony given by Mr. David Sarnoff in a cause pending in the United States District Court for the Southern District of New York, wherein Marconi Wireless Telegraph Company of America was plaintiff and DeForest Telephone & Telegraph Company was defendant—this is the same case, except that Mr. Sarnoff testified in the accounting proceedings before his Honor Judge Holt as Special Master—

may be considered as evidence in this case with the same force and effect as if Mr. Sarnoff had actually been called as a witness in this case and testified, and likewise give notice to Mr. Davis that if he does not so stipulate I will make application to your Honor for leave to take deposition of Mr. Sarnoff.

The Court: Is not he within reach of a subpœna?

Mr. Darby: He is in New York.

The Court: Where is Mr. Waterman?

Mr. Darby: He is in New York City.

The Court: The statute passed by Congress is a general statute. There was another statute passed I think by the last Congress either a year or two years ago and I consider that statute a general statute, and so if you want subpœnas you may have them. I see no reason why you should take depositions, but if you want subpœnas you may apply for them.

Mr. Davis: I have not seen the deposition and I do not know what it is about and I therefore refuse to stipulate.

Mr. Haight: I suggest that Mr. Davis would like to look that over overnight.

Mr. Davis: I shall be very glad to. So far as Mr. Sarnoff is concerned I have no doubt that if this Court wants him he would be here. Mr. Waterman, as your Honor knows, is a consulting engineer who may be in some other case somewhere. I do not think it will be necessary to subpœna Mr. Sarnoff if he knew this Court wanted him.

The Court: I do not want him, but Mr. Darby does.

Mr. Darby: I can confer with Mr. Davis this evening and we may be able to clear this up, and if not we will make either formal application to your Honor or make application for a subpœna.

(Discussion.)

Mr. Haight: I offer in evidence a letter from the Acting Examiner of Interferences to Dr. Langmuir care of Mr. Davis, dated September 8, 1916, asking that he specify more definitely than he had done in his original statement the date when he claims he had made the invention.

The Court: That is not in with the file wrapper.

Mr. Haight: That is not in the printed record, no, sir.

Mr. Davis: As I understand it, the Interference record is a separate record from the application record and this paper Judge Haight is offering is in the Interference record.

Mr. Haight: But it is not printed.

Mr. Davis: It is not printed.

Mr. Richmond: It is in the Interference record but not in the transcript that the Patent Office sent to the Court of Appeals.

The Court: Then you want it printed in the record here and it is admitted for that purpose.

(Received in evidence and marked "Defendant's Exhibit No. 85." *See Volume VI, Defendant's Exhibits, page 1069.*)

Mr. Haight: I offer in evidence a copy of a telegram by Mr. Davis to Mr. Williams, dated September 15, 1916, asking that further time for the submitting of the additional statement requested by the Examiner of Interferences be granted.

(Discussion.)

(Received in evidence and marked "Defendant's Exhibit No. 86." *See Volume VI, Defendant's Exhibits, page 1070.*)

Mr. Haight: I offer in evidence a communication addressed to the Commissioner of Patents by Irving Langmuir through Albert G. Davis, his attorney, in respect to the addition of more claims in the Interference.

(Received in evidence and marked "Defendant's Exhibit No. 87." *See Volume VI, Defendant's Exhibits, page 1071.*)

Mr. Haight: I offer in evidence a letter written by Mr. Folk, as attorney for the American Telephone & Telegraph Company to the Commissioner of Patents, dated October 14, 1920, enclosing a copy of the reference book and brief.

(Received in evidence and marked "Defendant's Exhibit No. 88." *See Volume VI, Defendant's Exhibits, page 1075.*)

Mr. Haight: I offer in evidence a copy of a letter written by Mr. Folk as attorney for the American Telephone & Telegraph Company, to the Commissioner of Patents, dated October 14, 1920, setting forth the reason why he would not appear to argue the question of the patentability of the Langmuir application, after the motion to dissolve had been made and testimony had been taken.

(Received in evidence and marked "Defendant's Exhibit No. 89." *See Volume VI, Defendant's Exhibits, page 1076.*)

Mr. Haight: Mr. Richmond calls my attention to the fact that as a matter of record he was attorney for Arnold. The letter is on the letterhead of the American Telephone & Telegraph Company, and of course Arnold's application had been assigned to the American Telephone & Telegraph Company or to the Western Electric Company, I do not know which, and this letter was to the Commissioner stating that although the brief had been filed, he would not appear for the argument, because of the agreement that had been entered into betwen the General Electric Company and the A. T. & T. for mutual exchange of licenses.

I offer in evidence a communication from Mr. Davis, as attorney for Dr. Langmuir, withdrawing certain claims in respect to which the motion to dissolve had been directed.

(Received in evidence and marked "Defendant's Exhibit No. 90." *See Volume VI, Defendant's Exhibits, page 1079.*)

Mr. Haight: I offer in evidence a stipulation signed by Mr. Davis as attorney for Langmuir and Mr. Folk as attorney for Arnold, dated March 16, 1921, adding three additional claims to the Interference.

Mr. Richmond: Two.

Mr. Haight: I understand these were the claims that related particularly to the three-element vacuum tube.

(Received in evidence and marked "Defendant's Exhibit No. 91." *See Volume VI, Defendant's Exhibits, page 1081.*)

Mr. Haight: I offer in evidence a communication from the Law Examiner, dated March 18, 1921, addressed to the attorneys of the respective parties, Arnold and Langmuir, in respect to these additional claims.

(Received in evidence and marked "Defendant's Exhibit No. 92." *See Volume VI, Defendant's Exhibits, page 1083.*)

Mr. Haight: Now I offer in evidence the seven patents which were shown to Mr. Hogan while he was on the stand, and which have been marked as Exhibits B, C, D, E, F, G and H for Identification.

(Received in evidence and marked "Defendant's Exhibits Nos. 93, 94, 95, 96, 97, 98 and 99" respectively. *See Volume VI, Defendant's Exhibits, pages 1085, 1090, 1095, 1099, 1104, 1108, 1117.*)

Mr. Haight: There are some additional patents which I am going to ask Mr. Richmond to offer because he can explain them to your Honor in case objection is made to them, far better than I can.

Now, before closing, I would like to reserve the right to call some one, if there is any one available now, in the Patent Department of the Telephone Company, to explain the reason why there was a delay in the filing of the Arnold application, between April, 1915, was it not, 1915, and November——

The Court: Any objection to that, Mr. Davis?

Mr. Davis: Not the slightest, your Honor.

The Court: Very well, you may have that reservation.

Mr. Haight: Now, there appears in the evidence, I think almost exclusively in the priority record, the testimony of Mr. Richards, Mr. Pierce, Mr. Trimble, Mr. Nicolson and Mr. Kendall.

This record under the stipulation which has been referred to, will become part of the evidence in this case, and we have not deemed it necessary to call these witnesses and will rest upon their statements that appear in the record. Now, we feel that it would be rather trespassing upon your Honor's patience and good nature, and probably unduly encumber the record if we did so, but I merely wanted to make that clear, to show you that we were not resting our case purely and simply on the fact witnesses that we have produced here; but their testimony is supplemented by Mr. Richards, who was present at the time that Dr.

DeForest first came; Mr. Pierce, Mr. Trimble, Mr. Nicolson and Mr. Kendall, who worked with Dr. Arnold, after November 1st, 1912.

Now, I understand that the Interference Record contains copies of the opinions of the tribunals of the Patent Office before that rendered by the Circuit Court of Appeals of the District of Columbia; that is correct, is it not?

Mr. Davis: Yes.

Mr. Haight: I merely state that because Mr. Howson has indicated that he wants the opinion of the Court of Appeals of the District of Columbia to be incorporated in the record in this case. We have no objection as long as the others are in.

Mr. Howson: Very well.

(Discussion.)

In accordance with the stipulation of April 30, 1926, defendant and plaintiff now jointly offer in evidence printed volumes, being the transcript of record in the Court of Appeals of the District of Columbia, January Term, 1924, Patent Appeal Docket in 1680, Langmuir v. Arnold, Appeal from the Commissioner of Patents in Interference No. 40,380; all testimony and other evidence and other proceedings by or for Arnold in said interference and in the Arnold patent application involved therein to be considered as evidence duly taken and presented on behalf of defendant in this suit, and all testimony and other evidence and other proceedings by or for Langmuir in said interference and in the Langmuir application involved therein to be considered as evidence duly taken and presented on behalf of plaintiff in this suit.

For the better identification of its several exhibits from the interference, plaintiff now offers in evidence in this case the following, which were in evidence in the interference proceedings.

LIST OF LANGMUIR EXHIBITS IN ARNOLD V. LANGMUIR INTERFERENCE NUMBERED AS PLAINTIFF'S EXHIBITS IN THIS CASE.

Plaintiff's Exhibit No. in this Case.		*Exhibit No. in Interference.*
20	Diagram, Fig. 1	1
21	Physical Review Paper of December, 1913	2
22	Diagram, Fig. 2	3
23	Diagram, Fig. 3	4
24	Diagram, Fig. 4	5
25	American Electro-Chemical Society Paper of 1916	6
26	American Chemical Society Paper of November, 1916	7
27	Diagram, Fig. 5	8
28	Diagram, Fig. 6	9
29	Diagram, Fig. 7	10
30	Diagram, Fig. 8	11
31	Diagram, Fig. 9	12
32	Logarithmic Plot of Volt-Ampere Characteristics of Regulator Kenotron with High Vacuum	13
33	Volt-Ampere Characteristics of Regulator Kenotron with High Vacuum	14
34	Logarithmic Plot of Volt-Ampere Characteristics of Regulator Kenotron with Filament Current at 1.25 Amperes and with High Vacuum	15
35	Volt-Ampere Characteristics of Regulator Kenotron with Filament Current at 1.25 Amperes and with High Vacuum	16
36	Logarithmic Plot of Volt-Ampere Characteristics of Regulator Kenotron with Mercury Vapor Present	17

Plaintiff's Exhibit No. in this Case.		*Exhibit No. in Interference.*
37	Volt-Ampere Characteristics of Regulator Kenotron with Mercury Vapor Present	18
38	Diagram of Circuit Connections	19
39	Regulator Kenotron with Appendix and Charcoal Tube	20
40	Nickel Anode Tube	21
41	Curve Sheets of Nickel Anode Tube	21-A
42	Standard Coolidge X-ray Tube	22
43	Volt-Ampere Characteristics of Standard Coolidge X-ray Tube	23
44	Logarithmic Plot of Volt-Ampere Characteristics of Standard Coolidge X-ray Tube	24
45	Standard Coolidge X-ray Tube with Cathode Shield Removed	25
46	Volt-Ampere Characteristics of Standard Coolidge X-ray Tube with Cathode Shield Removed	26
47	Logarithmic Plot of Volt-Ampere Characteristics of Standard Coolidge X-ray Tube with Cathode Shield Removed	27
48	Radiator Type Coolidge X-ray Tube	28
49	Volt Ampere Characteristics of Coolidge X-ray Tube, Radiator Type	29
50	Logarithmic Plot of Volt-Ampere Characteristics of Coolidge X-ray Tube, Radiator Type	30
51	Type P Pliotron	31
52	Volt-Ampere Characteristics of Type P Pliotron	32
53	Logarithmic Plot of Volt-Ampere Characteristics of Type P Pliotron	34

Plaintiff's Exhibit No. in this Case.		*Exhibit No. in Interference.*
54	Volt-Amepere Characteristics of Type P Pliotron, taken with Rotating Commutator	34
55	Logarithmic Plot of Volt-Ampere Characteristics of Type P Pliotron, taken with Rotating Commutator	35
56	Rotating Commutator	36
57	Diagram of Circuit Connections	37
58	Type U Pliotron	38
59	Volt-Ampere Characteristics of Type U Pliotron	39
60	Logarithmic Plot of Volt-Ampere Characteristics of Type U Pliotron	40
61	Type T Pliotron	41
62	Volt-Ampere Characteristics of Type T Pliotron	42
63	Logarithmic Plot of Volt-Ampere Characteristics of Type T Pliotron	43
64	Type G Pliotron VT-11	44
65	Type G Pliotron, VT-13	45
66	Volt-Ampere Characteristics of Type G Pliotron, VT-11	46
67	Logarithmic Plot of Volt-Ampere Characteristics of Type G Pliotron, VT-11	47
68	Volt-Ampere Characteristics of Type G Pliotron, VT-13, with Grid connected to Negative End of Filament	48
69	Logarithmic Plot of Volt-Ampere Characteristics of Type G Pliotron, VT-13, with Grid connected to Negative End of Filament	49
70	Volt-Ampere Characteristics of Type G Pliotron, VT-13, Grid Connected to Anode	50

Plaintiff's Exhibit No. in this Case.		*Exhibit No. in Interference.*
71	Logarithmic Plot of Volt-Ampere Characteristics of Type G Pliotron, VT-13, Grid Connected to Anode	51
72	Kenotron Regulator Tube, Type TB-1	52
73	Volt-Ampere Characteristics of Kenotron Regulator Tube, Type TB-1	53
74	Logarithmic Plot of Volt-Ampere Chart	54
75	Kenotron, with Filamentary Anode	55
76	Volt-Ampere Characteristics of Kenotron with Filamentary Anode at Different Filament Temperatures	56
77	Temperature Current Characteristics of Kenotron with Filamentary Anode	57
78	Logarithmic Plot of Volt-Ampere Characteristics of Kenotron with Filamentary Anode	58
79	Diagram, Fig. 10	59
80	Diagram, Fig. 11	60
81	Diagram, Fig. 12	61
82	Diagram, Fig. 13	62
83	Diagram, Fig. 14	63
84	Diagram, Fig. 15	64
85	Thomson Lecture Reported in *Engineering*	65
86	Logarithmic Plot of Richardson Data	66
87	Volt-Ampere Characteristics of Fleming Vacuum Valve	67
88	Logarithmic Plot of Volt-Ampere Characteristics of Fleming Vacuum Valve	68
89	Pliotron No. 79	69
90	Plot of Van der Bijl's Data on page 47 of Arnold's Record	70
91	Logarithmic Plot of Van der Bijl's Data on page 47 of Arnold's Record	71

Plaintiff's Exhibit No. in this Case.		*Exhibit No. in Interference.*
92	Plot of Van der Bijl's Data on pages 49, 50 of Arnold's Record	72
93	Logarithmic Plot of Van der Bijl's Data on pages 49, 50 of Arnold's Record	73
94	Plot of Van der Bijl's Data on page 51 of Arnold's Record	74
95	Plot of Van der Bijl's Data on page 67 of Arnold's Record	75
96	Logarithmic Plot of Van der Bijl's Data on page 67 of Arnold's Record	76
97	Plot of Van der Bijl's Data on page 211 of Arnold's Record	77
98	Logarithmic Plot of Van der Bijl's Data on page 211 of Arnold's Record	78
99	Sweetser Record Sheets S-1146 to S-1214, Experiment No. 291	79
100	Sweetser Record Sheets S-1345 to S-1432-13, Experiment No. 317	80
101	Langmuir Notebook No. 413, pages 1-145	81
102	Volt-Ampere Characteristics of Pliotron No. 79	82
103	Logarithmic Plot of Volt-Ampere Characteristics of Pliotron No. 79	83
104	Proceedings of the Institute of Radio Engineers, September, 1915	84
105	Tungsten Wire Audion No. 2	85
106	General Electric Review Article on Coolidge X-ray Tubes	86
107	Lt. Gutton's Article in Revue Generale de l'Electricite	87
108	Calculations Involving Maxwell's Distribution Law	88

Plaintiff's Exhibit No. in this Case.		*Exhibit No. in Interference.*
109	DeForest Audion Record Sheets	89
110	Logarithmic Plot of DeForest Audion Data	90
111	Logarithmic Plot of Pierce's Data	A
112	Logarithmic Plot of Pierce's Data	B
113	Plot of Pierce's Data	C
114	Plot of Pierce's Data	D
115	Plot of Pierce's Data	E
116	Plot of Pierce's Data on Audion 20.4	F
117	Plot of Pierce's Data on Tubes A-3 and B-3	G
118	Plot of Characteristics of Audion A-9 .111	H
119	Plot of Sweetser's Data of Aug. 1912	I
120	Volume Gillette Photographs	J
121	Gillette Negative	K
122	Photograph of Langmuir's Laboratory	L
123	Lamp Vacuum Committee Reports	M
124	Robinson Notebook	N
125	Mackay Notebook	O
126	Dushman Notebook No. 436	P
127	Dushman Notebook No. 464	Q
128	Plot of Data of Lamp No. 2 of November 19, 1912	R
129	Gartner Letter of February 6, 1913	S
130	Diagram	T
131	Langmuir Notebook No. 458	U
132	Langmuir Notebook No. 504	V
133	U. S. Patent No. 1,103,688 W. L. Richards	
134	" " " 1,114,845 H. DeF. Arnold	
135	" " " 1,128,279 ditto	
136	" " " 1,128,280 ditto	
137	" " " 1,128,292 E. H. Colpitts	
138	" " " 1,129,942 H. DeF. Arnold	
139	" " " 1,129,943 ditto	

Plaintiff's Exhibit No. in this Case.				*Exhibit No. in Interference.*
140	U S. Patent No.	1,129,959	E. H. Colpitts	
141	" " "	1,130,008	A. McL. Nicolson	
142	" " "	1,130,009	ditto	
143	" " "	1,130,042	H. J. Van Der Bijl, et al.	
144	" " "	1,130,043	ditto	
145	" " "	1,137,275	A McL. Nicolson	
146	" " "	1,137,315	R. A. Heising	
147	" " "	1,137,384	E. H Colpitts	
148	" " "	1,168,270	H. DeF. Arnold	
149	" " "	1,169,182	A. McL. Nicolson	
150	" " "	1,169,422	ditto	
151	" " "	1,183,875	R. V. L. Hartley	
152	" " "	1,193,206	H. J. Van Der Bijl	
153	" " "	1,194,820	E. H. Colpitts	
154	" " "	1,196,474	A. McL. Nicolson	
155	" " "	1,196,805	J. C. R. Palmer	
156	" " "	1,198,699	E. H. Colpitts	
157	" " "	1,198,700	ditto	
158	" " "	1,199,180	R. A. Heising	
159	" " "	1,200,796	H. DeF. Arnold	
160	" " "	1,237,210	Langmuir	
161	" " "	1,251,388	"	

It should be noted that the Rotating Commutator, which was Exhibit 36 in the Interference and has now been marked Exhibit 56 in this suit, is the same Rotating Commutator which was marked Plaintiff's Exhibit A for identification in the cross-examination of Dr. Chaffee.

Plaintiff also offers in evidence copy of the opinion of the Court of Appeals of the District of Columbia in Langmuir v. Arnold, dated June 1, 1925, Plaintiff's Exhibit 162.

(Received in evidence and marked "Plaintiff's Exhibit No. 162." *See Volume IV, Plaintiff's Exhibits, page 41.*)

(Whereupon, at 5.20 P. M., adjournment was taken until Friday, October 29, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del.,
Friday, October 29, 1926,
10 o'clock A. M.

TWELFTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Haight: For the better identification of its several exhibits from the Interference record, defendant now offers in evidence in this case the following exhibits which are in evidence in the Interference proceedings.

Ex. No.	*Designation.*	*Interference No.*
100	Van der Bijl Diagram No. 1	1
101	" " 2	2
102	" " 3	3
103	" " 4	4
104	" " 5	5
105	" " 6	6
106	" " 7	7
107	" " 8	8
108	" " 9	9
109	" " 10	10

Ex. No.	*Designation.*	*Interference No.*
110	**Vacuum Tube No. 17,482**	
111	**Van der Bijl Diagram No. 11**	11
112	" " 12	12
113	**Millikan Sketch No. 1**	1
114	"	2
115	**Arnold Exhibit No. 1-A**	1-A
116	" " " 1-B	1-B
117	" " " 2-A	2-A
118	" " " 2-B	2-B
119	" " " 3-A	3-A
120	" " " 3-B	3-B
121	" " " 3-C	3-C
122	" " " 3-D	3-D
123	" " " 4-A	4-A
124	" " " 4-B	4-B
125	**Buckley Article**	
126	**Calibration Curve No. 1**	1
127	" " 2	2
128	**Van der Bijl Diagram No. 13**	13
129	" " 14	14
130	**Van der Bijl Diagram No. 8 simplified**	
131	" " 15	15
132	" " 16	16
133	" " 17	17
134	" " 18	18
135	**Photograph of Tube R. d. Q. 165,**	
136	**Richardson Exhibit No.**	1
137	"	2
	(Above exhibits are printed on pp. 267 and 268 of the Interference Record.)	
138	**Vacuum Tube No. 17,482**	
139	**DeForest Audion 7-A**	39

Ex. No.	*Designation.*	*Off'd. Page*	*Ptd. Page*
140	Van der Bijl Test Circuits for Amplifier (Exhibit 40)	54	49
141	Van der Bijl Circuits for Detector (Exhibit 41)	54	52
142	Van der Bijl Comparison Test Circuits for Detector (Exhibit 42)	54	53
143	Vacuum Tube Conference Report of February 8, 1918 (Exhibit 43)	54	495
144	Signal Corps Specification for Receiver Tubes, Dated Feb. 12, 1918 (Exhibit 44)	59	500
145	Test Specification for Transmitter Tubes, dated Nov. 1, 1918 (Exhibit 45)	60	505
146	Diagram for Regulator Kenotron Experiment Carried to 300 Volts (Exhibit 46)	77	67
147	Diagram for Regulator Kenotron Experiment at Graded Pressures, with Tungsten Filament (Exhibit 47)	77	70
148	Diagram for Regulator Kenotron Experiment at Graded Pressures with Wehnelt Cathode (Exhibit 48)	77	76
149	Diagram Illustrating Effect of Filament Voltage Drop (Exhibit 49)	104	88
150	Logarithmic Diagram Illustrating Effect of Filament Voltage Drop (Exhibit 50)	104	89
151	Comparative Diagram Langmuir Exhibits 33 and 35 (Exhibit 5)	104	93
152	Logarithmic Diagram at Different Pressures with Wehnelt Cathode (Exhibit 52)	104	96

Ex. No.	*Designation.*	*Offd. Page*	*Ptd. Page*
153	Diagrams on Successive Days with Wehnelt Cathode, Using Liquid Air (Exhibit 53)	104	97
154	Logarithmic Diagram Corresponding to Exhibit 53, Rebuttal Fig. 13 (Exhibit 54)	104	99
155	Characteristics for Unbaked Tube with Filamentary Tungsten Anode (Exhibit 55)	129	106
156	Logarithmic Plot Corresponding to Exhibit 55, Rebuttal Fig. 15 (Exhibit 56)	129	108
157	Characteristics for Unbaked Tube with Coiled Filamentary Tungsten Anode (Exhibit 57)	129	110
158	Logarithmic Plot Corresponding to Exhibit 57, Rebuttal Fig. 17 (Exhibit 58)	129	112
159	Characteristics Corresponding to Exhibit 57, Fig. 17, but with Higher Temperatures (Exhibit 59)	129	113
160	Characteristics for Unbaked Tube with Equal Filamentary Tungsten Electrodes (Exhibit 60)	129	114
161	Characteristics for Unbaked Tube with Equal Parallel Carbon Electrodes (Exhibit 61)	129	116
162	Logarithmic Plot Corresponding to Exhibit 61, Fig. 21 (Exhibit 62)	129	117
163	Characteristics Corresponding to Exhibit 61, Fig. 21, but Pushed to Higher Currents (Exhibit 63)	129	119
164	Logarithmic Plot Corresponding to Exhibit 63, Fig. 23 (Exhibit 64)	129	120

Ex. No.	*Designation.*	*Offd. Page*	*Ptd. Page*
165	Characteristics for Unbaked Tube with Equal Carbon Hairpin Electrodes (Exhibit 65)	130	121
166	Logarithmic Plot Corresponding to Exhibit 65, Fig. 25 (Exhibit 66)	130	123
167	Characteristics for Unbaked Tube with Equal Carbon Electrodes (Exhibit 67)	130	124
168	Characteristics for Unbaked Tube with Equal Carbon Hairpin Electrodes (Exhibit 68)	130	125
169	Logarithmic Diagram Illustrating 2/3 Slope for Considerable Gas Present (based on Exhibit 47, Fig. 7) (Exhibit 69)	162	133
170	Comparative Direct Diagrams of Langmuir's Exhibits 32 to 35 (Exhibit 70)	162	149
171	Plate Current-Grid Volt Characteristic for Standard Telephone Repeater Tube (Exhibit 71)	162	156
172	Current-Voltage and Resistance-Voltage Characteristics for Standard Telephone Repeater Tube (Exhibit 72)	162	157
173	Logarithmic Plot corresponding to Exhibit 72, Fig. 37 (Exhibit 73)	162	158
174	Diagram showing two 3/2 slopes for a single tube (Exhibit 74)	171	167
175	Diagram showing three 3/2 slopes for a single tube (Exhibit 75)	171	169
176	Logarithmic diagram corresponding to Exhibit 67, Figure 27 (Exhibit 76)	171	170

Ex. No.	*Designation.*	*Offd. Page*	*Ptd. Page*
177	Comparative diagram for DeForest tube 7-A and General Electric tubes VT-11 and VT-13 (Exhibit 77)	198	182
178	Volt-ampere diagram for small Western Electric tube (Exhibit 78)	198	183
179	Logarithmic diagram corresponding to Exhibit 78, Figure 44 (Exhibit 79)	198	185
180	Diagram for small Western Electric tube, corrected for contact potential difference (Exhibit 80)	198	186
181	Logarithmic Diagram corresponding to Exhibit 80, Figure 46 (Exhibit 81)	198	187
182	Diagram showing volt-ampere and volt-ohm characteristics for VT-1 tube (Exhibit 82)	198	188
183	Diagram showing logarithmic volt-ampere characteristic for VT-1 tube (Exhibit 83)	199	189
184	Diagram showing plate current-grid volt characteristics for VT-1 tube (Exhibit 84)	199	190
185	Diagram for type W radio transmitting tube (Exhibit 85)	199	191
186	Logarithmic diagram for type W radio transmitting tube (Exhibit 86)	199	192
187	Diagram showing characteristics for type G power tube (Exhibit 87)	199	193
188	Diagram showing logarithmic characteristic for type G power tube (Exhibit 88)	199	194

Ex. No.	*Designation.*	*Offd. Page*	*Ptd. Page*
189	Diagram showing characteristics for type I power tube (Exhibit 89)	199	196
190	Diagram showing logarithmic characteristic for type I power tube (Exhibit 90)	199	197
191	Diagram obtained by pushing a VT-1 tube to excessive voltages (Exhibit 91)	209	203
192	Logarithmic diagram corresponding to Exhibit 91, (Figure 57) Exhibit 92	209	204
193	Diagram for a VT-1 tube to excessive voltage and then for decreasing voltages (Exhibit 93)	209	206
194	Logarithmic diagram corresponding to Exhibit 93, Figure 59 (Exhibit 94)	210	207
	(Above Exhibits 140-194 are indexed on pp. 462-465 of the Interference record.)		
195	Arnold Exhibit No. 95, Tube for Figs. 8, 12, 13 and 14;		
196	Arnold Exhibit No. 96, Tube for Figs. 15 and 16;		
197	Arnold Exhibit No. 97, Tube for Figs. 17, 18 and 19;		
198	Arnold Exhibit No. 98, Tube for Fig. 20;		
199	Arnold Exhibit No. 99, Tube for Figs. 21, 22 and 40;		
200	Arnold Exhibit No. 100, Tube for Figs. 23, 24 and 39;		
201	Arnold Exhibit No. 101, Tube for Figs. 25 and 26;		

Ex. No.	Designation.	Off'd. Page	Ptd. Page
202	Arnold Exhibit No. 102, Tube for Figs. 27 and 41;		
203	Arnold Exhibit No. 103, Tube for Fig. 28;		
204	Arnold Exhibit No. 104, Tube for Figs. 36, 37 and 38;		
205	Arnold Exhibit No. 105, Tube for Figs. 44, 45, 46 and 47;		
206	Arnold Exhibit No. 106, Tube for Figs. 48, 49 and 50;		
207	Arnold Exhibit No. 107, Tube for Figs. 51 and 52;		
208	Arnold Exhibit No. 108, Tube for Figs. 53 and 54;		
209	Arnold Exhibit No. 109, Tube for Figs. 55 and 56;		
210	Arnold Exhibit No. 110, Tube for Figs. 57 and 58;		
211	Arnold Exhibit No. 111, Tube for Figs. 59 and 60.		
	(A table of the above physical exhibits 195-211 appears on pp. 678-679 of the Interference record.)		
212	Direct volt-ampere plot for unbaked tubular bulb (Exhibit 112)	273	240
213	Logarithmic volt ampere plot for unbaked tubular bulb (Exhibit 113)	273	242
214-222 inclusive	Diagrams for batch of unbaked tubes pumped and tested December 12 and 13, 1919 (Exhibit 114)	293	278-286
223	Volt ampere diagram for tube of van der Bijl rebuttal XQs. 192 and 201 (Exhibit 115)	307	294

Ex. No.	*Designation.*	*Offd. Page*	*Ptd. Page*
224	Diagram for tube No. 35 (Exhibit 116)	307	295
225	Diagram for tube No. 36 (Exhibit 117)	307	296
226	Diagram for tube No. 38 (Exhibit 118)	307	297
227	Diagram for tube No. 45 (Exhibit 119)	307	298
228, 229 and 230	Diagrams for tube No. 50 (Exhibit 120)	307	299-301
231, 232 and 233	Diagrams for tube No. 67 (Exhibit 122)	307	302-304
234	Diagram for tube No. 67 (Exhibit 122)	331	329
235	Langmuir Exhibits 16 and 18 plotted together		367
236	Logarithmic Diagram for Von Baeyer data (Phys. Zeit. 10, 5, 169-1909)		403
237	Certified copy of Armstrong testimony in Marconi v. DeForest case (Exhibit 125)	493	(not printed in this volume.)
	(Above Exhibits 212 to 237 are indexed on pp. 465, 466 of the Interference record.)		
238	(3) Photostat copy of Richard's Book 4, pp. 137, 138 and 165. Dates and Diagrams for meeting with DeForest; address of McCandless; and notes on the artificial transcontinental line test.		
239	(1) Audion 7-A. A Physical Exhibit.		
240	(1) Photograph of Audion 7-A.		

Ex. No.	*Designation.*	*Offd. Page*	*Pld. Page*
241	(1) Audion No. 11. A Physical Exhibit.		
242	(1) Photograph of Audion No. 11.		
243	(1) Arnold diagram of audion circuits for November 1, 1912.		
244	(13) Photostat copy of Pierce Book 20, pp. 16 to 41 inclusive. Tests of DeForest Audion 7-A.		
245	(11) Blueprints of sketches accompanying Exhibit 7.		
246	(1) Comparative diagram for Audion 7-A and type G pliotron (Vt-13)		
247	(11) Photostat and blueprint copy of Pierce-Arnold memorandum of December 18, 1912, on "Efficiency of the Audion."		
248	(2) Copy of order for molecular pump.		
249	(1) Photostat copy of Letter to Crandell of March 17, 1913, fixing date of Arnold's trip to Princeton.		
250	(1) Photostat copy of Kendall Book 25, page 25, noting arrival of new molecular pump.		
251	(7) Photostat copy of Trimble Book 18, pp. 89 to 95. Record of pumping twenty audions in January, 1913.		
252	(4) Photostat copy of Arnold-Nicolson 3/2 law memorandum.		
253	(7) Photostat copy of Arnold-Kendall 3/2 law computations.		

Ex. No.	Designation.	Offd. Page	Ptd. Page
254	(2) Photostat copy of Arnold letter to Millikan of May 5, 1913, giving 3/2 law computations.		
255	(8) Photostat copy of Pierce Book 20, pp. 101 to 115, relating to use of new molecular pump with Audions 20, A and B.		
256	(4) Blueprints of sketches accompanying Exhibit 18.		
257	(2) Photostat copy of selected cards from Trimble's card index. Cards 1 to 10, 23, 64 and 100.		
258	(3) Photostat copy of Kendall Book 25, pp. 39, 40 and 50, relating to the audion installation at Philadelphia.		
259	(3) Photostat copy of Kendall Report of September 10, 1913, on two-way audion repeater with artificial lines.		
260	(8) Photostat and blueprint copy of Kendall memorandum of October 1, 1913, on the use of the audion for repeating.		
261	(1) 2 Blueprint of Kendall cord circuit audion repeater drawing of October 2, 1913.		
262	(1) Photostat copy of Kendall Book 42, page 5, on the commencement of commercial service at Philadelphia.		
263	(3) Photostat and blueprint copy of Kendall Report of October 22, 1913, on commercial operation of audion at Philadelphia.		

Ex. No.	*Designation.*	*Offd. Page*	*Ptd. Page*
264	(1) Photostat copy of Kendall Book 42, page for December 20, 1913. Record of commercial service for audions at Philadelphia.		
265	(1) Audion 6.11, a Physical Exhibit.		
266	(1) Photograph of Audion 6.11.		
267	(1) Audion 64, a Physical Exhibit.		
268	(1) Photograph of Audion 64.		
269	(1) Audion 100, a Physical Exhibit.		
270	(1) Photograph of Audion 100.		
271	(2) Photostat copy of Pierce Book 20, pp. 182 and 183, and ES-93571. Data on Audion 9.111.		
272	(2) Photostat copy of Colpitts' Memorandum of March 27, 1913, on audion improvements.		
273	(1) Photostat copy of Nicolson's daily memorandum sheet for February 4, 1913, fixing date for Exhibit 15.		
274	(2) Photostat copy of Richards' Book 4, pages 155 and 156, on connecting audion grid and plate with a high resistance leak.		
275	(1) Photostat copy of Pierce Book 20, page 146, showing resistance-capacity combination in audion plate circuit.		
276	Lip Test Record in April, 1914.	39	
277	Data from Langmuir's Lamp #2 of November, 1912.	40	

Ex. No.	*Designation.*	*Offd. Page*	*Ptd. Page*
278	Plot to exhibit the inaccuracy of a straight line relation between I 2/3 and E as an indicator of high vacuum.	41	

(Above Exhibits 238 to 278 are listed on pp. 2281-2284 of the Interference record, and the documentary exhibits among them, mostly blueprints and photostat copies, are bound in a single buckram-covered volume.)

Mr. Richmond: I wish to offer in evidence fifteen patents granted to the General Electric Company as assignee as follows: I have them here in order—Dushman No. 1,172,961; and Hawkins——

Mr. Davis: Just a moment, please. Application filed May 20, 1915. I would like to ask for what purpose the offer is made, against which patent and so on?

Mr. Richmond: They are all offered against the patent that we call No. 1, and they all contain admissions against interest.

(Discussion)

Mr. Davis: If your Honor please, my objection now is to the immateriality of that statement, the Arnold patent to which reference has just been made, 1,114,845, Interference record page 2345 sets up this protective device as a device to prevent blue haze in the tube.

The Dushman patent to which our attention has just been called sets up that an accident may happen by which the tube is exposed to very considerable over-voltage, or something of that sort, and puts in a protective device to protect the tube in case of that accident. In one case you are protecting the tube against its own bad construction and blue hazing on account of its own fault, and in the other case you are protecting against external electro motive force. I do not think any suggestion can be drawn such as my brother suggests and I think that patent is immaterial.

MR. HAIGHT: I do not take it that your Honor wants to go through all of these patents, and weigh them now; if they are immaterial they can do no harm.

THE COURT: No. Of course, you would not offer them on that basis, except as a remote protective bit of evidence; but do you mind pointing out as to this patent which is under consideration, your reply to Mr. Davis?

(Discussion.)

(Received in evidence and marked "Defendant's Exhibit No. 280." *See Volume VI, Defendant's Exhibits, page 1126.*)

MR. RICHMOND: The second patent in the list is Hawkins No. 1,172,990.

(Received in evidence and marked "Defendant's Exhibit No. 281." *See Volume VI, Defendant's Exhibits, page 1130.*)

MR. RICHMOND: Meikle No. 1,182,290.

(Received in evidence and marked "Defendant's Exhibit No. 282." *See Volume VI, Defendant's Exhibits, page 1133.*)

MR. RICHMOND: Meikle No. 1,266,517.

(Received in evidence and marked "Defendant's Exhibit No. 283." *See Volume VI, Defendant's Exhibits, page 1137.*)

MR. RICHMOND: Langmuir No. 1,273,628.

(Received in evidence and marked "Defendant's Exhibit No. 284." *See Volume VI. Defendant's Exhibits, page 1141.*)

Mr. Richmond: Langmuir reissue No. 15,278.

(Received in evidence and marked "Defendant's Exhibit No. 285." *See Volume VI, Defendant's Exhibits, page 1144.*)

Mr. Richmond: Berg No. 1,352,242.

(Received in evidence and marked "Defendant's Exhibit No. 286." *See Volume VI, Defendant's Exhibits, page 1150.*)

Mr. Richmond: White No. 1,365,576.

(Received in evidence and marked "Defendant's Exhibit No. 287." *See Volume VI, Defendant's Exhibits, page 1153.*)

Mr. Richmond: Pratt No. 1,374,679.

(Received in evidence and marked "Defendant's Exhibit No. 288." *See Volume VI, Defendant's Exhibits, page 1157.*)

Mr. Richmond: Alexanderson No. 1,477,413.

(Received in evidence and marked "Defendant's Exhibit No. 289." *See Volume VI, Defendant's Exhibits, page 1160.*)

Mr. Richmond: White No. 1,506,468.

(Received in evidence and marked "Defendant's Exhibit No. 290." *See Volume VI, Defendant's Exhibits, page 1163.*)

Mr. Richmond: Hull No. 1,523,776.

(Received in evidence and marked "Defendant's Exhibit No. 291." *See Volume VI, Defendant's Exhibits, page 1168.*)

Mr. Richmond: Alexanderson No. 1,535,082.

(Received in evidence and marked "Defendant's Exhibit No. 292." *See Volume VI, Defendant's Exhibits, page 1178.*)

Mr. Richmond: Alexanderson No. 1,549,737.

(Received in evidence and marked "Defendant's Exhibit No. 293." *See Volume VI, Defendant's Exhibits, page 1181.*)

Mr. Richmond: Langmuir No. 1,558,437.

(Received in evidence and marked "Defendant's Exhibit No. 294." *See Volume VI, Defendant's Exhibits, page 1194.*)

Mr. Richmond: In addition to the Dushman patent already discussed, another patent on protective devices, is the Hawkins Patent No. 1,172,990. Those two patents are classified together.

Mr. Davis: To which I make the same objection I made to the Dushman patent, being immaterial, and irrelevant to any issue in the case.

Mr. Richmond: The three patents, Meikle No. 1,182,290; Meikle No. 1,266,517 and White No. 1,365,576, state that the vacuum in an incandescent lamp is the proper criterion for the vacuum in a pure electron discharge device.

The Court: To satisfy my curiosity will you tell me about when that group was issued or applied for?

Mr. Richmond: Yes, your Honor. One of them was applied for on October 9, 1914. Another on the same date.

The Court: You need not run through them all.

Mr. Richmond: And the Meikle Patent No. 1,182,290 states on page 1, line 16:

> "My device is distinguished in one aspect from various prior devices containing an incandescent cathode by the presence of an inert gas at a considerable pressure, as distinguished, for example, from the highly attenuated residual trace of gas present in an envelop exhausted to what is termed a 'lamp vacuum.'"

Mr. Davis: This is entirely characteristic of this whole mass of exhibits. In the first place, the Meikle patent has to do with a high pressure device.

Mr. Richmond: And it distinguishes it from low pressure devices.

Mr. Davis: And in the second place, it is part of the same fallacy that has pursued us from the beginning of the motion to dissolve, that the invention here was a vacuum. It is not a vacuum, and never was and never will be. It is a tube, and it is not even a tube with a particular vacuum, but with a vacuum that will depend on the geometry of the tube, as has been brought out.

The Court: But it does what? You state in the negative. Do you mind telling generally what it is?

Mr. Davis: The invention, as I look at it, if your Honor please, is a tube in which the relation of the parts, the geometry of the tube, the nature of the gas, the amount of the gas, are so co-ordinated that a pure electron discharge will flow above ionization voltages.

Mr. Richmond: The vacuum is a very important factor.

Mr. Davis: The vacuum is one of the elements in the thing. The point I am trying to make is that these gentlemen have already demonstrated to our entire satisfaction, by certain tests taken and made on the motion to dissolve, that it is possible to have the discharge in a very poor vacuum relatively speaking, by very ingenious modification of the construction of the tube.

The tube which was put in evidence the other day by Dr. Kelly, the helium tube, will probably turn out to be such a tube, that is, probably turn out to be a tube having a pure electron discharge at two microns of helium owing to the ingenious relation of geometry in the tube, putting the grid very close to the anode, and so forth. I am perfectly willing to admit that by the year 1914, incandescent lamps had been made which had vacua which was as high as was necessary to be used in tubes having a certain geometry. That is all I want to say now.

The Court: Just a moment, Mr. Darby. Taking claim 11 of the first patent, as an instance:

"A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

Possibly it was from that claim that I rather gathered the impression that the novelty of this invention, that the patentable novelty of this invention, if patentable novelty there is, is at least centred around, or purposed upon the degree to which the space in that envelop is evacuated.

Mr. Davis: With reference to the geometry of the tube——

The Court: I would not have caught that from claim 11 possibly, without having my attention called to it; and then I want to say, I do not see it there now, but I will put the burden on you in showing to me in your brief, or argument at some other time. I may have missed that point.

(Discussion.)

The Court: Well, I get that your voltages which may be impressed upon the plate before ionization is produced, or results, is dependent upon several things, including the geometry of the tube, the degree at which the tube is evacuated, and the nature of the gas remaining in the tube. I am guessing at those things, but as I recall them, they constitute some.

(Discussion.)

Mr. Davis: And I have only to say, with reference to Claim 11, if your Honor please, that if the geometry of the tube were one geometry, then, a particular vacuum expressed in microns would produce a tube and these things would happen, and with some other geometry, the same microns would not produce such a tube.

(Discussion.)

Mr. Darby: Yes, sir; but what I wanted to interrupt Mr. Richmond about, is from my phase of the case, anticipation and lack of invention, because of this phrase that has crept into the case: "The geometry of the tube." It is not in the claims, and I listened patiently to find some witness testify to it, and to find some witness to point out where, in the patent, it refers to it; but thus far, it is in through the statement of counsel, and I might call your Honor's attention to the prosecution of the Langmuir Patent No. 1 in suit, where, in the office letter of February 28, 1914, the Examiner said: "If applicant's device is an improvement over the reference, he should define the difference by structural limitations."

That is your geometry tube. The answer to that was in the following amendment which was: "The structural limitations in this case are to be found in the differences of vacuum."

So I do not want your Honor to get confused on this geometry of the tube.

(Discussion.)

Mr. Davis: If there is one thing settled in the patent law, it is that correspondence of that sort is not to be used to limit or interpret the patent. That has been decided over and over again.

(Discussion.)

Mr. Davis: I have here one of the H tubes in which the distance between the anode and cathode looks considerably more than a quarter of an inch, that is an illustration of what my brother just says it depends upon the voltage and conditions of the tube; but I would like to have your Honor appreciate, which is a scientific fact, not an argument, that the question of course is as to whether the current that flows through the tube is substantially influenced by ionization. That is what we are all talking about now. The amount of ionization will depend on the nature of the gas, because some gases ionize at one voltage or begin to, and some at another; on the quantity of the gas and on the length and breadth of the path that the current flows through, because if you have two plates very close together, and of large area, and send a milliampere scattered over that large area, and a very short distance, you have one condition; whereas, if you have the plates a long distance apart, and perhaps smaller, so that your path is longer and smaller area then you have more chance of ionization.

The Court: Of collision?

Mr. Davis: Yes, sir, and when you talk about the geometry of the tube, that is the sort of thing we are talking about.

The Court: I understand.

Mr. Richmond: In the third group of these patents, there is only one patent, Langmuir reissue No. 15,278.

Mr. Davis: I understand this is offered because it contains that statement that was stricken from the original application; is that right?

Mr. Richmond: I will look at it and see.

Mr. Davis: If that is the only reason, I will not object to it.

Mr. Richmond: Yes, because it says that heating by bombardment is not essential.

Mr. Davis: I think that my brother is entitled to show that that error was made.

Mr. Richmond: It was made repeatedly, your Honor.

Mr. Davis: He is entitled to show it was made repeatedly. I shall not object.

Mr. Richmond: And I would like to know when the error was corrected in the first patent in suit.

Mr. Davis: You know the history which is in evidence.

Mr. Richmond: It was not until after the case had finished its course through the Court of Appeals in the District of Columbia.

The Court: Does your reference show that?

Mr. Richmond: Yes.

Mr. Davis: And my brother knows as well as I do that it was impossible to correct it during all these long years the Interference was going on.

The Court: Whatever the effect is, the file wrapper will show what the amendment was and when it was made.

Mr. Richmond: It is not impossible, your Honor, to give notice of such matters. The moment the error was detected, it could have been made a matter of record.

(Discussion.)

Mr. Davis: I have several times called attention to the fact that if an assignee is to be held responsible for all the statements made by every inventor whose application is purchased or filed, that most corporations would stop filing patent applications. There is no case ever decided by a court that I know of in which such a responsibility was imposed upon a patent owner.

Mr. Richmond: My next group of patents comprises two patents: Pratt No. 1,374,679 and White No. 1,506,468. Both of these patents state that the problem or task of evacuating the tube is substantially the same whether it is to be operated as a gas tube or as a high vacuum tube. In the case that the tube is to be operated as a gas tube, it is important, they say, to get out all of the residual gases free and occluded, so that the gas to be employed shall be pure, so that the problem is the same whether it is to be a gas-operated tube or a gas-free tube.

Those statements are of interest in connection with the comparison of Arnold's work with his Arnold mercury arc tube and his later work with the high vacuum audion.

Mr. Davis: To which I object, for the same reason, which, of course, is obvious, that if you want a certain amount of gas in the tube, you do not want any more. One of the things which followed from Dr. Langmuir's work was an enormous improvement in gas tubes; when once he learned how to make a tube, and from our point of view he was the first man who did, which was not continually giving off great quantities of gas, it was possible to produce a tube like the 200 tube, of which circulars were put in evidence, that is, a tube in which you definitely insert a specific quantity of gas, which is introduced to make it a more sensitive detector. You know how much there is in there, and its contents stay the same which is an enormous improvement over the DeForest audion.

My next group of patents comprises three: Berg No. 1,352,242; Alexanderson, No. 1,477,413, and Langmuir, No. 1,558,437. The Berg patent relates to what would appear to be clearly a high vacuum audion, but refers to it as a receiving device, 11, of the audion type. That is a terminology that appears in——

Mr. Davis: May I see the patent?

Mr. Richmond: It appears in all three of these patents. In the Langmuir patent, the claim is actually directed to a patent of the audion type. Now, a good deal has been said in this case to indicate that the audion is something different from the pliotron or high vacuum device, and I want to show that the General Electric Company was so far unconscious of the essential difference that they referred to their devices as of the audion type.

Mr. Davis: To which I object. It does not show that they did so refer to their devices. Dr. Berg is not one of the regular engineers of the General Electric Company, and has not been for many years. He is a professor of Union College. It is illustrative of how these things come in.

Mr. Richmond: The patent is issued to the General Electric Company as his assignee. It seems to me if it prosecutes and takes out the patent——

The Court: I understand your contention.

Mr. Richmond: Those are all.

The Court: Then after assigning of the application, your contention being that the whole procedure in connection with the prosecution of the patent application is under the control of the assignee?

Mr. Richmond: Yes, your Honor.

The Court: And consequently it becomes the assignee, and not the inventor who phrases the amendments, and obtains the claim; is that all of your patents?

Mr. Richmond: That is all.

Mr. Haight: With the reservations that were made yesterday, with the reservation regarding Mr. Waterman's testimony, the defendants rest.

The Court: Mr. Waterman and Mr. Sarnoff.

Mr. Haight: Yes.

The Court: What were those reservations?

Mr. Haight: That we would have an opportunity to show by some one from the Patent Department of the Telephone Company, or some one else who knew, the facts as to the delay in filing the application between April, 1915 and November, 1915. I am not sure that there is any one who can furnish the primary evidence, but we will ascertain that over the week-end.

The Court: All right.

Defendant Rests.

DEFENDANT'S DEPOSITIONS.

IN THE UNITED STATES DISTRICT COURT,
EASTERN DISTRICT OF NEW YORK.

General Electric Company,
Plaintiff,
v.
DeForest Radio Telephone & Telegraph Company and McPhilben Radio Electric Corporation,
Defendants.

IN EQUITY.
No. 1723.

General Electric Company,
Plaintiff,
v.
McPhilben Radio Electric Corporation and DeForest Radio Telephone & Telegraph Company,
Defendants.

IN EQUITY.
No. 1724.

Depositions taken *de bene esse* and in *perpetuam rei memoriam,* before W. W. Healey, notary public, at Crocker National Bank Building, 620 Market Street, San Francisco, California, beginning Monday, November 3, 1924, at 11 o'clock in the forenoon, pursuant to notices attached hereto.

Present: SAMUEL E. DARBY, JR., and EDGAR F. BAUMGARTNER, counsel for defendants;
S. O. EDMONDS and CHARLES MCCLAIR, counsel for plaintiff.

MRS. A. W. F. BECK.

Mrs. A. W. F. Beck (Helene Beck), witness produced in behalf of the defendants, being first duly sworn, deposes in answer to questions propounded to her, as follows:

By Mr. Baumgartner:

Q. 1. Please state your name, residence and occupation.

A. Helene Beck, 1061 Church Street; Ampoule, manufacturer.

Q. 2. Were you ever employed before you went into this business, and if so, by whom?

A. Yes; by G. E. Lamont.

Q. 3. What was his business?

A. Scientific glassblower.

Q. 4. Between what dates were you employed by him and what were your duties?

A. Year of 1900, I wouldn't remember the date, until November, 1920. Helper—making the filaments of incandescent lamps, exhausting X-ray tubes, exhausting lamps—general shop duty; also kept the books.

Q. 5. Did Mr. Lamont keep any accounts?

A. Yes.

Q. 6. What was the nature of them and who kept them?

A. All entries were made in the books—I made the entries in the books and made out bills.

Q. 7. Did the work done by you in Mr. Lamont's shop include any work on radio devices?

A. Yes.

Q. 8. Do you know who that was done for?

A. Federal Telegraph Company; National Telegraph Company; Herald College; Professor Jahnke; Mr. Hewlett.

Q. 9. What work was done on the radio devices that you refer to?

A. Repairing and exhausting audion bulbs—filaments repaired and exhaustion.

Q. 10. What do you mean by filaments repaired?

A. Taking out the old and putting in new filaments.

Q. 11. Is there any record that would show when such work was done?

A. Yes, somewhere around 1912, I don't know just the dates, the records are in Mr. Lamont's books.

Q. 12. You refer to the same books that you mentioned above?

A. Yes.

Q. 13. Would you recognize those books if you saw them now?

A. Yes.

Q. 14. I hand you these two books and ask you to state what they are.

A. These are the books that I kept for Mr. Lamont—in my own handwriting; from 1907, January to May, 1912 (book marked "Order book"). And the next book June, 1912, to July, 1918 (book marked "Cash").

Q. 15. What kind of filaments were the new filaments that you say you put in?

A. Tungsten.

Q. 16. Where were those Tungsten filaments secured from, if you know?

A. They were burned-out incandescent lamps.

Q. 17. Do you know where the lamps were got from?

A. Usually from lamps that we had about the place.

Q. 18. Do you know where they came from before they were in your place?

A. If I remember right, they were from Paul Seiler Electrical Company.

Q. 19. Who took the filaments out of the lamps and made the new filaments that you have referred to?

A. I did.

Q. 20. In the book marked "Cash" I find an entry on page 8 relating to the Federal Telegraph Company. Please explain what each item of that entry means?

A. September 19, 1912, Federal Telegraph Company, eighteen audion lamps exhausted—thirty cents each—$5.40—paid October 17, 1912. It means the exhausting of the eighteen audion bulbs—which means taking all the air out of them and producing as high a vacuum as possible.

Mr. Edmonds: Answer objected to as an interpretation of the book entry.

Q. 21. Who made that book entry that I referred to in question 20?

A. I did.

Q. 22. Who did the work that is referred to by that entry?

A. Mr. Lamont and myself.

Q. 23. When was that book entry made?

A. September 19, 1912.

Q. 24. When were the figures 10.17.12 entered?

A. 10/17/12—that's the date it was paid.

Q. 25. How was the exhausting that you refer to done?

A. Said article was put on mercury pump and the air extracted therefrom.

Q. 26. Can you briefly describe the pump?

A. Yes. The audion was first put on what we call a grinding and was put on a mercury pump which produces a very high vacuum and when high enough is sealed directly from the pump.

Q. 27. Will you mention some of the parts of the pump and tell how they operated?

A. First vacuum is obtained by preliminary pump for first twenty-nine inches and is finished by means of mercury. The percolator which receives the mercury, the percolator holds sixteen pounds of mercury, is first brought up by a small metal lift pump—flows out of a rubber tube to glass pump through a small jet into what we term glass shaft, running out into another receptacle back to the automatic lift.

Q. 28. Would you recognize a picture of the pump if you saw it?

A. Yes.

Q. 29. Can you mention some identifying characteristic of the preliminary pump that you spoke of?

A. Yes, the cylindrical pump with pistons.

Q. 30. Can you say what is shown in that picture?

Mr. Edmonds: Objected to as leading, the memory of the witness not having previously been exhausted with respect to the construction and operation of the apparatus.

A. Yes, I recognize the pump as the one I worked with.

Q. 31. When did you work with that pump?

A. Off and on the full time I worked with Mr. Lamont, that is, when the pump was needed.

Q. 32. With what pump did you exhaust the audions concerning which you have previously testified?

A. The same pump as is shown in the photograph.

Q. 33. Can you say what is shown in this picture?

Mr. Edmonds: Same objection as before.

A. Yes, this is the preliminary pump, preliminary vacuum pump.

Q. 34. Is that the preliminary vacuum pump that you previously mentioned?

A. Yes.

(The photograph referred to in Question 30 is offered in evidence as Defendant's Exhibit "A"—Lamont Mercury Pump.) (Admitted in evidence, Record, page 916, as Defendant's Exhibit No. 70. *See Volume VI, Defendant's Exhibits, page 1034.*)

(The photograph referred to in Question 33 is offered in evidence as Defendant's Exhibit "B"—Lamont Preliminary Pump.) (Admitted in evidence, Record, page 916, as Defendant's Exhibit No. 71. *See Volume VI, Defendant's Exhibits, page 1035.*)

Mr. Edmonds: Objected to as not proven.

Q. 35. Please describe the manner in which you proceeded in exhausting audion tubes, concerning which you have testified, by the use of the pumps shown in these pictures.

A. You first start the preliminary pump for the first twenty-nine inches of vacuum; the audion is placed on pump by means of a grinding seal; when this is obtained, preliminary pump is shut off by means of a glass stop cock; automatic lift is then used forcing the mercury in the percolator above which forces the mercury down the rubber tube into a glass pump through a small jet into a straight shaft to a lower receptacle and in to the automatic lift; by this means the air is exhausted from the audion above, which is heated at a very high temperature. The mercury flowing through the shaft shows the air taken from the audion, by means of small bubbles, which in time grows smaller and gradually disappears. Under this high temperature and the bubbles disappearing shows that we have a very high vacuum. Then the audion is sealed from the pump.

Q. 36. What was the condition of the audion filament while it was on the mercury pump?

Mr. Edmonds: Objected to as leading.

A. The filament was lit up to drive off all excess gases.

Q. 37. Can you point out any differences between the pump, the mercury pump as it is shown in Defendant's Exhibit "A" and the pump as it existed in 1912 to 1914?

A. There is a very slight difference, and that is the mercury was lifted by hand.

Q. 38. How was the mercury lifted as shown in the machine in Defendant's Exhibit "A"?

A. By means of sixteen-pound bottles and thrown in the percolator above.

Q. 39. To what period of time does your answer refer?

A. I don't just remember the time that happened.

Q. 40. Do you know approximately about how long sixteen-pound bottles were used?

A. As I said before, I have an idea between the years 1913 and 1914.

Q. 41. Then what was used?

A. The automatic lift.

Q. 42. Does that appear in the photograph of Defendant's Exhibit "A"?

A. Yes.

Q. 43. Please mention some identifying characteristic that would indicate where the automatic lift is shown in the photograph?

A. A small pump, with a large wheel, with rubber tubes connecting; also the glass tubes which takes the mercury up to the percolator.

Q. 44. Please mark the wheel with the letter "A"—the rubber tube with the letter "B"—the glass tube with the letter "C", and the percolator with the letter "D."

A. Witness does as requested.

Q. 45. Did Mr. Lamont or yourself in performing work in Mr. Lamon't shop, use any other vacuum pumps during the years 1912 to 1914 than those shown in Defendant's Exhibits "A" and "B"?

A. No.

By Mr. Darby:

Q. 46. Referring now to the entry on page 8 of the notebook, under date of September 19, 1912, do you recall whether or not the eighteen audion lamps referred to were received by you in a sealed or unsealed condition?

A. Sealed.

Q. 47. I call your attention to page 14 of the record book, under date of December 9, 1912, where the entry reads: "National Wireless Tel. & Tel., Co., 3 audion tubes rep., 200 ea. 600." Is that entry in your handwriting?

A. Yes.

Q. 48. Did you do the work concerning which the entry is about?

A. Both Mr. Lamont and I did the work.

Q. 49. Do you recall what work was done, in connection with the work referred to by the entry?

A. Yes.

Q. 50. What was it?

A. New filaments and exhaustion.

Q. 51. What does the entry 200 ea. mean?

A. Two dollars each.

Q. 52. What kind of filaments were used as the new filaments you refer to, if you know?

A. Tungsten.

Q. 53. Were the tungsten filaments for this order likewise acquired from incandescent lamps?

Mr. Edmonds: Objected to as leading.

A. Yes.

Q. 54. Did you ever acquire tungsten filaments for use in audion tubes from any source other than from incandescent lamps?

A. No.

Q. 55. I call your attention to page 18 of the record book, under date of February 13, 1913. Can you tell from that entry what work was done on the eleven audion bulbs mentioned, and if so, please state?

A. Audions were exhausted.

Q. 56. By that do you mean that they were put on the pumps concerning which you have testified above?

Mr. Edmonds: Same objection.

A. Yes.

Q. 57. I call your attention to page 50 of the record book, under date of June 19, 1914, reading "Herrold College, 6 audions rep. new filaments." Is that entry in your handwriting?

A. Yes.

Q. 58. Are all the entries in this book in your handwriting?

A. Yes.

Q. 59. On the same date, namely, June 19, 1914, there is an entry for the Federal Telegraph Company —"8 audions exh." Will you please state, if you know, what work was done for each of those customers?

A. New filaments and exhaustion for the Herrold College—the Federal was exhaustion only.

Q. 60. I call your attention to page 76, under date of July 7, 1915, "Marconi Wireless Telegraph Company of America—6 audion bulbs rep. & exh." Can you state what work was done on that order?

A. New filaments and exhaustion.

Q. 61. In the work concerning which you have testified, where new filaments were put in audion tubes, who actually mounted the new filaments on their support in the tubes, if you know?

A. I did.

Q. 62. What were the physical characteristics of the tungsten filaments you secured from the incandescent lamps?

A. They acted just like wire.

Q. 63. What I was endeavoring to ascertain was whether it was brittle, ductile, hard, soft, etc.; can you tell me a little more about the physical characteristics?

MR. EDMONDS: Objected to, the witness being obviously unqualified.

Q. 64. I will waive the answer for a minute and ask you if you personally handled the tungsten filament?

A. Yes.

Q. 65. Will you then please answer my question No. 63?

MR. EDMONDS: Objected to as before.

A. I could handle the tungsten just like wire—could bend it in any shape.

Q. 66. Did you actually bend it?

A. Yes.

MR. EDMONDS: Objected to as leading.

Q. 67. Will you please describe the appearance of the audion tubes or bulbs which you either alone or with Mr. Lamont worked on and concerning which you have testified up to the present time?

A. It is a bulb with, as we termed it, with two grids and one filament sealed.

Q. 68. What was the shape of the bulb?

A. Round.

Q. 69. Would you be able to recognize a bulb of the type that you worked on if you should see one?

A. Yes.

MR. DARBY: I offer in evidence the record books identified by the witness. The one named "Cash" as Exhibit C, and the one named "Order Book" as Exhibit B.

(Admitted in evidence, Record, page 917, as Defendant's Exhibits Nos. 74 and 75. *See Volume VI, Defendant's Exhibits, pages 1038 and 1048.*)

Q. 70. I show you an audion structure and ask you if this in any way resembles the type of audion tubes that you worked on in accordance with your testimony thus far taken?

Mr. Edmonds: Objected to as leading, the memory of the witness concerning the construction not having been previously exhausted.

A. Yes.

Q. 71. Does it differ in any respect?

Mr. Edmonds: Same objection.

A. No.

(Adjourned until 2.15 P. M.)

Met pursuant to adjournment.

Parties present as before.

Mr. Darby: I offer in evidence the audion structure referred to in the witness's last answer as Defendant's Exhibit E.

(Admitted in evidence, Record, page 920, as "Defendant's Exhibit No. 83," and afterwards withdrawn as an exhibit.)

Mr. Edmonds: Objected to as not proven.

Q. 72. I call your attention to your answer to Q. 35, where you state, "Under this high temperature, etc.," and ask you what you mean by that expression?

A. Seeing that the bubbles have entirely disappeared, and under this high temperature.

Q. 73. What was it that had the high temperature?

A. A gas burner on the outside of the bulb.

Q. 74. What did the gas burner heat?

A. The exterior of the audion.

Q. 75. Do you know to what degree the audion bulb was heated?

A. About 600 degrees Fahrenheit.

Q. 76. Was the pump in operation while the audion bulb was heated?

A. Yes,

Q. 77. Will you please apply reference letter "F" to the burner you have referred to, Exhibit A?

A. I have done so.

Q. 78. Will you please state what the cone-shaped member I have marked "G" is and what was its purpose?

A. An asbestos hood—it was to keep the heat in from the gas.

Q. 79. Do you mean the gas burner "F"?

A. Yes.

Q. 80. I hand you a glass structure and ask you, first, if you have ever seen this before—if so, where, and under what circumstances, and whether or not you know what it is, who it was made by and for whom it was made?

Mr. Edmonds; Objected to as leading.

A. Yes, I have. In Mr. Lamont's place of business—when he was making it. An audion bulb. Mr. Lamont made it—for Professor Jahnke—I believe that is the way you spell it; I am not sure.

Q. 81. Do you know approximately when that audion bulb was made by Mr. Lamont for Mr. Jahnke?

Mr. Edmonds: It is understood the last previous objection applies to further testimony of witness bearing upon the structure shown her.

A. Somewhere around 1908 or 1909.

Q. 82. Did you personally take part in the construction of any part of that audion bulb?

A. Yes, I mounted the filament.

Q. 83. Is there any record in the books of Mr. Lamont for that work?

A. I believe so.

Q. 84. I hand you record book "Exhibit 'C'" and ask you to please endeavor to locate the entry relating to the construction of this audion tube.

A. This was entered by Mr. Lamont September 4, 1909, 2 Audion Receivers.

Mr. Edmonds: Objected to.

Q. 85. Do you know whether or not more than two of this type of audion bulb were made for Professor Jahnke?

A. I think there were more, but I couldn't state how many.

Q. 86. I call your attention to an entry in this same book, under date of November 3, 1909, and ask you, first, in whose writing this entry appears?

A. My own.

Q. 87. The entry reads—A. Jahnke two special apparatus, $22.50. Will you please state, if you know, what special apparatus was referred to?

A. That I do not know.

Q. 88. Did Professor Jahnke have work other than the construction of audion tubes like the one you have been shown, done by Lamont?

A. No, not that I know of.

Q. 89. Do you know what kind of filament you put in the audion tube made for Jahnke?

A. Yes, Tungsten.

Mr. Darby: I offer in evidence the audion tube manufactured for Jahnke, identified by the witness, as Defendant's Exhibit "F"—Jahnke Tube.

(Admitted in evidence, Record, page 920, as Defendant's Exhibit No. 84, and afterwards withdrawn as an exhibit.)

Mr. Edmonds: Objected to as not proven or properly identified.

Q. 90. Referring to photograph Exhibit "A"—I have applied reference character "E" to what appears to be a bulbular glass portion of the pump. Will you please state what that part is, its purpose and operation?

A. That is what we call the acid bulb which takes up all the moisture which may be in the audion.

Q. 91. While you were with Mr. Lamont and operating the vacuum pump, did you do any work for a Dr. Selfridge?

A. Yes.

Q. 92. Will you please briefly state the nature of this work and the circumstances under which Dr. Selfridge gave you this work?

A. Very small lamps used for the eye, ear, nose and throat. Dr. Selfridge claimed Mr. Lamont had the best lamp on the market, which was due to the high vacuum. He claimed he could not use the eastern lamps because they would not hold up. The higher a lamp is exhausted, the cooler it remains, and will only stay cool under a high vacuum.

Mr. Edmonds: Objected to as hearsay.

Q. 93. How did you get this information as to what Dr. Selfridge claimed, as you have testified?

Mr. Edmonds: Objected to as not calling for the best evidence.

A. He told me so himself.

Q. 94. Did he tell you why he wanted the lamp to remain cool?

Mr. Edmonds: Same objection.

A. No, he didn't say that, but it is used in the throat.

Q. 95. Referring to your answer to Q. 92, what did you mean when you said, that the lamps "would not hold up"?

Mr. Edmonds: This and other answers of the witness giving hearsay evidence is objected to.

A. The filaments would burn out.

Q. 96. Under date of October 24, 1911, there is an entry "Dr. Grant Selfridge, 1 doz. special lamps 65¢ ea." Please state if that is in your handwriting and what, if you know, was the work done in connection with that order?

A. Yes, my own handwriting—one dozen small incandescent lamps.

Q. 97. Please state why, if you know, the filaments in the small incandescent lamps manufactured by Lamont for Dr. Selfridge lasted longer than the others that he used?

Mr. Edmonds: Objected to as leading.

A. Dr. Selfridge asked Mr. Lamont to make the lamps because he could not use any other—as the others would always burn out in the middle of a test.

Q. 98. Will you please read my last question again and see if you have completed your answer?

A. Because the filaments were stronger and the vacuum higher.

Q. 99. Did you know Mr. Palmer Hewlett in connection with your work with Mr. Lamont?

A. Yes.

Q. 100. Will you please briefly relate the circumstances of your acquaintance with Mr. Hewlett in connection with your work for Mr. Lamont?

A. Mr. Lamont repaired audions for Mr. Hewlett.

Q. 101. Please be a little more explicit as to just what this repair work consisted of?

A. Well, we repaired and exhausted audion bulbs and Mr. Hewlett tested them in Mr. Lamont's place of business so that he could test them as they came from the pump.

Q. 102. About when was this, what year?

A. About 1910.

Q. 102a. Did you witness the tests made by Mr. Hewlett?

A. Yes, some of them.

Q. 103. Can you recall briefly the circumstances of any of these tests?

A. I remember of one instance that I could hear speaking.

Q. 104. Where was this test that you refer to made?

A. At Mr. Lamont's—82 Second Street.

Q. 105. Can you briefly state just what the tests were that Mr. Hewlett made in your presence?

A. His main object was to test the vacuum and see which vacuum worked the best.

Q. 106. How did he vary the vacuum?

Mr. Edmonds: Objected to as leading and assuming.

A. By taking the audion from the pump at different stages.

Q. 107. Can you give the names of several other customers of Mr. Lamont's or people associated with him in any manner; and with whom you came in contact prior to 1915 who were interested in audion bulbs and the construction, repair or exhaustion thereof by Mr. Lamont?

A. Can't think of any only those mentioned.

Q. 108. Did you ever meet Emile A. Beyer while you were working with Mr. Lamont at Mr. Lamont's place of business?

A. Yes.

Q. 109. Did you ever meet Mr. Leland B. Clark at Mr. Lamont's place of business?

A. Yes.

(Direct examination closed.)

Mr. Darby: Formal notice is hereby given that Ralph Hyde and Leland B. Clark, of Oakland and Berkeley, California, respectively, will be produced and examined. It is noted that informal notice thereof was given opposing counsel this morning.

Mr. Edmonds: I ask to be advised to what particular defense or defenses raised by the answer in this case the foregoing testimony is directed.

Mr. Darby: Without recognizing any obligation on my part to supply this information at this stage of the proceedings in the case, I have no hesitancy in advising opposing counsel that the testimony of this witness, as well as of the other witnesses to be examined here in California, under the notice previously given and the one hereinabove set forth, will be relied upon in support of the defenses lack of novelty, lack of invention, the patentee not being the first inventor, prior knowledge and prior use; also, non-infringement, without in any sense confining the subject matter of the evidence to any specific prior use and sale thus far set up in the answer, the evidence will be utilized, in part at least, in connection with the prior use and sale and knowledge of Lee DeForest already pleaded. And notice is hereby given that on or prior to the commencement of the trial of this cause, motion will be made to set up in the answer by way of amendment thereto, or otherwise, the defense of prior knowledge or use by each and every witness produced at this session of taking the testimony.

Mr. Edmonds: Plaintiff objects to the use of testimony taken under the notice heretofore served for any purpose other than indicated by the answer in its present form, and cross-examines without waiver of this objection, or of other objections entered on this record.

CROSS-EXAMINATION.

By MR. EDMONDS:

XQ. 110. During the times you have referred to, in your direct testimony, what was the address of the Lamont shop where you were employed?

A. 82 Second Street, San Francisco.

XQ. 111. Did the shop include an office?

A. No.

XQ. 112. How many rooms were there?

A. Only one.

XQ. 113. And all your work was done in that one room?

A. Yes, sir.

XQ. 114. And Mr. Lamont's, as well?

A. Yes.

XQ. 115. Who else worked in that shop between 1909 and 1916, any one?

A. No.

XQ. 116. Now, in these instances where you say audions were brought in to be worked upon, what was the first thing you did with them?

A. Cut off the exhaust tip.

XQ. 117. That opened the interior of the tube to the outside air, did it not?

A. Yes.

XQ. 118. What was the next thing you did with them? Suppose, you take first the cases where you say you merely re-exhausted the tubes without changing the filaments.

A. You tubulated the audion.

XQ. 119. That is, you fused a short length of tube to the bulb at the place where the tip had been removed so as to communicate with the interior of the tube?

A. Yes.

XQ. 120. Then what did you do next?

A. The audion was sealed on to the grinding that fit to the pump.

XQ. 121. That is, the attached tube was sealed to the grinding?

A. Yes.

XQ. 122. Then what did you do next?

A. Then they were exhausted.

XQ. 123. That is, you first applied the piston pump and then the mercury pump?

A. Piston pump only.

XQ. 124. Now after you exhausted the tubes by the piston pump, was the next step to seal the tube off?

A. No.

XQ. 125. What did you next do after operating the piston pump?

A. Turning off the glass stop cock and starting the mercury pump.

XQ. 126. That stop cock does not appear in Defendant's Exhibit "B," does it?

A. No.

XQ. 127. Where was that stop cock, Mrs. Beck?

A. (The witness points to Exhibit "A.")

XQ. 128. Do you mean that there was a stop cock in the line between the piston pump and tube?

A. Not the tube but the pump.

XQ. 129. In Defendant's Exhibit "A," will you place the letter "H" on stop cock to which you are referring?

A. Witness does so.

XQ. 130. Now, we understand that the tube running from this stop cock on the left in Exhibit "A," which I now mark "I," is the tube that runs from the piston pump shown in Exhibit "B," ~~which tube~~ is also marked "I," on Exhibit "B"—is that correct?

A. Yes.

XQ. 131. About how long was that tube?

A. About nine feet, oh, no, more than that, about twelve feet.

XQ. 132. And about how big was it? Inside diameter?

A. About three-eighths—no it was quarter inch.

XQ. 133. Now, what was the construction of this stop cock "H," was it simply a device which was turned to close the chamber in which it was located?

A. Yes.

XQ. 134. What kind of stop cock grease did you use on that stop cock?

A. Beeswax and vaseline.

XQ. 135. Now, after you turned off the stopcock and so cut out the piston pump, as I understand, you operated the mercury pump?

A. Yes.

XQ. 136. Now, what was the next step after putting the mercury pump in operation?

A. Starting the automatic lift.

XQ. 137. Can you indicate on photographic Exhibit "A" the point at which the tube attached to the audion was sealed to the pump?

A. I have marked it "J."

XQ. 138. Please explain just how the tube attached to the audion was connected with the pump tube at point "J."

A. Through a grinding—the grinding makes a perfect fit, with enough grease to make a perfect seal.

XQ. 139. What sort of grease was used at that point?

A. Vaseline and beeswax.

XQ. 140. Now, after you put your mercury pump in operation, what was the next step?

A. To keep pump running until we received a high vacuum.

XQ. 141. Then what was the next step?

A. After all the gases were driven off and we reached the highest vacuum we could obtain, it was sealed directly from the pump.

XQ. 142. Where, close to the tube, close to the audion?

A. Yes.

XQ. 143. That was done by fusing off the previously attached tube from the audion and it left a tip on the audion again; is that so?

A. Yes.

XQ. 144. Now, what was next done with the audion after it had been sealed off?

A. Tested to see if the filaments were intact.

XQ. 145. That is to make sure that it had not been broken by jarring?

A. Yes.

XQ. 146. How would you do that?

A. By lighting the filament.

XQ. 147. That is, you applied voltage to the filament?

A. No; it was more of a test to see if the filament was lit.

XQ. 148. That is, you put electric current through the filament?

A. Yes.

XQ. 149. And that incandesced the filament to lamp brilliancy?

A. Yes.

XQ. 150. Now, what was the next step after testing the filament?

A. Nothing.

XQ. 151. That is, the work on the tube was finished?

A. Yes.

XQ. 152. And it was sent out to fill the order which brought it in?

A. Yes.

XQ. 153. Now, in detailing these steps, you have not said anything about applying heat to the audion. Do you mean that was not done in the cases we are now considering—that is where you did not put in new filaments?

A. We always used heat—I forgot to mention it.

XQ. 154. That was done while the mercury pump was in operation?

A. The heat is applied immediately—the audion is put on the pump.

XQ. 155. You mean the piston pump?

A. No, the mercury pump, in fact, both.

XQ. 156. I think you said that the part which appears in this photograph as an open-ended cone "G" was of asbestos?

A. Yes.

XQ. 157. How close to the audion did the gas flames from the burner "F" come?

A. As close as to keep it from sucking in.

XQ. 158. Were the flames in contact with the audion?

A. They were directly under the audion.

XQ. 159. Do you mean that the audion was heated by heat rising from the burner below it?

A. Yes.

XQ. 160. And what was the distance between the burner "F" and the nearest point on the audion bulb?

A. The burner circled around the lower part of the bulb.

XQ. 161. And the flame from the burner was not in contact with the audion itself?

A. It was an open gas flame coming out under the bulb and was set as close as would be permitted, without injuring the audion.

XQ. 162. But not in actual contact with the audion?

A. No.

XQ. 163. Now, in the cases where in addition to re-exhausting the audion, you also replaced the filament?

A. Yes.

XQ. 164. What was the first step taken in this process?

A. Breaking out the end which held the filament.

XQ. 165. How was that done?

A. By marking with a glass knife, and applying a little heat; it makes a clean break, releasing the part that holds the filament.

XQ. 166. That made it possible to withdraw the neck with the filament supports and filament?

A. Yes.

XQ. 167. Was the line of breakage close to the neck; state how far from the neck it was?

A. Right next to the bulb; first had to take the cap off and then it was cracked off.

XQ. 168. What do you mean by the cap; the base with the brass screw threaded contact such as shown in Defendant's Exhibit "E"?

A. Yes.

XQ. 169. Take Exhibit "E" and indicate thereon the point at which you would sever the neck of the audion from the bulb.

A. Half-way up (pointing to the base.)

XQ. 170. That is, half-way between the round part of the audion and the free extremity of the base?

A. Yes.

XQ. 171. Now, after you had made this separation of the parts and had withdrawn the neck with the attached lead-in wires and filament, what was your next step?

A. Mr. Lamont made preparations for me to remount the filament.

XQ. 172. What did you do?

A. I remounted the filament into what we termed the "stem" of the lamp. I meant that I mounted a new filament in this stem.

XQ. 173. Do you mean that you first detached the old filament, if there were one, from the lead-in wires, and then attached a new filament to those wires?

A. Yes.

XQ. 174. Now, say just how you did it.

A. Well, the wire was mounted and the part taken from the audion and when finished was given to Mr. Lamont to be resealed in the bulb.

XQ. 175. What I wish you to explain is how you secured the filament wire to the lead-in wires?

A. It was a piece of platinum wire with two tubes —filament was mounted in those tubes on some of the stems and others we could twist the wire around the end of the stem.

XQ. 176. What wire, the filament wire?

A. Yes.

XQ. 177. Drawing it into close contact with the stem? And around the stem?

A. Yes.

XQ. 178. Now, in the other cases, do you mean that the lead-in wires came into metallic sleeves in the stems?

A. Yes.

XQ. 179. And in those cases, you merely poked the ends of filament into those sleeves?

A. Yes.

XQ. 180. Did you do anything to keep the filament ends in those sleeves?

A. By pinching them with the tweezers.

XQ. 181. Did you use anything in the nature of cement?

A. No.

XQ. 182. Now, after you had put the filament in the stem or neck, what was the next step?

A. Mr. Lamont sealed it into a glass bulb.

XQ. 183. The same bulb from which the stem had been removed?

A. Yes.

XQ. 184. How did he do that; by grinding the adjacent surfaces together and then partially fusing the glass?

A. They were melted together.

XQ. 185. Now, during this operation of rejoining the parts, was anything done to prevent the bulb from breaking?

A. No.

XQ. 186. Had not the bulb been opened at the tip before the parts were joined?

A. To work upon this we worked with what we term a "handle." This handle is the part that we tubulate and is used as a handle for resealing into the bulb.

XQ. 187. Do you wish us to understand that before the neck and the body of the audion were rejoined by melting, as you have said, the tip on the bulb was fused off and a glass tube fused to the bulb at the point where the tip had been?

A. This part was prepared by Mr. Lamont. I said it wrong here, I didn't explain it the way it should be. My answer to XQ. 186 was wrong. The correct answer is—You ask here, had not the parts been opened at the tip before the parts were joined? I should have answered, yes, at the exhaust tip.

XQ. 188. Do you mean then that the tip on the bulb was fused off and what you have termed the "handle" was a glass tube which was fused to the bulb at the place where the tip had been removed?

A. It was not fused off, it was cut off.

XQ. 189. Otherwise, your answer to my question is, yes, is it?

A. Yes.

XQ. 190. Now, when the stem was being rejoined to the bulb, was it the practice to blow in this tubular handle?

A. Yes.

XQ. 191. That was done to prevent the possibility of collapse, was it not?

A. Yes.

XQ. 192. You are testifying solely from memory, are you not, and that explains the statement which you just had to correct?

A. Yes.

XQ. 193. Now, after the neck and bulb had been rejoined, what was the next step?

A. It was ready to put on the pump.

XQ. 194. At what point was the base replaced?

A. After it came off the pump.

XQ. 195. Now, was the pumping operation as used with these audions with replaced filaments the same as the operation you have already described with respect to audions which you merely re-exhausted but in which you did not replace the filaments?

A. Yes.

XQ. 196. After these audions with replaced filaments were sealed off from the pump, what next was done with them?

A. They were tested.

XQ. 197. How?

A. By the electric current.

XQ. 198. Heated up to lamp brilliancy?

A. Yes.

XQ. 199. Then what next was done?

A. The base was put on.

XQ. 200. Then what was the next thing?

A. That was all.

XQ. 201. The repaired audions were ready to be sent out in response to the order which had been received?

A. Yes.

XQ. 202. Have you any knowledge of chemistry or metallurgy?

A. No. Very little.

XQ. 203. So that in point of fact you cannot testify, can you, on your own knowledge as to just what was the material of the filaments which you took out of incandescent lamps and put in audions? I am not asking for anything you may have been told, but for what you know.

A. Well, I know that that was tungsten.

XQ. 204. How do you know it was tungsten? Please bear in mind that I am not asking for what you may have been told but for what you can swear to as your own personal knowledge.

A. I know it was tungsten that was called for and which Mr. Lamont gave to me to mount on the stems.

XQ. 205. Please note that I have already excluded what may have been told you by someone else. I am asking solely for your own personal knowledge as to the composition of those filaments. You either do know, of your own personal knowledge what those filaments were or else you do not, which is it?

A. Well, I do know that I worked on carbon filaments and certainly knew the difference between carbon and tungsten.

XQ. 206. Then the basis of your statement that the replacement wire you used was Tungsten is the fact that it was not carbon, is it not so?

A. Yes.

(Adjourned until 10 o'clock A. M., November 4, 1924.)

Pursuant to adjournment 2 P. M. November 4, 1924.

Present as before.

CROSS-EXAMINATION of Mrs. Beck (Continued).

By MR. EDMONDS:

XQ. 207. Referring again to the photograph "Exhibit A," will you please mark with the reference letter "K" the part to which you refer as "the straight shaft?"

A. (Witness does so.)

XQ. 208. Now will you mark with the reference letter "L" what you refer to as the "jet"?

A. The jet itself is in the bulb-like glass structure, which I mark "L." The jet itself, however, cannot be clearly seen in the Exhibit Photograph "A."

XQ. 209. Now, in addition to the stop-cock marked "H," there is another stop-cock, is there not?

A. Yes.

XQ. 210. Will you mark that "M"?

A. (Witness does so.)

XQ. 211. On that also you used stop-cock grease of beeswax and vaseline?

A. Yes.

XQ. 212. Now, what you have termed the "acid bulb" "E" lies directly above the stop-cock "M" and the tube runs from the stop-cock to a point above the level of the sulphuric acid in the bulb "E." Am I right thus far?

A. Yes.

XQ. 213. And the bulb "E" connects with the tube "J," which runs to the vessel being exhausted. Is that correct?

A. Yes.

XQ. 214. How long would a charge of sulphuric acid in the bulb "E" last?

A. Well, that isn't definite. By discoloration you could usually tell when the acid should be changed.

XQ. 215. Give us some idea as to the number of hours, or days, or weeks that you could use one charge of acid while the pump was in operation before you had to change it.

A. About every two weeks.

XQ. 216. Now what you have termed the "percolator" "D" was simply a vessel which held the mercury, was it not?

A. Yes.

XQ. 217. Did you ever have occasion to discard the mercury and put in new mercury?

A. No, we just cleaned the mercury. It was cleaned with nitric acid, the acid taken therefrom, ammonia to cut the acid, then washed thoroughly for about an hour, and then filtered through filter paper until perfectly cleaned.

XQ. 218. Did you use both of the pumps, "Exhibit A" and "Exhibit B," down to the time you left Lamont's employ in 1920?

A. Yes.

XQ. 219. And you used them when occasion arose, from time to time, from say 1910 to 1920?

A. Yes.

XQ. 220. On looking up the account books which you produced yesterday "Exhibits C" and "D," I gather that Lamont's work was chiefly repairing medical apparatus, such as X-ray tubes, for physicians here and around San Francisco. Am I right?

A. Yes.

XQ. 221. Were you called upon to considerable extent to re-exhaust X-ray tubes, say prior to 1914?

A. Yes.

XQ. 222. In doing this, did you follow the same procedure that you have already explained as having followed in re-exhausting audions, except, of course, for the step of incandescing filaments?

A. Yes.

XQ. 223. Referring now to Exhibit "F," the Jahnke tube, was this also exhausted just as you have been used to exhausting X-ray tubes at that time?

A. Yes.

XQ. 224. And was that also true of the small lamps made for Dr. Selfridge?

A. Yes.

XQ. 225. You have referred to an entry of October 24, 1911, in the "Order Book," Exhibit "D," of one dozen special lamps for Dr. Selfridge, what is it that enables you to recall the particular lamps to which this order refers? Had you made any small "special" lamps for him before or did you after?

A. I recall this instance that Dr. Selfridge was in trouble at this time with other lamps and begged Mr. Lamont to please make these lamps as no others would hold up.

XQ. 226. Then that was the first order from Dr. Selfridge for these special lamps, that is the order of October 24, 1911?

A. No, we had several orders from Dr. Selfridge.

XQ. 227. For these special lamps?

A. Yes.

XQ. 228. So on this order of October 24, 1911, you merely made for him what you have made before?

A. Yes.

XQ. 229. And all these special lamps that you made for him were made the same way?

A. Yes.

XQ. 230. And the lamps supplied him on the several orders were the same in construction and other characteristics?

A. Yes.

XQ. 231. You furnished him with these lamps as far back as 1909, did you not?

A. Yes.

XQ. 232. Referring again to Exhibit "F"—the Jähnke Tube—I think you said that you put in the filament, did you not?

A. Yes.

XQ. 233. How did you attach the ends of the filament to the lead-in wires?

A. It was a platinum wire with two tubes on the end.

XQ. 234. As I understand, this filament (Exhibit "F") is attached to two platinum wires, am I right thus far?

A. Yes.

XQ. 235. Those platinum wires come through the glass neck, do they not?

A. Yes.

XQ. 236. And extend beyond the blue tip on the glass neck?

A. Yes.

XQ. 237. And at some little distance from the blue tip on the glass neck you attached the filament to the ends of the platinum wires. Correct?

A. Yes.

XQ. 238. Did you bend the filament in doing this into the shape in which the filament is now shown?

A. No, the filament is first put into shape.

XQ. 239. Did you bend it into shape yourself.

A. Yes.

XQ. 240. That is, practically doubled it hair-pin fashion?

A. Yes.

XQ. 241. And then made it fast to the platinum leads?

A. Yes.

XQ. 242. When did you last see that Jahnke Tube previous to yesterday?

A. As long as I was with Mr. Lamont, up to 1920.

XQ. 243. And then when next did you see it?

A. When you showed it to me here yesterday.

XQ. 244. Between 1909 and 1920, did you make any other apparatus for Jahnke?

A. I don't remember.

XQ. 245. Referring now to the order from the Federal Telegraph Company of Septemtber 19, 1912, for re-exhaustion of eighteen audions, what person connected with the Federal Company gave this order?

A. I don't know.

XQ. 246. How about the order of February 13, 1913?

A. That I don't know.

XQ. 247. How about the order of June 19, 1914?

A. I do not know the names.

XQ. 248. Can you mention the name of anyone connected with the Federal Company who had a knowledge of, or anything to do with, these three orders or any of them?

A. I remember the name of Mr. DeForest.

XQ. 249. What did he have to do with these three orders?

A. I remember Mr. Lamont at that time mentioning his name.

XQ. 250. I am trying to find out, if possible, whether he had anything to do with these three orders. Did he?

A. Thinking back to that time, I am sure he did.

XQ. 251. Do you mean that you think now that he was the man, connected with the Federal Company, who had the work done which is referred to in these three orders?

A. Yes.

XQ. 252. Do you know anything about who it was who gave the order for the six audions mentioned in the account book as having been repaired June 19, 1914, for the Herrold College?

A. No.

XQ. 253. Answer the same question with respect to the order of July 7, 1915, for the Marconi Wireless Telegraph Co.

A. No.

XQ. 254. Referring again to the Jahnke matter, I understand from all you can recall, the work done for him consisted of the making of two tubes of which Exhibit "F" is one. Am I correct so far?

A. Yes.

XQ. 255. Your account book seems to show that Jahnke paid for both of these, does it not?

A. Yes.

XQ. 256. How did it happen that this particular tube (Exhibit "F") stayed around Lamont's shop down to the time you left in 1920?

A. Mr. Jahnke never called for it.

XQ. 257. Do you know for what reason?

A. Yes, his place was destroyed by fire and he lost everything.

XQ. 258. Is that the only reason you can give?

A. After that he never came back.

(End of cross-examination.)

RE-DIRECT EXAMINATION.

By MR. DARBY:

RDQ. 259. How many tubes like Exhibit "F," so far as you know, were made for Jahnke during the time that you were employed at Lamont's?

A. I think about five or six.

RDQ. 260. Record of work done for Jahnke is found in the record books (Exhibits "C" and "D"), is it not?

A. Yes.

RDQ. 261. In detailing, step by step, the operations performed in operating the pump, in your cross-examination, you did not mention at what stage of the operations the incandescent filament was lighted when the audion structure was on the pump, as you had previously testified in your direct examination. Will you please now state at what stage of the operations in filament of the audion was lighted?

A. After the first vacuum is secured the filament is lighted to drive off all gases. Should gases appear the filament is then turned off again, and this done until no more gases appear.

RDQ. 262. What did you mean in your last answer by "after the first vacuum is secured"?

A. The treatment by the preliminary pump.

RDQ. 263. Will you please explain a little more in detail the relation between the lighting and turning off of the filament and the appearance of gases—pointing out particularly where the gases appear?

A. When first starting the automatic lift after the audion is placed on the pump the mercury flows through the pump taking the air from the audion; as the mercury flows through, it shows large bubbles in the shaft "K" on Exhibit "A,"—these bubbles gradually disappearing as the vacuum increases; when they have entirely disappeared then the filament is lighted; should more bubbles appear in the shaft "K," the filament is then turned off again. This is done until no more bubbles appear.

RDQ. 263a. Did you seal off the audion tube from the pump immediately after the bubbles ceased to appear?

A. No, we run the pump a little longer to make sure of a good high vacuum.

RDQ. 264. What was the last time, either with Mr. Lamont or in your present business, that you did any work in connection with an audion tube, as near as you can recall?

A. As near as I can recall, somewhere around 1915 or 1916.

RDQ. 265. Have you ever testified in legal proceeding before?

A. No.

(Re-direct examination closed.)

(Deposition closed.)

(Sgd.) HELENE BECK.

Met pursuant to adjournment, November 4, 1924, 10 A. M.

Parties present as before.

DEPOSITION OF RALPH HYDE.

Ralph Hyde, a witness produced in behalf of defendants, being first duly sworn, deposes in answer to interrogatories propounded by Mr. Darby, as follows:

By Mr. Darby:

Q. 1. Please state your age, residence, and occupation.

A. Born in '76; residence, 529 Haddon Road, Oakland, California; consulting engineer for the Magnavox Company.

Q. 2. Do you know Mr. G. E. Lamont?

A. I do.

Q. 3. And, if so, about how long have you known him?

A. Since 1902.

Q. 4. Have you ever had experience in exhausting or repairing vacuum tubes employed in radio work?

A. I have.

Q. 5. When did you first have this experience?

A. Some time in 1911.

Q. 6. What was this work, that is, was it exhausting or repairing, or both?

A. Replacing of the burned-out filament and re-exhausting.

Q. 7. Have you done any of this work since 1911?

A. Well, more or less continuously.

Q. 8. Will you briefly describe the process of exhaustion that you used.

A. I used a number of different processes in ex-exhausting, depending upon what degree of vacuum I wished to obtain.

Q. 9. Will you please describe the process of exhaustion that you employed prior to 1914 in connection with radio vacuum tubes in which you obtained the highest degree of vacuum?

A. The following method for obtaining a high degree of vacuum I have used since 1904 on different vessels that I wished to evacuate, such as X-ray tubes, mercury arc rectifier tubes, audion bulbs, etc. This was to attach a bulb containing manganese dioxide, which was so connected that any degree of temperature desired could be applied both to the receptacle being exhausted and the receptacle containing the manganese dioxide. This would cause a throwing off or liberating of the occluded gases in the manganese dioxide, leaving it in a condition that when the heat was removed it would have a very high absorbing power, which would raise the vacuum to practically any degree desired. I can—it being understood that both the receptacle containing the manganese dioxide and the receptacle to be exhausted were tipped off from the pump before removing of the heat. In this way very high vacuum was obtained.

Q. 10. What kind of exhaust pump did you use?

A. The Garrick or walking beam type, usually referred to as the English pump.

Q. 11. After the receptacle containing the manganese dioxide and the audion tube being exhausted were, as you state, tipped off, did you then separate the manganese dioxide receptacle from the audion tube, by tipping off the audion tube therefrom?

MR. EDMONDS: Objected to as leading.

A. Yes, that was the method of procedure, that as soon as the desired degree of vacuum was obtained by absorption of the manganese dioxide the receptacle containing the manganese dioxide was tipped off from the audion bulb.

Q. 12. While the pump was in operation, what was the condition of the filament?

A. I don't know as I understand that question.

Q. 13. Was the filament lighted or unlighted?

A. Well, the filament had been lighted to throw off the residual gases.

Q. 14. When had it been lighted, and for how long?

A. Merely lighted for a very short period, while on the pump.

Q. 15. To what degree of brilliancy was it lighted?

A. Well, ordinary temperature of an incandescent lamp.

Q. 16. Do you recall the voltage of the current you passed through the filament while the audion was on the pump?

A. Well, it varied from four to five volts.

Q. 17. What material filament did you use for the repair or replacement work?

A. Drawn tungsten wires.

Q. 18. Did you ever use any other filament?

A. No. You mean since I started, from that time up to the present?

Q. 19. I meant up to 1914 particularly.

A. Nothing but drawn tungsten wires.

Q. 20. About when was it, as near as you can recall, did you first start to use some other type of filament than tungsten?

MR. EDMONDS: Objected to as assuming.

A. I experimented with many different types of filament, beginning in about 1916.

Q. 21. Prior to 1914 or '15 could you give the names of a few of the people for whom you repaired and exhausted audion bulbs?

MR. EDMONDS: Same objection.

A. Well, I am unable to place the dates exactly, but I done work for Palmer, Hewlett and Alvin Aster. Others that I am unable to recall at the present time.

Q. 22. I notice that you got Mr. Aster's name from a memorandum that you had in your pocket, will you please just briefly state the circumstances of the memorandum?

A. Well, I was trying to locate Aster in checking up my dates.

Q. 23. You were doing this at the request of Mr. Baumgartner?

A. Yes.

Q. 24. Were you successful in locating Mr. Aster up to the present time?

A. The information I got from his mother was that he is connected with the Western Electric Company, New York City.

Q. 25. Where did you obtain the drawn tungsten filament that you employed from 1911 on?

A. I obtained a small amount from Mr. J. Vandergrift, who was general manager of the Oakland Mazda Lamp Works at that time, and I was superintendent of the same plant at the time. I got this wire from Mr. Vandergrift for experimental purposes.

Q. 26. Were you asked to make a search to ascertain whether or not you had any of this wire left and still in your possession?

A. I was.

Q. 27. Have you thus far been able to find any?

A. I have not.

Q. 28. Can you approximate, from your recollection, the number of vacuum tube audions that you repaired, exhausted, or both, between 1911 and 1914?

A. Possibly three hundred.

Q. 29. Are you comparatively certain that it was over one hundred?

A. Yes.

MR. EDMONDS: Objected to as leading.

Q. 29a. With respect to the audion tubes which you repaired and/or exhausted for others than yourself were you paid for the work done by you?

A. I was.

Q. 30. Was work of that nature your business at that time?

A. When I first started it was more of an experimental work until such time as I was away from the General Electric Company, and after February, 1912, became my business.

Q. 31. When did you leave the employ of the General Electric Company?

A. February, 1912.

Q. 32. Will you please examine Defendant's Exhibit "E" and state whether or not this is the type of tube you repaired and exhausted between 1911 and 1914.

A. I repaired this type of tube some time during that period but the single plate and single grid were the first tubes that I repaired.

(Direct Examination Closed.)

Mr. Darby: Direct examination is closed, subject to the reproduction of the witness to identify and offer in evidence a piece of the drawn tungsten filament the witness used from 1911 on, if the witness is successful in locating a piece thereof.

Cross-Examination.

By Mr. Edmonds:

XQ. 33. When did you join the Magnavox Company?

A. The Magnavox—I done research work for them for the past two years, considerable amount of work in my laboratory—as near as I can remember was actively employed at their plant from February or March of this year.

XQ. 34. What was your employment next prior to your joining the Magnavox Company early in 1924?

A. I was doing work for the Magnavox Company and also doing work in my own laboratory.

XQ. 35. Were you in any regular employment by another prior to early in 1924?

A. I don't know as I understand that question.

XQ. 36. Where next before February, 1924, did you have a regular, steady employment by another concern?

A. I done some work for the Refill Lamp Company, Los Angeles.

XQ. 37. At Los Angeles, you mean you did this at Los Angeles?

A. Yes.

XQ. 38. What was the period of that employment?

A. About two months.

XQ. 39. When was it?

A. About September, no wait a moment, August, September and October, 1923.

XQ. 40. Where were you employed prior to August, 1923?

A. I don't understand that.

XQ. 41. Where were you employed prior to August, 1923?

A. My own laboratory.

XQ. 42. What regular steady employment did you have in association with any other person or concern next prior to August, 1923?

A. Covering a period of what time?

XQ. 43. I am asking for your business connection next prior to August, 1923.

A. That's regardless of the time elapsed? Morehead Laboratories.

XQ. 43a. When did you go there and when did you leave there?

A. I am unable to give those dates, but I'll say this—that I went there under the assurance by Mr. Henry M. Shaw, who was president of the Morehead Laboratories at that time, that they were not infringing and that they were absolutely open and above-board in the matter and that they were paying royalties and that they were consecutively numbering their bulbs and every indication pointed to the fact that they were open and above-board and I was not working for an infringing concern.

XQ. 44. Do you know when you left the Morehead Laboratory?

A. I don't remember that date.

XQ. 45. Do you know when you started there?

A. No, I don't remember that either.

XQ. 46. Where were you engaged, Mr. Hyde, in 1918?

A. As I remember, without being positive, we were making audiotron tubes with Mr. Cunningham and Mr. White.

XQ. 47. Mr. E. T. Cunningham?

A. Yes.

XQ. 48. And those tubes were being put on the market then by the Audiotron Sales Company?

A. Yes, sir, as I remember, that's true.

XQ. 49. You were engaged in that same activity, were you not, in 1918?

A. Without being able to check that date, I will say yes.

XQ. 50. When was it that you were made a party defendant in a suit under the DeForest Audion patents in the District Court here in San Francisco?

Mr. Darby: Objected to as irrelevant and immaterial and not proper cross-examination, and not the best evidence if a date is being sought to be established.

A. Am I to answer the question? The latter part of 1915 or the first part of 1916.

XQ. 51. Are you able to say whether or not a motion for a preliminary injunction was made in that suit?

A. In reference to myself?

XQ. 52. With reference to anyone concerned in the suit.

A. There was a motion made for a preliminary injunction.

XQ. 53. Are you able to say whether or not, in that suit, you executed an affidavit?

A. Yes.

XQ. 54. Now, when did your connection with Mr. Cunningham and Mr. White, as stated in your answer to XQ. 46, terminate?

A. I can't remember the date.

XQ. 55. When did it begin?

A. I couldn't give that date, either.

XQ. 56. When first did you engage in the business, either for yourself or with anyone else, of making vacuum tubes for radio use commercially?

Mr. Darby: In view of the dispute that has extended over a period of many years in the radio industry and is still in progress as to what is meant by the expression "commercially," I object to the question as indefinite.

XQ. 57. Please answer my last question, with the understanding that by "commercially" I mean for sale.

A. I repaired tubes in 1912, making a charge for so doing, and engaged in the manufacture of new tubes in 1915, which were put out in considerable quantities.

XQ. 58. When you speak of repairing tubes, did this include, in some instances, merely re-exhausting a previously made tube?

A. In no case was a tube repaired without replacing the filament.

XQ. 59. Now, this pump that you used was what is commonly referred to as a "rough" pump, was it not?

A. That's true, but I made changes on the pump that made it possible to obtain a vacuum, without use of any chemical, equal to rotary oil pumps used at the present time and roughly to a vacuum of four to six microns.

XQ. 60. What became of that pump, Mr. Hyde?

A. I still have it. In other words, I had two of those pumps, I still have one.

XQ. 61. Did you use both of those pumps in the course of your work?

A. Yes, sir.

XQ. 62. What other things did you exhaust on them besides audion tubes?

A. X-ray bulbs, mercury arc rectifier tubes, and some lamps.

XQ. 63. That is, whenever occasion arose during practically the last twenty years? That is, you used one or the other of those pumps?

A. Yes, sir. I believe in the latter part of 1912 I believe I had rotary pumps also.

XQ. 64. Are you still experimenting today in the radio field?

A. Yes, sir.

XQ. 65. And outside of your commercial work you have carried on these experiments for a number of years past, have you?

A. Yes, sir.

XQ. 66. With various radio devices, including tubes?

A. Yes, sir.

XQ. 66a. Now around a period, say in 1912 or 1915, there was a good deal of laboratory experimenting in the radio field, was there not?

A. Well, I can't say to what extent it was carried on—there was some.

XQ. 66b. Did you not run across amateur experimenters from time to time during that period?

A. Yes.

XQ. 67. Was Aster one of them?

A. Aster? Yes, sir.

XQ. 68. And Hewlett another?

A. Yes, sir.

XQ. 69. When did you last see Hewlett?

A. When did I last see Hewlett? About a week ago.

XQ. 70. With whom beside Mr. Baumgartner and Mr. Darby have you talked within the last three months concerning any matter that you have testified to today?

A. I believe the matter was discussed in the presence of Ford Greaves, Palmer Hewlett—we were at lunch one day and the matter was discussed. I don't think of any others. I'd like to qualify that statement. It is not my testimony was discussed but the case in general of the higher vacuum patents—the fact of the matter is I don't believe that they knew I was going to testify.

XQ. 71. Are you now under injunction granted under the DeForest patents covering the audion?

Mr. Darby: Objected to as irrelevant, immaterial and improper cross-examination.

A. Yes, sir, I am under injunction under conditions that I made before in regard to mis-statements made by Henry M. Shaw that they were working under a license.

Re-Direct Examination.

By **Mr. Darby**:

RDQ. 72. Was it before or after you left the employ of the Oakland Mazda Lamp Works of the General Electric Company that you first began your work of repair and exhaust of audion tubes?

A. I done some work before I left them.

RDQ. 73. When you tipped off the manganese dioxide receptacle and the audion tube being exhausted, still connected together, did your process of exhaustion include any further operations before you tipped off the receptacle from the audion tube?

Mr. Edmonds: Objected to as leading.

A. Yes.

RDQ. 74. Please describe the operations which you then followed.

A. The bulb—I meant to say the filament was lighted and the vacuum allowed to raise past the point where you get a fluorescence of the bulb from the spark coil. Standard practice of exhausting X-ray tubes at that time that I used was to place a glass stop cock between the manganese dioxide-receptacle and the tube which would permit of the closing off or stopping the exhaust at the desired degree of vacuum on X-ray tubes.

RDQ. 75. Your last answer mentions the standard practice of exhausting X-ray tubes. Will you please state the practice you employed in exhausting the audion tubes?

A. The filament was lighted and absorption allowed to take place until past the fluorescent point of the bulb when excited by a spark coil.

RDQ. 76. Did you employ a glass stop cock between the manganese dioxide receptacle and the audion tube?

A. I don't remember that I done that.

RDQ. 77. After the audion bulb passed the fluorescent point when excited by a spark coil, what did you then do?

A. The bulb was tipped off, finished.

RDQ. 78. How long a period elapsed between the time the filament was lighted and the fluorescent point was passed?

A. It varies somewhat—five to ten minutes.

(Re-direct examination closed.)

RE-CROSS-EXAMINATION.

By Mr. Edmonds:

RXQ. 79. Did your pump with which you exhausted audion bulbs have a glass stopcock?

A. No, I did not use that commercially, I tried experiments on it.

RXQ. 80. When you used this experimentally in exhausting audion bulbs, what kind of stopcock grease did you use?

A. Used vaseline and beeswax—about 50 per cent each—and then kept stopcock covered with a wet cloth to keep it cool—that's been standard practice for twenty-five years.

RXQ. 81. When you started to make audion tubes in 1915, for sale, did you continue the practice of using the stopcock or did you abandon it?

A. First they were made for some time, say perhaps six months, were mounted on what was called a glass fork, holding sixteen bulbs, which contained a stopcock, but not using the manganese dioxide principle.

(Deposition closed.)

(Sgd.) RALPH C. HYDE.

(Adjourned until 2 P. M.)

DEPOSITION OF PALMER HEWLETT.

Palmer Hewlett, a witness produced on behalf of defendants, being first duly sworn, deposes in answer to interrogatories propounded to him, as follows:

By Mr. Baumgartner:

Q. 1. Please state your name, age, residence and occupation?

A. Palmer B. Hewlett; am thirty-nine; residence, 163 Belvedere Street, San Francisco; retired capitalist.

Q. 2. Are you acquainted with G. E. Lamont?

A. I am.

Q. 3. Please state when you became acquainted with him, and the circumstances.

A. I hired Mr. Lamont to re-exhaust and manufacture vacuum tubes and perfect some experimental work which I was doing—on or about November, 1912.

Q. 4. Please be a little more explicit as to the kind of vacuum tubes.

A. The tube is a three-element tube, containing filament, grid and plate in evacuated glass tube; the purpose to be used for radio telephony and for radio telegraph.

Q. 5. I'll show you Defendant's Exhibit "E" and ask you if the tubes referred to resembled that?

A. In general appearance it did resemble this tube, yes.

Q. 6. Just what work did Mr. Lamont do on these tubes for you?

A. Mr. Lamont renewed the filament and exhausted the tube to a vacuum, under my direction.

Q. 7. What kind of a filament did Mr. Lamont put in the tubes that you refer to?

A. I ordered him to put in a filament which would stand a higher incandescence than the one I had been using and suggested that he put tungsten filament in the tube as I had read an account of the use of this in a book and thought it would be a better filament than the one that I had in the tube originally.

Q. 8. Do you know where Mr. Lamont got the filaments that he put in?

A. Mr. Lamont did not have any tungsten wire, that is, spool wire, so he secured some tungsten filament from some incandescent lamps.

Q. 9. Please make a sketch of the pump that Mr. Lamont used in exhausting tubes for you, and describe the sketch, applying numbers to the parts that you refer to.

A. (Witness makes sketch.) Well, No. 4 is the receptacle wherein mercury is poured through a strainer (6) made of cloth and flows down a glass tube (3) through nozzle (7) down to (8) into receptacle (5), which acts as a reservoir, drawing air through trap (2) and which is connected to the work to be exhausted. No. 1 is a glass stopcock, which is connected to a piston pump, which is used to start the vacuum process.

Q. 10. Did you see both the mercury pump and piston pump that Mr. Lamont used in 1912?

A. I operated and handled the pump and am familiar with it.

Q. 11. Do you recognize what is shown in this picture—Defendant's Exhibit "A"?

A. This is the same with exception that this lift pump I placed on there after a later date. (I have marked the lift pump with the letter "N.") We used a quart bottle at that time and poured the mercury from the reservoir (5) to the container (4) by hand. (Witness refers to the numbers on his own sketch.)

Q. 12. I show you Defendant's Exhibit "B" and ask you if you recognize what is shown therein?

A. This is a piston pump similar to the one used by Mr. Lamont. From the photograph I can see no difference from the one he used.

> Mr. Baumgartner: The sketch made by the witness in answer to Q. 9 is offered in evidence as Defendant's Exhibit "G," Hewlett sketch.
>
> (Admitted in evidence, Record, page 916, as "Defendant's Exhibit No. 72." *See Volume VI, Defendant's Exhibits, page 1036.*)

Q. 13. Did you see Mr. Lamont do the work of exhausting radio tubes that you took to him in 1912?

A. I did.

Q. 14. Please describe the procedure that he employed at that time.

A. The vacuum tube was connected to part of mercury pump marked "to tube" on my sketch and the preliminary vacuum was made by starting the piston pump. After this pump had operated for a sufficient length of time, the stopcock (No. 1) was closed and the mercury pump was started in operation. The tube was left on this pump for at least an hour and during this time the tube was heated with a circular gas burner—Bunsen burner, I think they call it—and in the latter part of the exhaustion the filament was lit and the process carried till the vacuum reached a high degree, which was evidenced by the lack of bubbles showing in the stand column (No. 8) and by an actual test of the tube in connection with a radio set and a variable B-battery, consisting of forty-five cells of dry battery in series.

Q. 15. What was the highest voltage of B-battery that you used while at the same time securing proper operation of the radio tube?

A. It was customary to use on the tubes exhausted by Mr. Lamont in my limited commercial station a variable B-battery ranging from forty to seventy volts.

Q. 16. What part of that voltage did you actually use?

A. The voltage depended upon the degree of exhaustion of the particular tube I had in use and I would say it ranged around about sixty volts, but I had a glass beaker with a thermometer and the tube in the oil of this beaker and by lighting a small alcohol lamp under this beaker I could somewhat control the amount of B-battery used for best results.

Q. 17. What was the effect of heating the vacuum tube in the manner you describe?

A. Heating the tube lowered the amount of B-battery used on the tube.

Q. 18. Please say how brightly the filament was lit during the exhaustion of the vacuum tubes or what voltage was employed, if you know, when lighting it?

A. The filament of the vacuum tube was lit to a brilliant incandescence and the filament was controlled by a small rheostat from a suitable battery.

Q. 19. Was the brilliance of the filament less than, equal to, or greater than the brilliance obtained by the filament during normal operation of the vacuum tube?

A. I usually lit the filament at a slightly greater incandescence than when in actual use.

Q. 20. What was the experimental work that Mr. Lamont did for you?

A. I suggested that by bringing down my receiving set and by erecting an aerial on Mr. Lamont's roof so I could test the bulb on the exhaust pump in connection with a suitable circuit, that it would be a more advantageous way than breaking the seal and taking the bulb to my station for trial and then have to bring it back, break the seal and re-exhaust it, and I had my set at his laboratory and conducted experiments and used this method for obtaining an effiecient vacuum tube.

Q. 21. Please explain what you mean by "my set."

A. My receiving set consisted of a Murdock, loose coupled-inductive tuner, a Murdock sliding plate condenser, a B-battery and an A-battery and a rheostat to regulate the filament of the tube.

Q. 22. Then you wish it to be understood that your test of the bulb consisted in determining its operation as a radio vacuum tube while it was still on the pump, by means of your receiving set?

A. That is right.

Q. 23. When did Lamont repair the vacuum tubes and assist you with the tests that you have spoken of?

A. In the latter part of 1912.

Q. 24. In answering the last question, you referred to a memorandum. Please explain very briefly what that is?

A. This particular memorandum I happen to be looking at is a list of checks issued by a corporation of which I was a member and by tracing these checks it limits the date in which the work is done?

Q. 25. Who prepared the list and how does it limit the dates?

A. This particular account I have was checked over by Haskins & Sells, Certified Public Accountants, San Francisco; this account was made by the secretary of George Hewlett, Inc., a corporation of the State of California, of which I was a member and when it dissolved July 1, 1916, it was audited by Haskins & Sells and found correct. Do you wish illustrations of the items in the account showing the nature of the work I was doing and what it was for?

Q. 26. Please state just what it is that you find in the list that limits the date in which that work was done by Lamont.

A. On March 20, 1912, I bought a ticket for Europe for $150; also a ticket on the Southern Pacific—one way—for $90.75. This certifies then that I started on or about March 20, 1912 for Europe; on December 3, 1912, I have a check here on the First National Bank made payable to R. B. Williams, and on December 10, another on the First National Bank, made to Hihn-Hammond Lumber Company for $91.30, and the one to Williams was $118.25. The purpose of these two checks was to build a mast at Hollister, California, at my commercial station. Therefore, these two illustrations show that I left San Francisco on about March 20th, 1912, and I was back December 3d. Previous to this time I have a number of checks in this list showing I was here the latter part of October and November, that is why I used this list to refresh my memory.

Q. 27. When with respect to the erection of that mast was the work, concerning which you have testified, done by Lamont?

A. The work was done before the erection of the mast.

Q. 28. Are you acquainted with Ralph Hyde?

A. I am.

Q. 29. Please state when you became acquainted with him and the circumstances.

A. I met Mr. Hyde at his laboratory in West Oakland and to my best knowledge and belief, it was in the latter part of 1911, and he did work for me in exhausting tubes during the latter part of 1911 and '12.

Q. 30. Why did you have Hyde exhaust those tubes?

A. I went to Hyde as he is a skilled glassblower —I traded over there the same as I trade with any firm. The purpose of Mr. Hyde exhausting the tubes was to obtain a high vacuum and the tube was to be used for, in conjunction with a radio telegraph station and receiving set which I had in San Francisco.

Q. 31. Did you merely take complete vacuum tubes to him and have him exhaust them?

A. Mr. Hyde re-exhausted tubes for me and also made complete new tubes.

Q. 32. Please describe briefly just what Mr. Hyde did to those tubes.

A. Mr. Hyde exhausted the tubes with an oil pump and used auxiliary heat and also used a chemical in the vacuum line and used tungsten filament of which he had a large quantity and did not have to resort to breaking incandescent lamps to get the filament.

Q. 33. You have mentioned tubes that you took to Hyde and tubes that he made for you. In which of these did he use the tungsten filament?

A. In tubes which I took to him to have the filament renewed he used tungsten—that seemed to be the only filament he had and he seemed to have a large quantity of it on hand, and used this filament exclusively, to my knowledge.

Q. 34. Did Hyde renew the filaments of all of the tubes which you took to him?

A. He did.

Q. 35. What use did you make of the tubes that you had Hyde repair or make for you?

A. These tubes were used for receiving purposes and also one of them was used in my commercial station in Hollister.

Q. 36. Throughout your testimony you have referred to vacuum tubes. Do you mean what is known as an audion tube?

A. I do.

(Direct examination closed.)

(Adjourned to 10 A. M., November 5, 1924, at same place.)

Wednesday, November 5, 1924.

Met pursuant to adjournment.

Parties present as before.

CROSS-EXAMINATION.

By MR. EDMONDS:

XQ. 37. Of what make were the cells of dry battery mentioned toward the end of your answer to Q. 14?

A. They were made by a company who had an office on Folsom Street and this company was the predecessor of the present Ever-Ready Company.

XQ. 38. How did you come by the audion tubes which you gave to Lamont and to Hyde as stated in your direct testimony, and what were they?

A. The tubes which I had in my possession were given to me by Mr. W. W. Hanscom, 868 Clayton Street. These tubes were a part of the original equipment which was on the fleet when it came around the Horn with Fighting Bob Evans in 1908. Mr. Hanscom's brother had charge of the naval stores at Mare Island and gave them to his brother. They were De-Forest audions.

XQ. 39. At the time you got these tubes did they have tantalum filaments?

A. To my best knowledge and belief the filament was tantalum.

XQ. 40. Were these tubes of the single grid, single plate type, or of the double grid, double plate type?

A. These two particular tubes referred to were of the single grid, single plate type.

XQ. 41. How many did Hanscom give you?

A. He gave me two. Mr. Hanscom had, I believe four tubes, of which he gave me two, and he now has in his possession two of the tubes left.

XQ. 42. Now, the station at which you use these two tubes was at Hollister?

A. At Hollister, yes, sir.

XQ. 43. Will you please sketch the receiving circuit wiring and devices, at the Hollister station?

A. This is the receiving set?

XQ. 44. Yes, while you are making the sketch make reference numerals on the various parts and explain them.

A. I have made the sketch, the parts are as follows: "D" is the antenna, "A" is the variable condenser, "B" is the primary of the tuner, "C" is the ground, "J" is the secondary of tuning coil, "E" is the grid, "F" is the plate, "G" is the head phone, "H" is the B battery, "K" is the A battery, "I" is the filament, "M" is the rheostat, "N" is the variable tap for the B battery.

Mr. Edmonds: The sketch made by the witness is marked for identification "Exhibit 1 for identification."

XQ. 45. In addition to the reference letters which you have named, you have marked the filament battery "A" and the plate battery "B."

A. That's right.

XQ. 46. What was the normal operating voltage of the filament?

A. I never tested the voltage across the filament as I had a rheostat in series with the filament and used my eye as a judge of its brilliancy.

XQ. 47. How many cells did you have in the "A" battery?

A. This particular battery which I had, consisted of an Edison primary battery and the total number of cells, was about, oh, I had in that particular battery eight cells and I varied the potential of the battery to conform to the curve of the discharge of the battery and the operating characteristics of the tube.

XQ. 48. How were the eight cells connected?

A. These eight cells were connected in series.

XQ. 49. Do you know the resistance of the rheostat?

A. It's twelve years ago, let me see—I do not remember but my best recollection believe that it had a fairly high resistance—I don't know that.

XQ. 50. Are you acquainted with Emile A. Beyer?

A. I don't remember him by name.

XQ. 51. Are you acquainted with Leland B. Clark?

A. I am.

XQ. 52. How long have you known him?

A. I have known Mr. Leland B. Clark about twelve years.

XQ. 53. Who else beside yourself worked with the receiving set at the Hollister station or witnessed its operation?

A. Mr. Ford King, Mr. Arthur Street, Mr. W. W. Hanscom, Mr. Ellery W. Stone, president of the Federal Telegraph Company,—thirty-five men working on the ranch, I can give you their names——

XQ. 54. Let me interrupt you so as to avoid wasting time. I am not referring to any uninformed persons who might have casually wandered in and have seen the receiving set or witnessed its operations. I refer to men who either worked with it or who understood its operation.

A. The four already mentioned are radio men.

XQ. 55. Any other radio men?

A. There were other radio men which I do not recall at this particular, but I could look up my records and find their names for some future time if they are required.

XQ. 56. Was Hall Berringer one of these radio men?

A. That had seen my radio set?

XQ. 57. Yes, was he?

A. I have known Hall Berringer for a great number of years and to my best knowledge and belief he has seen everything I own.

Mr. Edmonds: That is all, Mr. Hewlett.

(Cross-examination closed.)

Re-Direct Examination.

By Mr. Darby:

RDQ. 58. Referring to "Exhibit 1 for identification, Hewlett's sketch of circuit," will you please tell me what means you employed to effect tuning?

A. I varied the antenna inductance, "B," and capacity, "A," to bring it in resonance with secondary, "J."

RDQ. 59. Was the secondary, "J," of fixed value?

A. Secondary, "J," was a part of my Murdock receiving set already referred to and had a variable tap on the secondary and by this means I was able to bring the set to resonance.

RDQ. 60. Did you use any fixed or variable condenser in the receiving circuit as distinguished from the antenna earth circuit?

Mr. Edmonds: Objected to as leading.

A. I sometimes employed a small variable condenser across the secondary, "J," but did not employ at this time any other fixed condenser in the circuit.

(Deposition closed.)

MR. DARBY: Notice is hereby given that the depositions of H. L. Rodman, address unknown, business address care of Federal Telegraph Company, Hobart Building, San Francisco; James O. Watkins, of San Francisco, California, and A. Y. Tuel, of San Francisco, California, will be taken.

(Adjourned until 2 P. M.)

(At same place.)

(Sgd.) PALMER B. HEWLETT.

Wednesday, November 5, 1924, 2 P. M.

Met pursuant to adjournment.

Parties present as before.

DEPOSITION OF LELAND B. CLARK.

LELAND B. CLARK, a witness produced on behalf of defendants, being duly sworn, in answer to interrogatories propounded to him, deposes as follows:

By MR. BAUMGARTNER:

Q. 1. Please give your name, age, residence, and occupation.

A. My name is Leland Bertram Clark; thirty-six years of age; born in Northern California; physicist, employed by the University of California Hospital, radium department; home address is 1310 Milvia Street, Berkeley, California.

Q. 2. Are you acquainted with G. E. Lamont?

A. I am, quite well.

Q. 3. Please state when you became acquainted with him and the circumstances.

A. I became acquainted with Mr. Lamont shortly after getting out of college; in fact, about the time that I got out of college in 1911; the occasion for making his acquaintance was my natural interest towards glass-blowing, as I had quite some years previously made certain scientific instruments which demanded more or less glass work.

Q. 4. What college do you refer to and what degree did you get at that college?

A. University of California; B. S.

Q. 5. Where was Mr. Lamont's shop at that time and what kind of work was being done there?

A. At the time I made Mr. Lamont's acquaintance he was located at 82 Second Street, San Francisco, California. The type of glass blowing that he did was a very diversified line, including general chemical apparatus, thermometer work, production of incandescent lamps, mainly miniature lamps, I don't mean miniatures of the order of flashlights, but a size mainly used on signs in those days, as well as a special type that were used on boats that were used to indicate the port and starboard lights. At that time he did quite an extensive amount of X-ray work, as well as high frequency electrodes, all of which demanded an extensive amount of vacuum work.

Q. 6. What were the high frequency electrodes that you refer to?

A. These were applicators used in the so-called ultra-violet machines used at the time.

Q. 7. Do you recall whether any work was done in Lamont's shop on radio tubes?

A. Quite a bit of work. With the advent of the audion tube and the short life of the filaments quite a bit of amateur work was done. This work consisted in putting in new filaments and re-exhausting the tube. They also did some commercial work, that is, one instance I have quite good recollection of, being for Dr. Lee DeForest. It might be well for me to state conditions under which I know this. While at the shop with Mr. Lamont one day during 1912, the exact month I cannot place, some tubes were either brought in by Dr. Lee DeForest or sent in by messenger to be re-exhausted only. The general type of these tubes, as I remember, were not the conventional round bulb having a small candelabra base; their exact shape I cannot place in my mind. These tubes were in good shape, that is I mean operable, except that Dr. DeForest insisted that they be exhausted just as high as possible. These tubes were put on to the exhausting fork that Mr. Lamont used for exhaustion of his incandescent lamps in the morning about 10.30 or 11 o'clock, if I remember; Dr. DeForest came in while the tubes were on the pump and looked under the asbestos hood, which was a heat shield, that was to prevent the heat from escaping that was used to bake them; he said that he would return about two o'clock. Dr. DeForest did not come back that afternoon. His tubes were exhausted till very near mid-afternoon, very near three o'clock, making a total of possibly four or four and a half hours' time on the pump.

Q. 8. Were you actually present while these tubes were being pumped?

A. I was, most assuredly.

Q. 9. Please describe the process by steps that was employed in pumping those tubes.

A. The previous exhaust tip was cracked off, the tubes were re-tubulated and subsequently sealed to the exhausting fork. The back-up pump, which was a modified Geryk pump, a two-cylinder pump, was used as a preliminary exhaust. This was used until the mercury in the shaft of the final pump reached barometric height. It was then closed off and the mercury jet pump started. We had an asbestos hood that was lowered over the tubes and underneath the tubes a Bunsen burner was lit and the atmosphere surrounding the audion bulbs brought up to just as high temperature as we knew was safe, that is, I mean by safe the tubes would not collapse due to the partial melting of the glass. In the meanwhile the jet pump was carrying out the gases remaining in the tubes. This particular type of jet pump allowed one to have a rough estimation of the vacuum conditions in the system as the gases would be entrapped between small amounts of mercury and carried down and out of the pump. When there were no longer amounts so far as the eye could see, coming over, the filaments were ignited at greater intensity than a normal burning rate. The idea of all this being to drive out all the occluded gases possible. This process was continued for several hours until what we estimated a sufficient time to thoroughly exhaust the tubes. We had, of course, no elaborate means of measuring the degree of exhaustion as at that time there was no such type of instrument on the market. The tubes while still burning and the jet pump going were then sealed off and allowed to cool in cotton waste, as breakage was one of our serious worries.

Q. 10. Please make a diagrammatic sketch of the mercury jet pump that you have referred to showing it as you knew it in 1912, at the time the work that you have described was done. Mark the parts with letters and refer to them in briefly describing your sketch.

A. I have made the sketch. In the diagram I have shown the automatic lift "A" for the mercury but that was not a part of the pump that I first saw when I came with Mr. Lamont. The idea of the automatic lift was to get rid of the manual labor of lifting a quart bottle of mercury from the floor to the level of one's shoulder. This little device "A" used for automatic lifting consisted of a small gear pump made by the Johnson Oil Burner people to force crude petroleum. It was made solely of steel and we had no hesitancy in using it in the vicinity of mercury, as there was no chance of amalgamating. Mr. Palmer Hewlett was the one who located this small gear pump and it was I who incorporated it into the pump, that is, it was I who made the motor drive, reduction gear, etc. In the diagram I possibly have not shown the jet "J" as being coaxial with the shaft "S"; this is quite necessary because the lowest fall of the mercury in the shaft "S" is quite necessary for the speed and all around efficiency of the pump. The shaft, that is, from the point of the jet to the mercury level "L" below, is greater than barometric height, that is, it is greater than 76 centimeters. Also the U-tube "U" from its lowest portion to the top of the jet was also greater than 76 centimeters.

Q. 11. How was the heat applied in the hood?

A. The heat was applied by means of Bunsen burner in the shape of an annular ring.

Q. 12. Please indicate that on the drawing, if possible, and tell how you have labeled the part.

A. "B" is the Bunsen burner—it set on some feet—there was a shelf there. I have written the names of some of the other parts on the drawing.

Q. 13. What is the part that you have labeled "drying tube"?

A. It is a small spherical bulb, directly below the exhaust fork—its purpose being to take up water vapor; it was so arranged that we could use any of the conventional dryers—either sulphuric acid or phosphoric anhydride.

Q. 14. Which of these dryers did you actually use?

A. We used either of them at our leisure.

Q. 15. I show you Defendant's Exhibit "A" and ask you if you recognize what is shown in that picture?

A. Yes, I recognize the photograph as being that of the mercury jet pump that Mr. Lamont had used for so many years—in fact the pump is the same as we used when I first went with Lamont—same board—it's on the same bench—I guess that is all.

Q. 16. In what respects, if any, does the pump shown in Defendant's Exhibit "A" differ from the pump you saw Mr. Lamont use in 1912?

A. The only difference being the automatic lift, "N."

Q. 17. When did you last see the mercury pump that Mr. Lamont now uses?

A. I see Mr. Lamont several times a week, I have seen him in the last few days. I see the pump every time I go in the shop.

Q. 18. In what respects, if any, does the pump that Mr. Lamont now has, I refer to his mercury pump, differ from the pump that is shown in the photograph?

A. None.

Q. 19. I show you Defendant's Exhibit "B" and ask if you recognize what is shown therein?

A. Yes, this is the twin-cylinder Geryk that we used as a preliminary pump. This pump for the class of work that we did, gave very good service, as we had no difficulty in obtaining 29½ to 29¾ inches of mercury—all depending of course, upon the barometric pressure. The valve mechanism consisted of small discs of oiled silk.

Q. 20. Do you remember any other work on radio tubes for Dr. DeForest beside that which you have testified about?

A. The work done for him personally?

Q. 21. Personally, or for his use?

A. There were a number of tubes that were repaired or re-exhausted for the Federal Telegraph Company—likewise, there was a shipment of tubes that were sent to Marconi Company at Marshall; some Wells Fargo messenger evidently tossed or roughly handled the box and the grids and plates, and filaments were all bent out of their natural shape. These tubes were opened on the side and the grid and plate straightened up—the hole on the side closed and the tubes re-exhausted. There was always quite a bit of amateur repair work—mainly burned out filaments, and these filaments were replaced and the tubes were re-exhausted.

Q. 22. Did you exhaust every audion tube to the same degree of vacuum that you exhausted the tubes that Dr. DeForest sent or brought to you, as stated in your foregoing testimony?

A. Some yes, and some no. The degree of exhaustion was usually a matter of demand of the customer—some wanted hard tubes and some wanted soft tubes and we endeavored to satisfy them. We differentiated between hard and soft tubes by the length of time we left them on the pump for the exhausting process.

Q. 23. Where were the filaments with which you replaced burned-out audion filaments obtained from?

A. That was one of the more important of our worries. The filaments were obtained mainly from new lamps, new tungsten lamps, rather, some times tantalum lamps. The possibility at that time of getting tunsten wire was practically nil, the General Electric Company didn't care to give out very much of it. The tubes at that time cost more than the ones we make now, in my estimation, because we used platinum for the leads, that is, the lead-in to the glass, rather than a nickel copper alloy we use now. The platinum was flattened down on the end and drawn through a little die which gave us a little tube. The tungsten filament is placed in the tube, the tube collapsed by a pair of needle pliers—thus firmly securing the filament in place.

Q. 24. What was the shape of the filament after it was actually mounted and secured in place in the tube?

A. Either single or double hair pin.

Q. 25. How was the filament formed in that shape?

A. By either cracking out one of the top loops in the filament, which had a natural bend in it, or else taking a straight piece and shaping it in that form. We made lots of trials before we usually got one that was all right.

Q. 26. How did you shape a straight piece to the hairpin form?

A. By gently bending it to form a hairpin loop.

Q. 27. In your answer to Q. 23, you state: "The Tungsten filament *is* placed in the tube." Please state whether you intended to use the present tense?

A. It should be *was* placed in the tube.

Q. 28. Referring to the incident of Dr. DeForest's visit to Lamont's shop that you related in your answer to Q. 7, did Dr. DeForest state to you, or to any one in your presence, the reason why he wanted the tubes exhausted to as high a vacuum as possible?

A. Not that I remember. He only having said that he desired the tubes pumped as high as we could pump them.

(Direct examination closed.)

Mr. Baumgartner: The sketch drawn by the witness in response to question 10 is offered in evidence as Defendant's Exhibit "H"—Clark Sketch. (Admitted in evidence, Record, page 916, as Defendant's Exhibit No. 73. *See Volume VI, Defendant's Exhibits, page 1037.*)

CROSS-EXAMINATION.

By MR. EDMONDS:

XQ. 29. Do you know of what sort of glass the audion tubes you refer to were made?

A. Yes, lead glass, because we had to seal platinum into them.

XQ. 30. You have said that these tubes were sealed to the pump, how was that done?

A. The tubes had a short length of tubing of about 3/16-inch diameter with a square end on it and those were butt up against the fork and heated in a reducing flame such as would not break down the lead glass, melted down and blown out. This type of glass will not stand handling in an ordinary glass fire, the lead silicate would be reduced and the surface of the glass become translucent with a metallic luster on it. We use the glassblowers typical cross-fires.

XQ. 31. What was the size of the Tungsten lamps from which you obtained Tungsten filaments, as stated in your direct testimony?

A. From forty to sixty watts.

(Cross-examination closed.)

(No re-direct examination.)

(Deposition closed.)

(Sgd.) LELAND B. CLARK.

MR. DARBY: Notice is given that R. R. Beal, of Palo Alto, California, will be examined.

(Adjourned till Thursday morning, November 6, 1924, 9.30 A. M.)

Thursday, November 6, 1924.

Met pursuant to adjournment.

Parties present as before.

DEPOSITION OF MR. G. E. LAMONT.

G. E. LAMONT, a witness produced on behalf of defendants, being first duly sworn, in answer to interrogatories propounded to him, deposes as follows:

By MR. BAUMGARTNER:

Q. 1. Please state your name, age, residence and occupation.

A. G. E. Lamont, business location, 143 Second Street, San Francisco, California, glassblower.

Q. 2. Please mention some of the devices that you have worked upon in your business as glassblower.

A. Scientific apparatus made of glass, thermometers, barometers, X-ray tubes, incandescent lamps, audion bulbs repaired—that includes nearly everything.

Q. 3. What kind of repairs did you make on the audion bulbs?

A. Renewing filaments and re-exhausting.

Q. 4. When did you first renew filaments of audion bulbs and re-exhaust them?

A. It was prior to 1912—the exact date it is impossible to tell.

Q. 5. Have you any records that would show these dates?

A. I go according to the entry of the items in the day book.

Q. 6. Who kept the day book?

A. At that time my sister-in-law, Miss Plagemann, at present Mrs. Beck.

Q. 7. I show you Defendant's Exhibits "C" and "D" and ask you to state whether you recognize these books?

A. Yes, sir, I do.

Q. 8. Please state what they are.

A. My day books.

Q. 9. Please state what period of time is covered by these books, and in whose possession they have been since the entries were made in them?

A. Exhibit "D," from January, 1907, to May, 1912; Exhibit "C," from June, 1912, to August, 1918, and they always have been in my possession.

Q. 10. Can you give the names of some persons or concerns for whom you worked on audion tubes?

A. One, Mr. Hewlett; the National Telephone Company; I might have said Wireless, because I am not sure whether they went under the name National or National Wireless Telephone Company. I am trying to recollect the man in San Jose; Federal Telegraph Company; Mr. DeForest; and several others I cannot mention just now—can't recollect the names.

Q. 11. By referring to your books, can you say what work you did for those people, and when?

A. I recollect now the name of the man in San Jose—it's Mr. Herrold. The Federal Telegraph Company, September 19, 1912—eighteen audion lamps exhausted, page 9 of Exhibit "C."

Q. 12. Did you do any work for Dr. DeForest or Federal Telegraph Company on audion tubes before the date of that entry?

A. I may have.

Q. 13. Do those books contain entries of all the work you did in your shop?

A. No, sir. It was neglected at times to put things down as a settlement was affected in paying for work done—not having to give an account to anybody. As payment for work was made, by neglect it was dismissed from our mind, as I had to give no account to anybody.

Q. 14. Were items of work for which cash was immediately paid entered in that book?

A. Not always, as I said from neglect or pressure of time.

Q. 15. What were your instructions concerning the exhausting of audion tubes for Dr. DeForest or the Federal Telegraph Company?

A. On this special lot of eighteen I was instructed to put in as high a vacuum as possible; from my own conclusion I found that the tubes had been already exhausted with the explanation it was unsatisfactory and to exhaust them as high as I could.

Q. 16. Were the tubes sealed or unsealed when you received them?

A. I found them sealed.

Q. 17. Did you carry out the instructions to exhaust them as high as you could?

Mr. Edmonds: Objected to as leading.

A. As well as the pump could do at the time.

Q. 18. Did your pump produce a high vacuum at that time, or did it not?

A. It did.

Q. 19. Why did you say that your pump did produce a high vacuum at that time?

A. For my own satisfaction in turning out X-ray work—X-ray tube exhausting.

Q. 20. On what pump did you exhaust the incandescent lamps that you made?

A. I only had one pump I did all my work on; by this I mean the glass pump—the pump made of glass.

Q. 21. How did the incandescent lamps that you made stand up?

A. From the reports I received from my customers, they considered them as good as any, if not better.

Q. 22. Can you mention any particular instance?

A. I made lamps for Philadelphia Shoe Company of San Francisco; the report I got was the lamps lasted over three years—being lit in summer from eight till twelve o'clock, and in winter from five to twelve o'clock—every night in the year, and the first renewal order I received was after three years and three months. Another instance is the Novelty Sign people, for whom I made quite a number of lamps. While they had to pay a few cents more for my lamps he was dissatisfied with the price and ordered ten thousand lamps East under contract. One day he came to me and explained why he wanted my lamps back—claiming that he had to have a man out every night exchanging new lamps for the old, which he never experienced with my lamps.

Q. 23. To what do you attribute the durability of the lamps made by you?

A. I attribute that to the high vacuum produced in those lamps.

Q. 24. Did you believe at that time that you were obtaining a higher vacuum from your pump than was obtained by others in the lamp manufacturing business?

Mr. Edmonds: Objected to as leading.

A. I believe that to be the case.

Q. 25. I show you Defendant's Exhibit "A" and ask you if you recognize what is shown in that picture?

A. This picture represents my vacuum pump made of glass.

Q. 26. How long have you had that pump?

A. You mean this particular type of pump?

Q. Yes.

A. Since the fall of 1906.

Q. 27. Please state just what you did in re-exhausting the audion tubes concerning which you have testified.

A. I attached same to a grinding, a glass fitting to the pump; we put a Bunsen burner under the bulb, covered with a hood; after thoroughly heating started the mechanical pump. As soon as the highest point of evacuation occurred in the mechanical pump we closed the stopcock and started the mercury flowing—operation being continued until a sufficient vacuum was obtained to light the filament. The exhaustion of tubes vary from an hour up to two and a half. When vacuum completed, as the shaft of the pump indicates, the bulb is sealed off—that completes the evacuation.

Q. 28. How brightly was the filament lighted?

A. Up to incandescene, the first very low, and as the vacuum increases we brighten the filament. In fact, overrunning the incandescence to expel all gas.

Q. 29. What was heated by the Bunsen burner?

A. The bulb, which naturally would heat the interior as well—due to the fact that the bulb was still full of air.

Q. 30. To what degree, if you know, was the bulb heated?

A. Between 500 degrees F. and 700 degrees F.

Q. 31. In your answer to Q. 27, you say, "When vacuum completed, as the shaft of the pump indicates." Please explain a little more fully what you mean.

A. The shaft of the pump is a long slender tube containing a column of mercury (marked "K" on Exhibit "A"), sealed on the bottom by being immersed in mercury, in a percolator. The indication of the vacuum is when there are no more bubbles appear while the pump is still in operation.

Q. 32. Did you stop the pump just as soon as no more bubbles appeared?

A. No, sir. I sealed off the lamp or lamps first, then shut down the pump.

Q. 33. Did any time elapse between the time when there were no more bubbles to be seen in the shaft and the time when you sealed the tube off?

A. Well, just the natural time to seal it—whatever time it takes to seal it off.

Q. 34. Did you, or did you not, cause the pump to run after bubbles no longer appeared in the shaft?

A. When everything is sealed off, we shut down the pump.

Q. 35. In your answer to Q. 27, you state: "The exhaustion of tubes vary from an hour up to two and a half"?

A. Yes, sir.

Q. 36. Could you see bubbles in the shaft during all of the two hours and a half when you pumped a tube that long?

A. No, sir, they would not show.

Q. 37. Then, it is to be understood that you allowed the pump to go on running after bubbles no longer appeared in the shaft?

Mr. Edmonds: Objected to as leading.

A. We continue for some time, to make sure that we get them all.

Q. 37a. I show you Defendant's Exhibit "B," and ask you if you recognize what is shown therein.

A. It is my primary vacuum pump which I used to produce the first vacuum in the glass pump.

Q. 38. Can you point out the glass stopcock that you said you turned after the highest point of evacuation with the mechanical pump occurred?

A. It is shown by the letter "H."

Q. 39. Please state the purpose of the part indicated by letter "E" in Defendant's Exhibit "A."

A. The glass bulb is filled with chemicals to absorb moisture.

Q. 40. What chemicals did you use?

A. Pentoxide or phosphoric anhydride.

Q. 41. Did you ever use sulphuric acid as a dryer, or did you not?

A. I have used it.

Q. 42. I show you a drawing and ask you if you recognize what is shown therein.

A. Yes, sir, I recognize it. It is my mercury vacuum pump.

Q. 43. Please state in what respects, if any, the pump shown in the drawings differs from the pump you used in 1912 in exhausting the audion tubes concerning which you have testified.

A. It is the identical type of pump.

Q. 44. Please state the operation of the pump, by referring to the drawing.

A. The mechanical pump is attached to the stopcock "H"; the mechanical pump being started the mercury will rise in the shaft tube "K," as well as in supply tube "O." After mercury comes to its full height stopcock "H" is closed and the mechanical lift "N" is started, which causes the mercury to rise and fall into the supply percolator "D." When "O" is filled to the top the mercury will force its way to the jet "P" forming a stream of mercury in the shaft "K" hitting the column of mercury, thereby forming bubbles of the gases which are above the mercury column. These bubbles are then forced down to the percolator "R" and liberating the gases and the mercury being taken up again by the mechanical lift "N."

Q. 45. Do you consider the mechanical lift a part of the pump proper?

A. No, sir, I do not.

Q. 46. Did you, or did you not, always use the mechanical lift "N"?

A. I did not.

Q. 47. What did you use, if anything, before that to perform the same function?

A. Well, they used bottles to receive the mercury—when filled, when bottle was filled we poured mercury into percolator "D."

MR. DARBY: The drawing referred to by the witness in his last answers purports to be a drawing made from scale taken directly from Mr. Lamont's pump and giving the measurements thereof. It is offered in evidence as Defendant's Exhibit 'I.'" (Admitted in evidence, Record, page 915, as Defendant's Exhibit No. 68. *See Volume VI, Defendant's Exhibits, page 1031.*) And it is stipulated that if G. Arnberg were called as a witness in behalf of defendants he would testify that he is a draughtsman, located in San Francisco, California, and that last week he made this drawing and the measurements directly from Mr. Lamont's pump and that the measurements indicated, as well as the drawing, are accurate to the best of his belief.

MR. DARBY: A drawing of a similar nature, showing details of the parts "K" and "L," indicated on the photograph—Defendant's Exhibit "A"—is offered in evidence as Defendant's Exhibit "J," under the same stipulation set forth with respect to the drawing, Exhibit "I."

(Admitted in evidence, Record, page 916, as Defendant's Exhibit No. 69. *See Volume VI, Defendant's Exhibits, page 1033.*)

Q. 48. When you renewed the filaments of audions, concerning which you have testified, where did you obtain the new filament which you put in?

A. I bought Tungsten lamps to obtain the filaments.

Q. 49. How were the filaments for the audion tubes repaired and mounted?

A. We formed small tubes on the end of platinum wire and mounted the filaments in there.

Q. 50. How were the filaments formed?

A. Formed in the shape of a horseshoe. We used the hairpin shape of the filament itself.

Q. 51. Please say what you mean by the "hairpin shape of the filament"?

A. In most cases the Tungsten lamp came with the filament formed in the hairpin shape and we always made use of the hairpin shaped end, and it is next to impossible to reshape the Tungsten filament.

Q. 52. Did you, or did you not ever succeed in reshaping the Tungsten filament?

A. I have succeeded.

Q. 53. How did you do that?

A. I have had the filament in a double clamp and hanging thereon a slight weight and bringing said filament to incandescence in a vacuum, thereby the weight dragged down the filament to form into a "U" shape. It was then ready to use for lamp work.

Q. 54. I call your attention to an entry on pages 14 and 15 of Defendant's Exhibit "C," the words "Dec. 1912" appearing at the top of those pages, and the item reading "9 National Wireless Tel. & Tel. Co. —3 audion tubes rep. 200 ea. 600," and ask you to explain, if you know, what work that referred to?

A. Work done on these tubes was to let air in, cut off the tip, add the new tube to act as a handle, then cut out the filament end of the tube, then pull out the old filament, add a new filament, reseal the two parts—join the two parts—seal the tubes on the grinding, "J," set on the pump and exhaust, adding heat, mechanical pump, and work vacuum pump afterward until final exhaust.

Q. 55. For whom was that work done?

A. National Wireless Telegraph and Telephone Company.

Q. 56. When was that work done?

A. According to this exhibit, December 9, 1912.

Q. 57. Was that work paid for?

A. Yes, according to book it was, 12/9/12.

Q. 58. I call your attention to an entry on pages 18 and 19 of Defendant's Exhibit "C" relating to Federal Telegraph Company, and ask you to state when that work was done and of what it consisted?

A. There was exhausted eleven audion bulbs, charged for 45 cents each, which made it $4.95. The work was done on February 13, 1913—it was paid on March 27, 1913.

Q. 59. I call your attention to an entry on pages 50 and 51 of Defendant's Exhibit "C" relating to Herrold College, and ask you to state when that work was done and of what it consisted?

A. Done on June 19, 1914, six audions repaired, new filaments added—paid 7/7/14.

Q. 60. In the repair of filaments for the National Wireless Tel. & Tel. Co., concerning which you have testified, and in the repair of filaments for Herrold College, concerning which you have testified, where did you obtain new filaments?

A. Out of lamps.

Q. 61. Do you refer to the same lamps that you referred to above or to different lamps?

A. Same lamps as above.

Q. 62. Where did you obtain those lamps, if you remember?

A. Our usual supply came from Paul Seiler Electrical Works, San Francisco, California.

Q. 63. I call your attention to an entry relating to Federal Telegraph Co., on pages 50 and 51, of Defendant's Exhibit "C," and ask you to state when that work was done and what work is referred to?

A. June 19, 1914, Federal Tel. Co., eight audions exhausted; 8/28/14 paid—amount $5.00.

Q. 64. I call your attention to an entry on pages 76 and 77 of Defendant's Exhibit "C" relating to

Marconi Wireless Telegraph Co. of America, and ask you when that work was done and of what it consisted?

A. July 7, 1915, six audion bulbs repaired and exhausted—paid for in July, 1915—$10.00.

Q. 65. Of what did that repair consist?

A. No doubt adding filaments and exhausting.

Q. 66. What other repairs did you ever make on audion tubes beside adding filaments, if any?

A. I have had tubes come in with the tip broken off which meant re-exhausting to put them in working order.

Q. 67. What would you have charged for repairing an audion that merely had its tip broken off?

A. Seventy-five cents to one dollar.

Q. 68. What did you charge the Federal Telegraph Company for exhausting tubes in June, 1914?

A. All depending on the number sent in—from forty to fifty cents apiece.

Q. 69. What did you charge Herrold College for new filaments in June, 1914, as shown by your account book?

A. Six audions repaired, new filaments, ten dollars.

Q. 70. Does the amount of the charge made to the Marconi Company in 1915, as it appears on page 77 of your account book, Exhibit "C," indicate anything to you as to the character of the repair referred to in that item?

A. It does not.

Q. 71. Do you recall doing any work in connection with audions prior to any of the entries in your books, that have been referred to?

A. I can't recollect.

Q. 72. Would your books show?

A. Not always.

Q. 73. If an entry in one of your books referred to an audion, what would that indicate to you?

A. That the work was actually done.

Q. 74. In your account book, Defendant's Exhibit "D," I call your attention to an item referring to Prof. Jahnke, and ask you to state in whose handwriting that appears, if you know? What work is referred to and when it was done?

A. September 4, 1909, two audion receivers—paid for 9/4/09, $15. It is my own handwriting.

Q. 75. Of what did that work consist, if you know?

A. Doing the glass work on the audions complete.

Q. 76. Do you remember any distinguishing features of those particular audions?

A. There were two half-shells of metal mounted on a glass stem, a spiral of metal as well, and the filament placed in between—inside the shell.

Q. 77. What was the general shape of those audions, if you remember?

A. A bulb with three ends to it.

Q. 78. Who did the work on those bulbs?

A. Myself—the glass part.

Q. 79. If you remember, please state who did any other part.

A. I think I requested Prof. Jahnke to furnish me the metal and I would form the shells—and I did the rest of the work.

Q. 80. Who mounted the filament?

A. Mrs. Beck.

Q. 81. I show you Defendant's Exhibit "F" and ask you if you recognize it.

A. I do. I consider it useful for the same purpose as the present audion bulb.

Q. 82. My question was, whether you recognized that bulb and know anything about the bulb itself as distinguished from its intended or possible purpose.

A. Well, I was told at the time it was for wireless work.

Q. 83. At what time and who told you?

A. Prof. Jahnke.

Q. 84. When did he tell you that?

A. The time he gave me the order to make it.

Q. 85. To make what?

A. To do the work on this Exhibit "F."

Q. 86. Then, will you please say just what this exhibit is?

A. A bulb with three ends to it, containing the electrodes as well as filament.

Q. 87. Do you know who made it?

A. I made it myself for Prof. Jahnke.

Q. 88. When did you make it?

A. It is charged up on September 4, 1909.

Q. 89. I call your attention to another item in your account book, Defendant's Exhibit "D," referring to A. Jahnke, and ask you to state what that item refers to and when the work was done.

A. I could not describe it.

Q. 90. The item appears to have the date November 3, 1909, and refers to "2 special apparatus." Do you remember what that apparatus was?

A. I do not.

Q. 91. Do either of the two last entries referred to relate to Defendant's Exhibit "F," or do they not?

A. They do.

Q. 92. Can you say which one?

A. Entry September 4, 1909.

Q. 93. I show you Defendant's Exhibit "E" and ask you whether it resembles or is illustrative of the audion tubes that you worked on in 1912.

A. Yes, it is.

Q. 94. Did you ever meet Dr. DeForest in a business or other way, or see him?

A. I have.

Q. 95. Please relate the circumstances.

A. I recall him coming in with an audion bulb at my place of business at 82 Second Street, San Francisco, bringing a tubular shape bulb which bulb contained a plate—circular plate, rather—and filament, but no wire grid, and Dr. DeForest requested me to remodel this tube by inserting a wire grid and re-evacuated.

Q. 96. Do you recall when this incident occurred?

A. I cannot.

Q. 97. Can you say whether this incident occurred before or after you exhausted audion tubes under instructions to exhaust them to the highest vacuum, concerning which you have testified?

A. I could not recall that.

Q. 98. Can you, or can you not recall any other time that Dr. DeForest visited your shop?

A. I do not.

By Mr. Darby:

Q. 99. Do you recall who gave you your instructions to evacuate the lot of eighteen tubes for DeForest or the Federal Telegraph Company to as high a vacuum as possible, as you testified in answer to Q. 15?

A. I recall the request but I do not know who the party was.

Q. 100. So far as you recall now, did you only meet Dr. DeForest at your shop the one time, concerning which you have testified?

A. Only the one time.

Q. 101. Were you informed by anyone, if you can recall, why a high vacuum was wanted in the vacuum tubes or audions exhausted by you for Dr. DeForest or the Federal Telegraph Co.?

A. I was requested to evacuate them to the highest point I could but not mentioning for any purposes or reason.

Q. 102. Mr. Lamont, has your laboratory work impaired your health and physical condition?

A. To what extent?

Q. 102a. To any extent.

A. Yes, sir.

Q. 103. To what extent?

A. X-ray has made the greatest troubles for me.

Q. 104. Has it necessitated your consulting a doctor?

A. It has, numerous times.

Q. 105. I do not want to pry into your personal affairs, but it was my understanding that your physical condition and health had been impaired by your laboratory work and I merely wanted to put on the record such facts as to your physical condition and health as you advised us prior to your testifying, on which our understanding was based, provided you had no objection to stating them. With this in mind, will you please briefly state the nature and extent of the impairment of your health and physical condition, and if you care to, the instructions and advice you have received from your physician with respect thereto, particularly with respect to your future conduct and amount of labor?

A. One thing is the inability to get around, due to an infection I got in my right hand in 1919 whereby I had to keep from work for six months. I also had cancerous condition on the face and hands, which so far has been cured through means of radium. The infection has produced on me an ulcer on the left leg which hampers me a great deal in getting around. It produced what is called thrombosis or milk leg in the left leg. This condition is a great drawback to my getting around and is very painful. I am supposed to lie flat as much as possible, never to massage my leg as I may release a blood clot, which eventually may go to the heart, with the chances of death.

Q. 106. Were you advised by your physician as to the amount of physical exercise you should or should not subject yourself to?

A. Not exactly, except to stay off my feet.

Q. 107. I notice in your answer to Q. 1, that you failed to state your age.

A. Fifty-eight.

(Adjourned to 2 P. M. at same place.)

November 6, 1924, 2. P. M.

Met pursuant to adjournment.

Parties present as before.

By Mr. Baumgartner:

Q. 108. Can you give the names of any people who were familiar with the vacuum pumps, particularly the mercury pump that you used in 1912, in connection with the work concerning which you have testified?

A. Mrs. Alphonse Beck; Mr. Leland Clark; Mr. Hewlett. I wouldn't let anyone else handle them on account of being glass and easily broken.

Q. 109. Do you know of any other pumps that were made like yours at that time?

A. No, sir.

Q. 110. Do you know Emile Beyer?

A. Yes.

Q. 110. How long have you known him?

A. I have known him for about twenty years—yes, in fact more, twenty-five years.

Q. 112. Do you know whether or not he was ever in your shop?

A. Many times.

Q. 113. And why he came there?

A. I used to make lamps for him.

Q. 114. Did he ever see your mercury pump, around 1912, or did he not?

A. He did.

Q. 115. Did he or did he not have an opportunity to be familiar with that pump at that time?

A. He did, he was familiar with it.

Q. 116. Please state what opportunity Beyer had to become familiar with your pump.

A. He watched the process of exhaustion.

Q. 117. With the exception of the exhausting of audion tubes that you have done for me, when did you last do any exhausting of audion tubes?

A. It's all of a year that I have done any exhausting of audion bulbs.

Q. 118. Do you wish it understood that you have done exhausting of audion tubes up to some date about a year ago?

A. About that.

Q. 119. How did Mrs. Beck become familiar with your vacuum pump?

A. I had instructed her how to run it.

Q. 120. Under what circumstances did you instruct her to run it?

A. In exhausting lamp bulbs.

Q. 121. She worked for you?

A. Yes.

Q. 122. Did she do any work on audion tubes in your shop?

A. She did the filament part of it.

Q. 123. How did Leland Clark become familiar with your pump?

A. From spending part of his time in my shop watching proceedings.

Q. 124. Have you been asked by me whether you will sell your present mercury vacuum pump?

A. Yes, sir.

Q. 125. What was your answer to that?

A. I couldn't do it.

Q. 126. When the mercury pump that you have is running, what is the level of the mercury in the percolator "R"?

A. When the pump is running the mercury is below the shaft tube "K"—two inches below.

Q. 127. With the exception of any broken parts that may have been replaced, is the mercury pump which you now have the same pump that you had in 1912 and used in the re-exhausting of audions for Dr. Lee DeForest and the Federal Telegraph Company concerning which you have testified?

A. The same pump, the same identical type of pump.

Mr. Darby: This closes the direct examination of Mr. Lamont. As part of the testimony, we propose to request Mr. Lamont to pump two old-type of three-electrode tubes, two newly constructed old-type of three-electrode tubes, one UV-200 tube of plaintiff and one UV-201 tube of plaintiff, if the same can be obtained, and if not, in that event, one C-301 type of tube, and to follow strictly the same procedure employed by him in 1912 and '13 in repairing and exhausting the three-electrode tubes which he repaired and exhausted for Dr. DeForest or the Federal Telegraph Company, concerning which he has testified. As soon as these tubes are sealed off of the pump and cooled and tested against filament breakage during exhaustion they are to be delivered to Mr. Healey, the notary before whom these depositions are taken, to be shipped to the clerk of the court as part of the testimony and to remain in the custody of the clerk of the court until the trial of this cause. Opposing counsel are invited to attend the operations performed by Mr. Lamont pursuant to this request and to note on the record any facts which occur during the same, which they desire, also to cross-examine Mr. Lamont during the operations, or subsequent thereto, should they so desire. For the purpose of making the matter clear on the record, I will ask Mr. Lamont the following question:

Q. 128. Will you repeat on each of the six tubes that we will supply you with and properly mark for identification the operations of exhaust, and repair if necessary, that you went through with on this same pump in the period of 1912, or thereabout, in connection with audion tubes, for Dr. DeForest or the Federal Telegraph Company under their instructions to pump to the highest possible vacuum?

A. I will, only the old type tubes, not the ones with the caps on, the present type tubes I cannot repair as I cannot repair the filament.

Q. 129. As I understand it, you cannot repair the filament on the present type tubes because of the caps or base employed on the present type tubes?

A. Yes, besides the inclosure of the, or the surroundings rather, of the grid and plate and filament between them, I cannot get at it.

Q. 130. Then, with the understanding that with respect to the type "UV" or type "C" tubes, repair work—even though necessary—is eliminated, will you do as requested?

A. I will.

(Direct examination closed.)

Mr. Edmonds: I have no cross-examination for the witness at present on the testimony thus far taken and do not expect to cross-examine him thereon at all unless this seems necessary after the completion of the test work, which the witness has been called upon to do.

Mr. Darby: It is stipulated by and between counsel that if Ralph C. Hyde were recalled in behalf of defendants, he would testify that at my request, on the completion of his deposition, he made search among his personal effects to endeavor to definitely fix, by documentary records, the date when he left the employ of the General Electric Company. That pursuant thereto he ascertained from his contract with the General Electric Company that he ceased working for the General Electric Company on or about March 1, 1913, although his salary continued a short time thereafter, but that the other dates as given in his deposition are correct as stated, to the best of his knowledge and belief.

DEPOSITION OF MR. RALPH R. BEAL.

Ralph R. Beal, a witness called in behalf of defendants, after being first duly sworn, deposes in answer to interrogatories propounded by Mr. Darby, as follows:

By Mr. Darby:

Q. 1. Please state your age, residence and occupation.

A. Age, thirty-seven; residence, Palo Alto, California; occupation, radio engineer.

Q. 2. Were you ever employed by the Federal Telegraph Company of California?

A. Yes, I was.

Q. 3. When did you enter their employ, and when did you leave?

A. I entered on the permanent payroll in June, 1912, and left the first of September, 1924.

Q. 4. While you were employed by the Federal Telegraph Company, did you know Dr. Lee DeForest?

A. Yes, I knew the Doctor.

Q. 5. What was the nature of your employment with the Federal Telegraph Company in 1912 and where was the employment?

A. The employment was in Palo Alto, California, principally. The nature of the work for the first part of my employment was of drafting, drawing of electrical circuits, mechanical designs, and later that of laboratory assistant in the development of radio equipment.

Q. 6. Was the factory of the Federal Telegraph Company located at Palo Alto?

A. Yes, the factory was at Palo Alto.

Q. 7. Did your employment in 1912 and '13 make you familiar with any work or apparatus used in connection with three-electrode vacuum tubes?

A. I was only indirectly associated with that particular development—it having been under the direction of Dr. Lee DeForest, then research engineer for the Federal Telegraph Company of California. I had knowledge indirectly of the work he was doing, I, myself, having taken a great interest in his research work and having discussed it frequently with his assistants, Mr. Logwood and Mr. Van Etten.

Q. 8. In 1912 and 1913, did the Federal Telegraph Company of California, if you know, make or use apparatus employing three-electrode vacuum tubes?

A. To the best of my knowledge, they did; they made and used equipment employing three-electrode tubes.

Q. 9. Generally speaking, what was the type of the equipment made and used by the Federal Telegraph Company, that is, its purpose, in 1912 and '13?

A. In the fall of 1912 and the spring of 1913 the greater portion of the equipment was used for amplifying purposes. The amplifiers were developed for high speed radio telegraphone and arranged in such a way that messages could be received at high speed and translated at a lower speed. The amplification was necessary to accomplish the high speed recording the signal.

Q. 10. What other purpose, if any, was the three-electrode vacuum tubes used for by the Federal Company?

A. It was used as a detector of radio frequency signals, sometimes used in connection with an interrupter provided to produce audio frequency signals.

Q. 11. Was it the practice, if you know, to use the same vacuum tube for amplification as was used as a detector?

Mr. Edmonds: Objected to as leading.

A. It is my recollection that in the fall of 1912 there was a defined distinction between detector tubes and amplifier tubes—the latter being used for amplifying purposes in connection with the system developed for high speed radio telegraph signalling.

Q. 12. Were you able, pursuant to my request, to locate any documents from the records or files of the Federal Company of California where the audion bulbs were listed in accordance with their use?

A. In the summer of 1924, and prior to September 1st, while investigating old stock cards and records stored at the present factory of the Federal Telegraph Company of California I located one stock card showing audion bulbs listed under the headings of "detector bulbs" and "amplifier bulbs."

Q. 13. What did you do with this stock card when you located it?

A. I placed the cards in the active records of the Federal Telegraph Company of California for future reference.

Q. 14. Is the card which I now hand you the card to which you refer?

A. Yes, the card.

Q. 15. When and by whom, if you know, was the card extracted from the active file to which you refer?

A. This card was extracted from the active file on this date, November 6, 1924, by myself, in company with Mr. C. E. Scholz of the Federal Telegraph Company of California.

Q. 16. Where?

A. At the Palo Alto factory of the California Company.

Mr. Darby: The card referred to by the witness is offered in evidence as Defendant's Exhibit "K." (Admitted in evidence, Record, page 918, as Defendant's Exhibit No. 77. *See Volume VI, Defendant's Exhibits, page 1055.*)

Mr. Edmonds: Objected to as not proven.

Q. 17. How many audions or stages of amplification were employed in the amplifier apparatus with which you were familiar and manufactured and used by the Federal Telegraph Company in 1913?

A. The first development consisted of a single audion amplifier constructed in the early fall of 1912. The later developments consisted of three-step audion amplifiers constructed in the fall of 1912 and the spring of 1913.

Q. 18. Pursuant to my request, were you able to find any documentary record in the files of the Federal Telegraph Company of California in 1912 or '13 relating to a three-stage amplifier apparatus?

A. Yes, I found one stock card showing that three-stage amplifier apparatus had been manufactured by the Federal Telegraph Company of California in the fall of 1912.

Q. 19. Is this the stock card which you refer to which I hand you?

A. This is the card.

Q. 20. Is the history and location of this card and its production here today the same as that recited with respect to Defendant's Exhibit "K"?

A. It is the same.

Q. 21. Do you know in whose handwriting the entries on these cards are?

A. I don't recognize the handwriting; it is my recollection, however, that the files at that time were in the hands of a man named Longenecker.

Q. 22. Do you know where Longenecker is located now?

A. To the best of my knowledge and belief he is employed by the Federal Telegraph Company of California at its Palo Alto factory.

> Mr. Darby: I offer in evidence the card last referred to by the witness as Defendant's Exhibit "L." (Admitted in evidence, Record, page 918, as Defendant's Exhibit No. 76. *See Volume VI, Defendant's Exhibits, page 1054.*)

> Mr. Edmonds: Same objection.

Q. 23. You have referred to a single audion amplifier apparatus manufactured by the Federal Telegraph Company of California in 1912, and I hand you a blueprint numbered 88 and ask you if you recognize the same as being any work with which you had any personal connection?

A. I recognize the blueprint as that made upon a tracing paper by me in 1912.

> Mr. Darby: I offer in evidence the blueprint referred to by the witness as Defendant's Exhibit "M"—Beal Blueprint. (Admitted in evidence, Record, page 919, as Defendant's Exhibit No. 81. *See Volume VI, Defendant's Exhibits, page 1065.*)

Q. 24. I show you another blueprint numbered 229, of the Federal Telegraph Company of California, and ask you whether or not you recognize that blueprint or the equipment shown therein?

A. I recall this blueprint as having been made by a draughtsman at the factory of the Federal Telegraph Company of California in the early part of 1913. The draughtsman's name, I believe, was Bjerre.

Q. 25. Do you know where Bjerre is?

A. It is my recollection that he is now employed by the Western Union Telegraph Company as supervisor of automatic telegraph equipment in San Francisco.

Q. 26. Will you please state, if you know, how this blueprint was obtained?

A. Upon authorization of the executive office of the Federal Telegraph Company of California this blueprint was made and delivered to Mr. Baumgartner as representing the DeForest Telephone & Telegraph Company, being delivered to Mr. Baumgartner on April 28, 1924.

Q. 27. By whom was the original tracing obtained for the purpose of making this blueprint?

A. The original tracing, as I recall, was obtained by myself from the files of the Federal Telegraph Company of California at their factory.

Mr. Darby: The blueprint referred to by the witness is offered in evidence as Defendant's Exhibit "N"—Beal 1913 Blueprint. (Admitted in evidence, Record, page 919, as Defendant's Exhibit No. 82. *See Volume VI, Defendant's Exhibits, page 1067.*)

Mr. Edmonds: Same objection.

(Direct examination closed.)

(No cross-examination.)

(Deposition closed.)

(Sgd.) RALPH R. BEAL.

DEPOSITION OF AUSTIN Y. TUEL.

Austin Y. Tuel, a witness called in behalf of defendants, being first duly sworn, deposes in answer to interrogatories propounded by Mr. Darby, as follows:

By Mr. Darby:

Q. 1. Please state your age, residence and occupation.

A. Age forty-two; residence, 363 Twenty-ninth Avenue, San Francisco, California; occupation, general manager of the Traffic Department, Federal Telegraph Company.

Q. 2. How long have you been connected with the Federal Telegraph Company?

A. Since September, 1910.

Q. 3. In what capacity were you employed by the Federal Telegraph Company between September, 1910, and January 1, 1914?

A. 1910 until September, 1912, I was the operator in charge of the Beach Radio Station, San Francisco, and from September, '12 to 1914, I was the Chief Operator for the company in charge of all its radio stations.

Q. 4. During the time you were at the Beach Station, did you employ any apparatus employing three-electrode tubes?

A. Yes.

Q. 5. What was the nature of that apparatus?

A. Vacuum tubes were used as detectors and as amplifiers in the receiving system.

Q. 6. Will you please briefly describe the amplifier apparatus that you employed, referring to vacuum tube apparatus? I am confining my questions to the period of time that you were operator at the Beach Station.

A. We employed the vacuum tube first as a detector and later as an amplifier. The tests were conducted—using an amplifier during the latter part of 1912 for the amplification of radio signals received at our Beach Station from our Los Angeles Station. The amplifier used consisted of three-tubes or three-stages of amplification.

Q. 7. Are you using the expression "three-tubes or three-stages of amplification" as meaning two different arrangements or as meaning the same arrangement?

A. Meaning the same arrangement. By means of this three-stage amplifier, signals were amplified and recorded on a telegraphone. We used the combination amplifier and telegraphone in the handling of commercial messages between San Francisco and Los Angeles.

Q. 8. Who supplied you with the vacuum tubes you used in the amplifier?

A. Vacuum tubes were supplied by our Palo Alto factory.

Q. 9. Did you have any trouble with these amplifier tubes?

A. It was necessary to select certain tubes out of the supply we had, finding some tubes better suited for amplification than others.

Q. 10. Did you know at that time what characteristic of the tubes fitted some to the purpose of use as amplifiers better than others?

A. We found that some of the tubes would not stand sufficient plate voltage to give us the amplification required.

Q. 11. When the tubes did not stand what you term "sufficient plate voltage," what indication did you get of that fact?

A. Blue glow between the plate and filament.

Q. 12. Was this blue glow visible?

A. It was.

Q. 13. What did you do with the tubes that evidenced the blue glow?

A. Discarded them.

Q. 14. Did you know why some tubes would blue glow at the desired voltage and others did not?

A. It was my understanding that tubes having the blue glow did not have sufficient vacuum.

Q. 15. When was that your understanding?

A. During the time I was supervising the operation of equipment.

Q. 16. Did you have that understanding when you were the operator at the Beach Station?

A. Yes.

Q. 17. Do you know whether or not anything was done with the tubes that you discarded to remedy that difficulty?

A. Certain tubes were returned to our Palo Alto factory and, as I understood at the time, were repumped.

Mr. Edmonds: Objected to as immaterial.

Q. 18. How many cells of B-battery did you have in the apparatus employed by you in the three-stage amplification?

A. To the best of my recollection there were thirty-six.

Q. 19. What make battery?

A. They were flashlight cells of 1½ volts each. I don't recall the maker—they were standard batteries.

Q. 20. I show you a photograph of some equipment and ask you if you recognize any of the equipment there?

A. Yes.

Q. 21. Please state briefly what equipment you recognize and what it is.

A. There are two amplifiers in this picture, of three tubes each, a telegraphone, and the equipment associated with the telegraphone. This is the equipment we used in handling commercial business between our stations on the Pacific Coast.

Q. 22. Is that the same equipment, or equipment like you used when you were operator at the Beach Station?

Mr. Edmonds: Objected to as leading.

A. It is equipment like we used while I was at the Beach Station.

Q. 23. Do you know what became of the equipment you used at the Beach Station?

A. No, I do not.

Mr. Darby: I have marked the photograph for identification Exhibit "O."

(Direct examination closed.)

(No cross-examination.)

(Deposition closed.)

(Sgd.) AUSTIN Y. TUEL.

DEPOSITION OF MR. JAMES O. WATKINS.

James O. Watkins, a witness produced by defendants, deposes in answer to interrogatories propounded to him by Mr. Darby, as follows:

By Mr. Darby:

Q. 1. Please state your age, residence, and occupation.

A. Thirty-nine years—1543 Forty-seventh Avenue, San Francisco, California—radio engineer.

Q. 2. By whom are you at present employed?

A. Federal Telegraph Company of California.

Q. 3. How long have you been employed by the Federal Telegraph Company?

A. Since October, 1911—except during the war.

Q. 4. What were you doing during that time?

A. I was employed by the Mare Island Navy Yard.

Q. 5. I hand you a photograph, which has been marked for identification "Exhibit 'O'," and ask you if you recognize this photograph?

A. I do.

Q. 6. Who took the photograph of which this is a print?

A. I did.

Q. 7. Where was it taken?

A. At Lents, Oregon.

Q. 8. When was it taken?

A. In the spring of 1914.

Q. 9. At what place?

A. At Lents, Oregon—at the Federal Telegraph Company's radio station.

Q. 10. How long were you at that station?

A. A few weeks only.

Q. 11. Was this photograph taken while you were there?

A. It was.

Q. 12. Who set the apparatus up?

A. I did.

Q. 13. Was the apparatus operated there?

A. It was.

Q. 14. By whom?

A. By myself and the station force at that time; later, by the station force.

Q. 15. Will you please give us the names employed by yourself and the station force and other employees of the Federal Telegraph Company, if you know, for the apparatus?

A. The apparatus in the picture consists of two three-stage amplifiers, which we call triple boosters, also two recording telegraphones with their appurtenances.

Q. 16. Do you know where each of these triple boosters had previously been used?

A. I do.

Q. 17. Where?

A. One of them at the Los Angeles Station and one of them at the Beach Station, San Francisco.

Q. 18. Was the apparatus used by you at Lents, Oregon, in the commercial operation of the Federal Telegraph Company's business?

A. It was.

MR. DARBY: That is all.

(Direct examination closed.)

CROSS-EXAMINATION.

By MR. EDMONDS:

XQ. 19. Who else besides yourself knew of this apparatus at the Oregon station?

A. Mr. Frank H. Barstow, Floyd Stone, R. E. Ham—I believe that was all—I can't recall any more.

XQ. 20. Who was familiar with the use of similar apparatus at the Beach Station in 'Frisco about that time?

A. The only one I know was Mr. Oxenham.

XQ. 21. Now, answer the same question with respect to the Los Angeles station.

A. Mr. C. H. Blake.

MR. EDMONDS: That is all.

(Cross-examination closed.)

RE-DIRECT EXAMINATION.

By MR. DARBY:

RDQ. 22. At the time you were in Oregon was Mr. Tuel, to your knowledge, connected with the Federal Telegraph Company?

A. Yes, chief operator.

RDQ. 23. What stations did he have supervision of, if any, at that time?

A. All stations indirectly—that is, all of the company's stations indirectly were under his supervision.

RDQ. 24. Do you know where Mr. Oxenham is at the present time?

A. I do not, I believe he is in Honolulu—I am not sure.

RDQ. 25. Do you know where the three gentlemen whom you named at the Lents, Oregon, station are at this time?

A. Mr. Barstow is at Portland, Oregon; I don't know where the rest of them are.

RDQ. 26. What type of tubes did you have in Lents, Oregon?

A. I had tubes with double grids and double plates, also single grids and single plates. I don't believe I had any double filament tubes. The tubes in photograph may be of either variety—I can't tell from the photograph and have no definite recollection.

RDQ. 27. What happened, if you know, to the equipment shown in the photograph?

A. It was wrecked and junked in 1916.

> Mr. Darby: The photograph concerning which this witness testified and which was previously marked for identification as Exhibit "O," is now offered in evidence and marked "Defendant's Exhibit 'O'—Watkins' Photograph." (Admitted in evidence, Record, page 919, as Defendant's Exhibit No. 80. *See Volume VI, Defendant's Exhibits, page 1064.*)

(Deposition closed.)

(Sgd.) J. O. WATKINS.

DEPOSITION OF HAROLD LEE RODMAN.

Harold Lee Rodman, a witness produced on behalf of the defendants, being first duly sworn, deposes in answer to interrogatories propounded by Mr. Darby, as follows:

By Mr. Darby:

Q. 1. Please state your age, residence and occupation.

A. Age, thirty-three; residence, 5215 Bond Street, Oakland, California; occupation, radio engineer.

Q. 2. By whom are you employed?

A. Federal Telegraph Company.

Q. 3. How long have you been employed by the Federal Telegraph Company?

A. Have been employed at two different periods—the first time six years ago and I was away from them for awhile and I recently joined them about six months ago.

Q. 4. When did you first enter their employ?

A. May, 1911.

Q. 5. When did you leave their employ the first time?

A. When the war broke out in March, 1916—as soon as they commenced recruiting for war service.

Q. 6. In what capacity were you first employed by the Federal Telegraph Company?

A. Radio operator.

Q. 7. Where?

A. Stockton, California.

Q. 8. How long were you there?

A. Stockton? Possibly two months—it was a training station.

Q. 9. And from there, where did you go?

A. Kansas City, Mo.

Q. 10. Were you ever employed at the Beach Station?

A. Yes, when I returned from Kansas City.

Q. 11. When was that?

A. I left Kansas City August 1, 1912; I commenced to work at the Beach Station approximately August 15, 1912.

Q. 12. How long did you stay at the Beach Station?

A. Two years.

Q. 13. In what capacity??

A. Part of time as radio operator, and last year or so in charge of the station and new installation work, and also upkeep of the equipment.

Q. 14. While you were operator at the Beach Station, did you employ any three-electrode vacuum tube apparatus?

A. Yes.

Q. 15. For what purpose was the apparatus used?

A. The three-electrode tube apparatus was used as an amplifier in what we call the rapid system.

Q. 16. How many stages of amplification were employed in what you term "rapid system"?

A. We used three stages, that is, we had three tubes.

Q. 17. I show you a photograph, Defendant's Exhibit "O," and ask you if you recognize any equipment in the picture therein?

A. Yes, I should say so. They have here an installation in duplicate—there are two three-stage amplifiers; I recognize the telegraphones—two of them—they are in boxes.

Q. 18. In what respect does the apparatus there differ from or resemble the apparatus you employed at the Beach Station?

A. Well, it is practcially the same, except, as I remember it, we did not have a duplicate installation at the Beach Station and the physical arrangement was a little different on the table.

Q. 19. In using the audion amplifiers in connection with the apparatus you used at the Beach Station, did you encounter any difficulty?

A. Yes, we encountered difficulties.

Q. 20. What were some?

A. Well, the greater difficulty was in using the amplifiers—when there was too much plate potential. They would go blue.

Q. 21. By that do you mean that a visible blue glow would occur?

A. Yes.

Q. 22. Did you understand why that occurred?

A. To a certain extent, as I remember, in association with Dr. DeForest and in conversation around the Beach Station, that he believed it desirable to obtain tubes of the highest vacuum possible so we could use higher plate potentials and secure better amplification, as I remember it.

Q. 23. Did Dr. DeForest visit the Beach Station while you were there?

A. Yes, several times Dr. DeForest put in this rapid system at the Beach Station while I was there.

Q. 24. Did you discuss with Dr. DeForest the question of degree of vacuum, or is your testimony based on what I may term gossip among the operators at the station?

A. It is not based on gossip as I was probably the only operator there at the time who understood what Dr. DeForest meant by higher vacuum. I remember that comparison of the vacuum in an ordinary incandescent lamp was compared to the vacuum in the audion tubes. I don't know whether I answered the question right or not. I might add that the question of vacuum was discussed with Dr. DeForest with reference to where and how to get the tubes pumped around the bay cities.

Q. 25. Did you know A. Y. Tuel?

A. Yes.

Q. 26. Did you know him in 1912?

A. Yes.

Q. 27. Did you know where he was located at that time?

A. Yes, A. Y. Tuel was in charge of all the Federal Telegraph Company stations.

Q. 28. Did you ever discuss, during 1912, with Mr. Tuel, the question of high vacuum for the amplifier tubes?

A. Not that I remember of. Mr. Tuel at that time was interested in the results from a message-handling standpoint more than anything else.

Mr. Darby: That is all.

(Direct examination closed.)

(No cross-examination.)

(Deposition closed.)

(Sgd.) HAROLD LEE RODMAN.

(Adjourned until ten o'clock tomorrow morning, November 7, 1924, at Mr. Lamont's shop, 143 Second Street, San Francisco.)

Met at 2 P. M., November 7, 1924.

Pursuant to adjournment and to the agreement of counsel as to the delay.

Parties present as before.

Mr. Darby (in attendance Mr. Barrows and Mr. Jones, with counsel for plaintiff): We are here at Mr. Lamont's place of business at 143 Second Street, San Francisco, California. The mercury pump in its assembled condition was inspected and instructions given to proceed in accordance with the request contained on the record. The vertical shaft was cleaned and jet was likewise cleaned by means of a soft cloth injected therein.

The first tube, which will be identified hereafter as "Tube No. 1," and as stated on record yesterday, an old tube, was then given to Mr. Lamont, who first broke the seal and at the broken part of the seal tubulated the same. A portion of the mercury pump, which is detachably seated in the portion at which the dryer chemical part forms a part, was removed from the pump, and in the glassblower's flame attached to the end of the tubulation secured to the audion bulb. The pump was then assembled with the stem extending through the circular Bunsen burner. The Bunsen burner ignited at 2.12 P. M. and the asbestos hood placed over the audion tube substantially as shown in the Exhibit Photograph "A." The top of the flame of the Bunsen burner was put four inches below the bottom of the audion bulb. The terminals of the filament were then connected to a current source, the circuit of which was open. The current supply for lighting the filament consists of a battery of eight dry cells of the Ever-Ready Company. They are marked "Ever-Ready Igniter Dry Cells" and the eight of them are connected in series with the filament of the bulb through two rheostats in series. A volt meter is connected directly to the terminals of the filament. The volt meter is a standard Weston volt meter numbered 134.

At 2.19 P. M. the preliminary or piston pump was set in operation. The acid trap or dryer bulb, marked "E" on photograph Exhibit "A" of defendants, contains pentoxide.

At 2.20 P. M. the preliminary pump was turned off and the mercury pump started in operation. It is noticed that gas bubbles appear in the shaft of the mercury pump, being readily detectable at a short distance from the pump. Mr. Lamont, by means of wooden blocks, is adjusting the shaft so as to direct the stream of mercury from the jet to as near as possible the exact center of the surface of the column of mercury in the shaft.

At 2.25 P. M. the lamp was lighted to three volts.

At 2.30 the voltage on the filament was raised to five and one-half volts.

At 2.37½ P. M. the voltage was raised to six and one-half volts.

At 3.42 P. M. the current was taken off of the filament and the pump stopped to permit the jet, which had become dirty, to be cleaned; the stopcock leading to the audion being closed. The shaft was removed and a pipe cleaner twisted into the jet nozzle, and at the same time Mr. Lamont's assistant cleaned the shaft by passing a wire therethrough with a cloth attached to the end.

The apparatus was then re-assembled and at 3.48 P. M., the preliminary pump started again and stopped at 3.49 P. M., and the mercury pump was started—the preliminary pump pipe line being disconnected by means of the stopcock.

3.50½ P. M., the stopcock is turned putting the vacuum tube on the mercury pump again. The current is put on the filament at 6½ volts at 3.51 P. M.

4.25 the bubbles in the shaft appeared to be small.

At 4.29 P. M., while the filament was lit and the Bunsen burner was still burning and the pump running, the tubulation below the audion was heated with a small gas flame and the audion was sealed off from the tubulation that carries the grinding. The filament current was turned off. This was the end of the exhausting process on this particular tube.

At 4.32 P. M., the pump was opened and the shaft removed for the cleaning of the shaft of the mercury pump and the jet.

At 4.33 P. M., a tube that will be known hereafter as "Tube No. 2" was handed to Mr. Lamont for treatment in accordance with the instructions previously given him of record, this tube being an audion recently constructed on behalf of defendants as a copy of old DeForest audions.

At 4.33 P. M., Tube No. 2 was opened up by removing the sealing tip.

At 4.34 P. M., Tube No. 1, which up to this time had been in the hood, was removed from the hood.

At 4.36 P. M., the tubulation of No. 2 audion was begun and completed at 4.39½ P. M.

At 4.40 P. M., the mercury pump was re-assembled and closed.

At 4.41 P. M., the tubulated audion was fused on to the tube of the pump carrying the grinding and mounted in the proper place in the mercury pump.

At 4.42 P. M., the Bunsen burner was lighted under the audion and the asbestos hood was placed in position on top of the audion—the relation of the flame to the audion being substantially the same as in the exhausting of the first audion above mentioned.

At 4.46 P. M., the preliminary pump was started and the glass stopcock leading thereto was opened.

At 4.47¼ P. M., the glass stopcock in the line leading to the preliminary pump was closed.

At 4.47½ P. M., the mercury pump was started.

At 4.56 P. M., the filament was lighted at 2½ volts.

At 5.04 the tubulation tube bent over and the battery was taken off, and the stopcock to the tube was closed.

At 5.06 P. M., the Bunsen burner was turned off and the pump stopped—the audion bulb sucked in, or collapsed.

Operations on this bulb, therefore, were impossible, Mr. Lamont explaining that different glass was used in the bulb than that used in the tubulation—it being much softer and very inferior stuff.

At 5.11 P. M., Mr. Lamont began the tubulation of the next tube, which will hereafter be identified as "No. 2-A."

At 5.16 P. M., tubulation completed and Mr. Lamont re-inserts the stem through the burner and makes the grinding fit.

Tube No. 1 was marked with hydrofluoric acid "1," and the remainder of the tubes similarly marked on the bulb.

(Adjourned until tomorrow morning, Saturday, November 8, 1924, at 9 o'clock, in Mr. Lamon't office, same place.)

---

9 A. M., November 8, 1924.

Met pursuant to adjournment.

Parties present as before.

Mr. Darby: Mr. Lamont recalled in connection with the tests, with the understanding that you are still under oath.

By Mr. Darby:

Q. 131. During the operation of your pump yesterday in the middle of the pumping you closed the stopcock leading to the audion and broke the seal between the vertical shaft and the jet, disassembled and dismounted the shaft and cleaned the jet with a pipe cleaner and cleaned the shaft by running a wire therethrough having a cloth attached to one end thereof. That is correct, is it not?

A. Yes.

Q. 132. What necessitated your doing this?

A. Particles lodging in the jet itself which prevent the free play of the mercury.

Q. 133. Did that prevent the proper functioning of the pump?

A. It did.

Q. 134. In pumping the audion tubes in 1912, did you have to take apart the pump in that manner during the pumping operations?

A. No, sir.

Q. 135. Is the jet structure in the same condition now as it was when you used it in 1912 and when Mr. Baumgartner first saw it.

A. No, sir.

Q. 136. What is its condition now which is different.

A. There is a crack leading from the end of the jet to about two inches upward.

Q. 137. When did this crack develop?

A. Last week.

Q. 138. Do you know how it cracked?

A. The draughtsman trying to take measurements of it inserted a piece of metal and I attribute the crack to that fact.

Q. 139. Was that draughtsman Mr. Arnberg, who made these drawings for us, do you know?

A. I don't know him by name.

Q. 140. Prior to the cracking of the jet, how long did you use the pump without cleaning the jet?

A. From four to five hours.

Q. 141. When did you clean the pump?

A. About once every three months—depending on the amount of work to be done on it.

Q. 142. What method do you employ in dislodging particles collected in the jet without taking the pump apart?

A. By compressing the rubber tube and releasing it rather suddenly it would cause a sudden rush of mercury. I refer to the rubber tube leading from the percolator tube to the pump.

Q. 143. Can you do that to the pump at the present time effectively without injury to the pump?

A. No, sir.

Q. 144. Why not?

A. The jet would split and fall off.

Q. 145. How long would it take you to build a new pump and re-assemble the apparatus in case it should break?

A. About two days.

Q. 146. Are you willing to take the chance to break that jet in view of your regular work and which this testimony is interrupting?

A. I would.

Q. 147. Did you not just a little while ago in discussing this matter with me state that you would prefer not to run the risk of injuring the pump if unnecessary, by rejetting it, in view of your pending work for other customers which has been held up by the work you have been doing for us?

A. I did.

CROSS-EXAMINATION.

By MR. EDMONDS:

XQ. 148. Is this the audion bulb on which you operated yesterday, to be known as "No. 2," and which after a short time "sucked in"?

A. Yes, sir.

(Cross-examination closed.)

MR. DARBY: I offer in evidence for convenience of opposing counsel, the tube referred to as Defendant's Exhibit Audion Tube No. 2.

RE-DIRECT EXAMINATION.

By MR. DARBY:

RDQ. 149. I believe you stated with reference to this tube that this was soft, inferior lead glass, is that correct?

A. Yes, sir.

RDQ. 150. You told us yesterday, did you not, that the mercury which is now in the pump had been recently put in?

A. It has, yes, within the last week.

MR. DARBY: That is all.

(Re-direct examination closed.)

(Deposition closed.)

(Sgd.) G. E. LAMONT.

STIPULATION.

MR. DARBY: I produce what purports to be four original letters from H. W. McCandless & Company, Inc.—two dated May 4, 1912, another June 19, 1912, to Federal Telegraph Company at San Francisco, and another dated December 23, 1912, to the Federal Telegraph Company c/o U.

S. Wireless Station at Arlington, Va., and another to the Federal Telegraph Company at Palo Alto, California.

And It Is Stipulated and Agreed that if E. F. Baumgartner were called as a witness he would testify that he, personally, took these four original letters from the files of the Federal Telegraph Company at San Francisco. Also, that if Charles Blake were also called as a witness he would testify, that he is an employee of the Federal Telegraph Company and has been since about 1911, he was present and saw these letters removed from the files as above stated and that such letters had been in such files prior to such removal, presumably since the date of receipt.

I offer photostats of these letters in evidence as Defendant's Exhibit "P-1"—letter of May 4, 1912; "P-2"—the letter of June 19, 1912; "P-3" —the letter of December 23, 1912, and "P-4"— the letter of January 8, 1913. (Admitted in evidence, Record, page 918, as Defendant's Exhibits, Nos. 78, 78-A, 78-B and 78-C. *See Volume VI, Defendant's Exhibits, pages 1056-1059.*)

I produce photostat copies of carbon copies purporting to be carbon copies of letters, one dated April 27, 1912, another dated July 26, 1912, from Lee DeForest to H. W. McCandless & Co., a third dated August 14, 1912, from Federal Telegraph Company to H. W. McCandless & Co., and a fourth, dated October 16, 1912, directed to G. E. Lamont, no signature, but initialed dates "HPV."

It Is Stipulated that if E. F. Baumgartner were called as a witness he would testify that he, personally, took the copies from which the photostat copies were made, from the files of the Federal Telegraph Company in San Francisco within the past six months. Also, that if above-named

Charles Blake were called as a witness he would testify that he was present when such carbon copies were taken from the files for the purpose of being photostated and that such carbon copies had been in the said files presumably since their dates. I offer these letters in evidence as Defendant's Exhibit "Q1"—the letter of April 27, 1912; "Q2"—the letter of July 26, 1912; "Q3"—the letter of August 14, 1912, and "Q4"—the letter of October 1, 1912. (Admitted in evidence, Record, page 919, as Defendant's Exhibits Nos. 79, 79-A, 79-B and 79-C. *See Volume VI, Defendant's Exhibits, pages 1060-63.*)

Mr. Edmonds: The offer in evidence is objected to as to the four copies last above enumerated, on the ground that such copies are secondary.

Mr. Darby: In view of the situation which has developed which makes it apparent that further tests continued with this pump in its present injured condition would not be fairly illustrative, we are abandoning, at this time at least, the plan of test and operation of the Lamont pump outlined in the record. Opposing counsel were requested to compare the blueprint drawings—Exhibits "M" and "N"—and the measurements thereof, with the pump, and pursuant to this request Mr. William Jones, with counsel for plaintiff, has made a comparison of the measurements.

(Depositions closed.)

NOTARIAL CERTIFICATE.

STATE OF CALIFORNIA,
CITY AND COUNTY OF SAN FRANCISCO, } *ss.:*

I HEREBY CERTIFY, that on the third to the eighth and inclusive days of November, 1924, before me, W. W. HEALEY, a notary public in and for the City and County of San Francisco, State of California, at my office, room 208, Crocker Building, 620 Market Street, in the City and County of San Francisco, personally appeared, pursuant to the notices hereto annexed and contained in the minutes of the testimony annexed hereto, between the hours of 10 A. M. and 5 o'clock P. M., the witnesses, Mrs. A. W. F. (Helene) Beck, Mr. Ralph Hyde, Mr. Palmer Hewlett, Mr. Leland B. Clark, Mr. G. E. Lamont, Mr. Ralph R. Beal, Mr. Austin Y. Tuel, Mr. James O. Watkins and Mr. Harold Lee Rodman, named in said notices, and Samuel O. Edmonds, Esq., and Charles McClair, Esq., appearing for plaintiff, and Samuel E. Darby, Jr., Esq., and Edgar F. Baumgartner, Esq., appearing for defendants, and the said witnesses each being by me first duly cautioned and sworn to testify the whole truth and each being carefully examined, deposed and said, as in the foregoing annexed depositions set out.

I FURTHER CERTIFY that deposition of Mrs. A. W. F. (Helene) Beck was begun on the third day of November, 1924, and continued until the fourth day of November, 1924, when the same was completed; that the deposition of Ralph Hyde was begun on the fourth day of November, 1924, and completed on the same day; that the deposition of Palmer Hewlett was begun on the fifth day of November, 1924, and completed the same day; that the deposition of Leland B. Clark was begun on the fifth day of November, 1924, and completed on that day; that the deposition of G. E. Lamont was begun on the sixth day of November, 1924, and continued from day to day until the eighth day of November, 1924, when the same was completed, and that the depositions of Ralph R. Beal, A. Y. Tuel, James O. Watkins and Harold Lee Rodman were all begun and completed on the sixth day of November, 1924.

I Further Certify that the several exhibits accompanying these depositions, and the two physical exhibits sent to the Clerk of the Court with these depositions, but under separate cover, were offered in evidence and marked for identification, as is set out in minutes of said depositions; and that the two exhibits, *viz.*, Defendant's Exhibits "E" and "F," were sent to the Clerk of Court, under separate cover, because they are physical exhibits.

I Further Certify that the said depositions were then and there reduced to typewriting under my personal supervision, except that the depositions of Ralph R. Beal, A. Y. Tuel, James O. Watkins and Harold Lee Rodman, and that part of the deposition of G. E. Lamont following the tests were, by agreement of counsel, taken down in shorthand and thereafter reduced to typewriting, and were, after they had been reduced to typewriting, subscribed by the witness, and the same have been retained by me for the purpose of sealing up and directing same to the Clerk of the Court, as required by law.

I Further Certify that tests of the vacuum pumps of G. E. Lamont beginning November 7, 1924, and continued to November 8, 1924, were made at the shop or laboratory of G. E. Lamont at 143 Second Street, San Francisco, California, that the tests were attended by S. O. Edmonds, Esq., Charles McClair, Esq., as counsel for plaintiff, by Mr. Barrows and Mr. Jones who accompanied counsel for plaintiff, and by

S. E. Darby, Jr., Esq., and E. F. Baumgartner, Esq., as counsel for defendants, and that the record of the tests as it appears in the minutes of the depositions annexed hereto was, by agreement of counsel, taken down stenographically and thereafter reduced to typewriting.

I Further Certify that Edgar F. Baumgartner, Esq., appearing for defendants, delivered to me carbon copies of what purports to be letters dated October 22, 1924, and respectively addressed to American Telephone & Telegraph Company, 195 Broadway, New York, N. Y., Western Electric Company, 195 Broadway, New York, N. Y., and Radio Corporation of America, 233 Broadway, New York, N. Y., and also letters dated October 29, 1924, and respectively addressed to American Telephone & Telegraph Company, 195 Broadway, New York, N. Y., Western Electric Company, 195 Broadway, New York, N. Y., and Radio Corporation of America, 233 Broadway, New York, N. Y., and that I annexed said copies of said letters to said depositions.

I Further Certify that I am not of counsel or attorney for either of the parties, neither am I interested in event of the cause.

I Further Certify that the fee for taking said depositions, $265.20, has been paid to me by defendants and the same is just and reasonable.

Witness my hand and official seal at City and County of San Francisco, California, this twenty-ninth day of November, 1924.

(Sgd.) W. W. HEALEY,
Notary Public,
In and for the City and County of
San Francsico, State of California.

(Seal)

PLAINTIFF'S REBUTTAL PROOFS.

IRVING LANGMUIR.

Irving Langmuir, called as a witness in rebuttal, on behalf of the plaintiff, having been duly sworn, testified as follows:

Direct Examination.

By Mr. Lunt:

Q. 1. Please state your name, residence, and occupation.

A. Irving Langmuir; Schenectady, New York; assistant director of the Research Laboratory of the General Electric Company.

Q. 2. Are you the Langmuir who was patentee of the four patents in suit?

A. I am.

Q. 3. And you are the same Langmuir who gave the testimony in the interference record or transcript?

A. Yes.

Q. 4. Will you tell us something of your education, especially as it may have proceeded along scientific lines?

A. After graduating from Columbia University in 1903, with the degree of metallurgical engineer, I went to Germany to the University of Goettingen for post-graduate work and there worked under Professor Nernst with physical chemistry as my major subject and mathematical physics and mathematics as secondary subjects. In January, 1906, I received the degree of master of arts and doctor of philosophy from the University of Goettingen.

Q. 5. Am I correct in my understanding that you are a member of the National Academy of Sciences, also of the American Academy of Arts and Sciences, also of the American Philosophical Society, also the

American Physical Society, also the American Chemical Society and a member of the Institute of Radio Engineers, past president of that institute, and an honorary member of the Royal Institute of London?

A. That is correct.

Q. 6. Am I correct in understanding that you have received certain medals, I think the Nichols medals. What are those?

A. The Nichols medal is given each year by the New York section of the American Chemical Society. I received that medal twice, the first time for the work that I published on chemical reactions in gases at very low pressures, and the second time for a paper that I had published on structure of atoms and molecules.

Q. 7. Did you receive the Hughes medal, and if so what was it and what for?

A. I received the Hughes medal from the Royal Society of London for researches in molecular physics.

Q. 8. Am I correct in understanding that you have received the Rumford medal?

A. The Rumford medal is given by the American Academy of Arts and Sciences and was established, well, over one hundred years ago by Count Rumford, to be given at intervals for researches in light and heat. I received this gold and silver medal from the Academy of Arts and Sciences in Boston for "Researches in thermionic and other related phenomena" and I was told by the chairman of the meeting that the other related phenomena were particularly with reference to the gas-filled lamp.

Q. 9. I understand that you have received some prize by some Italian Association. Will you explain what that is?

A. I received the Cannazzario prize from the Royal Academy of the Dei Lincei in Rome, which corresponds to our National Academy of Sciences.

Q. 10. What matter had this to do with?

A. It was not stated definitely but for chemical work, I think, on surface tension and the orientation of molecules in liquid and so on.

Q. 11. When did you come to the research laboratory?

A. In the summer of 1909.

Q. 12. And you have been connected with that laboratory ever since?

A. Yes.

Q. 13. What was the nature of your work in the laboratory up to the summer of 1912? In giving your answer will you give us some idea and some detail as to the equipment and facilities in the laboratory for carrying out work on vacuum devices?

A. In July, 1909, I came to the laboratory expecting to spend only two months during the summer. I was particularly interested in pure science rather than industrial applications, but I valued the opportunity to be in this laboratory because I knew that they had unusually fine equipment, so much better than most college men have opportunity to use, that I thought it would be very valuable to me to get the experience and work there even for such a short time.

I found the work in the laboratory very interesting in many ways. The biggest problem before the laboratory at that time was the making of drawn tungsten wire in a form which would not show the phenomena of off-setting.

Two or three lots of wire had been produced, apparently more or less by accident, which did not show any offsetting. This phenomena of offsetting caused the lamp to fail, all except these especially good wires that I spoke of—caused the lamps to fail when run on alternating current at normal efficiency, whereas, on direct current these lamps would last 1500 hours. The phenomenon was practically the same as had previously been observed with tantalum filaments, in which case also the shortening of the life was practically limited to the case when they were run with alternating current; the offsetting phenomena not being at all important when the lamps are run on direct current.

These good lots of wire that had been obtained could not apparently be duplicated. No one in the laboratory had been able to find out why these particular ones were good and why the others were bad.

When I first came to the laboratory Dr. Whitney suggested that I spend several days——

Q. 14. Pardon me. Who is Dr. Whitney?

A. He is the director of the laboratory and was director at that time. He suggested that I spend several days to become more or less familiar with the work that is being done by different men and suggested that I pick out my own problem or at least he would be glad to consider any problem that I would like to work upon. It was very obvious to me that the offsetting problem was one of the most important and although I had no particular interest in the industrial problem involved, as a development problem, it seemed to me that there was one factor that had not been considered by any one in the laboratory and that is that the offsetting might possibly be due to impurities in the wire in the form of gases; that perhaps gases were contained in the wire which might account for these peculiar properties.

I had in mind particularly the statements that were then common in the literature as, for example, in J. J. Thomson's book, that wires in vacuum continued to give off gases almost indefinitely and that it is practically impossible by heating or any other way to get metals so free from gas that they would not continue to give off gas.

So I thought *that* would be a problem that I thought I might finish in two months and so I undertook to apply some of the methods that were developed in the laboratory for obtaining high vacuum for measuring the quantities of gas obtained from these wires.

I would like to say a word, too, about the other work that was going on in the laboratory at that time in connection with lamp investigations. The drawn tungsten wire that was made was tested by running in incandescent lamps and usually on 110 volt circuits. These lamps were made up from the wire that was made in the laboratory and exhausted in a room where there were perhaps six ovens and exhaust systems for exhausting such lamps. Each oven was equipped for exhausting six lamps at a time.

The lamps were heated in these ovens to about 360 and sometimes 400 degrees C. for a period of time that varied from twenty minutes to an hour and in some cases three or four hours, depending upon the particular problem that was being studied.

There were many factors in these methods of exhaust that were different from the methods that were being used in the lamp factories at that time. In the first place, all the lamps were sealed onto the glass system. We did not use as a rule the rubber connection that was used in the factories. They did not use the Malignani exhaust which was almost always used for the commercial manufacture of lamps.

Q. 15. Why was that, Doctor?

A. Because it was considered not to give a clean vacuum. There were phosphorus compounds present and there were gaseous compounds, compounds due to the reaction of the gas with the phosphorus which was liberated on the pump and would come off during the life of the lamp, although at low pressure. It introduced uncertainties and variable factors which was thought undesirable in connection with our studies where we wanted to have tungsten filaments in as good a vacuum as possible and under as definite conditions as possible so that we could reproduce the conditions to which the tungsten filaments were exposed.

Although this made it very much more difficult to exhaust the lamp so that we had to use twenty minutes to an hour to exhaust, whereas otherwise it could be done in much less time, all our lamps were exhausted in that way.

Directly below the lamps, that is, just below the oven containing the lamps, was a large tube about two and a half feet long and an inch and a half in diameter, containing a boat, a long tube filled with phosphorus pentoxide. This was placed just as close to the lamps as possible to absorb the moisture given off from the glass during the exhaust treatment.

The vacuum was obtained by specially devised rotary oil pumps which reduced the pressure when they were in good working condition, to about one micron, but more often to about three or four microns.

These pumps were backed up—that is, the gases that were taken by the pumps from the lamps were not exhausted from the pump and did not escape into the atmosphere but escaped into a rough pump line in the laboratory which was piped into every room and in which the pressure was maintained at about one centimeter pressure, ten millimeters pressure.

During the exhaust of these lamps, the filaments were run to very high temperature, considerably above normal operating temperature, that is, temperatures probably 2600 degrees absolute, for a large fraction of the time that the lamps were on the pump, that is, after the vacuum had become good, so that the McLeod gauge showed no further decrease in pressure and then the lamps were run over a considerable time in order to get the gas out.

After the lamps were sealed off they were put on life test and were aged at normal efficiency for usually twenty-four hours and then candlepower readings were taken and they were then put back on the life test and every day thereafter during the life, candle-power readings were taken.

The lamps frequently showed a blue glow when they were first run up to high voltage after having been taken off the pump, but if the lamps had been thoroughly well exhausted, the bulbs had been heated to very high temperature, the blue glow soon stopped within a very few seconds, and after that the lamp would never show blue glow.

But if the lamp had not received sufficiently good heat treatment, if the bulb had been exhausted for too short a time or too low a temperature the blue glow instead of disappearing would get worse, would persist for quite awhile. The current across the lamp terminals would increase at constant voltage and unless the resistance was put in series with the lamp to prevent an undue rise of current, the lamp arced across and would be absolutely destroyed. It would usually break the stem of the lamp and allow atmospheric air at atmospheric pressure to enter.

In other words, it was well recognized that blue glow, although it would clean up the vacuum in a well-exhausted lamp would have just the opposite effect in a lamp that was not well exhausted.

Q. 16. What use did you make of this resistance, how long did you use it, to what extent?

A. It was used whenever there was danger of blue glow destroying the lamps, when the high voltage was first used on the lamps. During the exhaust process on the pumps the resistance was used to limit the current. If, after the lamp had gone through its initial treatment on the life test it was run on a constant voltage circuit with no series resistance, and if blue glow occurred, then it would mean a dead short circuit across the line with complete destruction of the lamp.

I thought then that I would apply what seemed to me the unusually good vacuum technique that had been developed in this laboratory to a study of the amounts of gas that were given off from different samples of drawn tungsten wire. However, it did not seem to me exactly practical to do exactly what they were doing in the laboratory, making up complete lamps and exhausting them. I did not at that time realize the importance of all the elements that were used in the exhaust processes in the laboratory and so I did what I have usually seen done in Germany at the University, build up an apparatus with a ground glass joint so that I could put in a piece of wire in the form of a loop and heat it to get gas off and measure the pressure with the McLeod gauge and then could take out that piece of wire and put in another piece of wire and measure the gas that came off that second piece. I wanted to be able to shift rapidly from one piece of wire to another and thought it would not be necessary to bake out the tube in which I was making these measurements because it was a simple operation, which did not involve heating the tube.

So my first work, my first few weeks of work was with a Sprengel pump which I resurrected from somewhere around the laboratory; because they had been used in the laboratory very considerably before that, but none were used at that time. My apparatus consisted of a Sprengel pump and a bulb into which I could put the filament and a McLeod gauge.

As soon as I started these measurements, lighting the filament at different temperatures I found that the filaments gave off surprisingly large quantities of gas. I think I only worked a few days or at most a couple of weeks on this before I realized that something was entirely wrong with my set-up of apparatus, because I found that this filament in the course of a couple of days had given off 7000 times its own volume of gas and that there was no indication that the gas was going to stop. That had gone on to an unreasonable degree, for I knew that the filament could not give off 7000 times its own volume of gas. So I knew it must have come from something else and I then came to realize that I had not taken proper precautions to dry out my apparatus although I had a P2 O_5 tube right between the pump and the bulb.

Q. 17. What is the significance of a P2 O_5?

A. Phosphorus pentoxide, which is used to remove traces of water vapor. So then I built an apparatus in which I really did use the technique that was being used in the laboratory around me, that is, to seal the wires into lamp bulbs, to exhaust these by heating to a high temperature and remove the moisture effectively and to avoid anything like the ground glass joint which could give off hydrocarbon vapors.

What I had found was that the unlimited amount of gas that came from the filament really was due to decomposition of water vapor on the heated tungsten filament producing a continuous supply of hydrogen, the oxygen of the water vapor combining with the tungsten to form an oxide. Similarly the tungsten filament reacted with hydrocarbon vapors from the grease used, which was made of vaseline, and rubber or beeswax, the vapors from this vaseline coming into contact with the hot tungsten filament decomposed, producing hydrogen, an action causing the pressure to rise steadily.

During the rest of that summer and for the first couple of months in the fall of that year I continued this work on gas, however, no longer with the intention of improving the quality of the drawn tungsten wire, but simply as a problem of interest in itself.

I did not like to use phosphorus pentoxide, because that was a powdered material which could absorb relatively large quantities of gas and that could give up relatively large quantities of carbon dioxide gas, and I intended to measure the amount of gas that I had obtained from the filament and I did not want to have any gas either given off by the phosphorus pentoxide or absorbed by it.

So I wanted a clean method of removing the water vapor, that would remove practically nothing but the water vapor and would not by any possibility introduce other gases.

I found that in the laboratory there was a liquid air machine which had been bought a year or two before, but had never been used. So it occurred to me that if I could get liquid air I could remove the water vapor completely without the possibility of introducing other gases. So I got them to start up the liquid air machine, this was in the fall of 1909, and I used that liquid air on a trap just below the lamp which was being exhausted so as to condense out there any water vapor and carbon dioxide that was evolved from the lamp.

Then by taking off the liquid air and substituting in place of it solid carbon dioxide I could allow the carbon dioxide to evaporate from inside of the tube holding, however, the water vapor back.

Solid carbon dioxide is obtained by taking a tank of compressed carbon dioxide liquid which is used in soda water fountains and turning it upside down and tying over the nozzle of the tank a canvas bag and opening the valve of the tank and letting the liquid squirt out into this bag. As the high pressure in the tank is released the liquid boils so fast that it is cooled and solidifies and so it fills the bag with a solid white powder which has a temperature of 78 degrees below zero Centigrade. And it is very convenient to use when you want to get low temperature in that way and you have not got a supply of liquid air available.

We used it, however, in order to distinguish the water vapor given off by a lamp or by a filament from the carbon dioxide that might be produced in that way.

I did not use charcoal and liquid air for largely the same reason that I did not want to use phosphorus pentoxide, because charcoal gave off gases as well as absorbed them. When you take off the liquid air the charcoal gives off a gas. When you cool it in liquid air it absorbs gas and it absorbs some gases very slowly.

Furthermore, if the gas is absorbed you cannot get it back again completely and it was my object to measure the amount of gas that escaped from the filaments or from the lamps.

About that time Dr. Whitney was becoming very much disturbed over the fact that the whole success of the drawn tungsten wire work was being held up apparently indefinitely by a failure to overcome the offsetting of the tungsten wire. So that he asked me if I would not, as an emergency matter, undertake to see what I could do to co-operate with others in trying to overcome this effect and I did so for a period of, I think, two or three months in the fall of 1909. By that time I decided to stay in the laboratory. So I worked for about two or three months on that problem.

The way that I planned to carry on my work on that problem I want to describe briefly as an illustration of a scientific method which I have had very frequent occasion to use. There is nothing novel about it, but it does seem to me that it has not been sufficiently emphasized. What I mean is this:

The offsetting difficulty had occurred for a long time and nobody knew exactly how to solve it. It was presumably due to traces of impurities but everything seemed to show that no attempt to get pure wire went anywhere near far enough. So everybody that was working on the problem was attempting to get a more and more highly pure tungsten filament and since they did not know what the impurity was it was a very baffling problem.

I thought the time had probably arrived when it would pay to go at it with a different point of view. Namely, to put in all kinds of impurities and deliberately making the wire worse so as to become familiar with the effects of impurities and learn some of the fundamental effects. I thought if I could find something that would make the offsetting 100 times worse that I would then have a clue as to what perhaps caused the offsetting that did occur. So I put into the filament all kinds of things that I could think of.

The process that I was working with started out from a squirted filament. Although I put in aluminum oxide, and silica and other things of that sort, none of the results were at all successful. So that the work that I did was of no importance in that field.

Shortly after that I stopped the work there in order to get back to vacuum work which I was very much more interested in. Shortly after that Dr. Coolidge discovered how to prevent offsetting by the Battersea method and then later with the thorium oxide.

So I went back to the vacuum work. I had become extremely interested in a fundamental study of all the factors that had anything to do with the vacuum in tungsten lamps. I confess I did not see that the thing ever could be of any particular value—I did not conceive of any way in which the thing could be of any direct benefit to the General Electric Company. A couple of times I talked that matter over with Dr. Whitney and I said I suppose that a thorough fundamental knowledge of the facts involved in gases in tungsten lamps will be worth while, but I do not know where it will lead.

Dr. Whitney, however, said that he did not care whether it led anywhere or not, that he would like to see me continue working along that line and as long as I was working on anything that looked like a fundamental step getting information in regard to the vacuum in lamps and any other factors that are of interest in lamps, I was perfectly free to go ahead. As a matter of fact I worked for two years or nearly three years before any practical application was made of any of the work that I had done.

Now, during that time, that is, from the late fall of 1909 to 1912, the summer of 1912, I might summarize the kind of things I worked on. I did them without any direction from Dr. Whitney or any pressure to produce any useful result. There was no thought at all in my mind during that time of getting any industrially useful result.

There were, however, at times, different questions that Dr. Whitney asked, which showed perhaps that he had some applications in mind. I will just mention one thing that I think of particularly. Dr. Whitney had the idea in connection with the tungsten incandescent lamps, that if you could get a much more perfect vacuum than any one had previously obtained in a vacuum lamp, it would perhaps be possible that you would get very much less blackening of the lamp. Because the general idea was not only in our own laboratory, but I think generally among those who were skilled in tungsten lamp manufacture, that the blackening of the bulbs of the tungsten lamps, which was the main factor that limited their useful life, was due to secondary causes, such as electric discharges.

It was well known, for example, that blue glow caused very rapid blackening of the lamp bulb. Then there was the attack by gases; it was, for instance, well known that if there was much water vapor in the lamp, then without blue glow the lamp very rapidly blackened. So it was natural that Dr. Whitney should have extrapolated, you might say, from the best theories of that time, that if you got a perfect vacuum, you would get a very far superior lamp with a much longer life, or one that could be run with a filament at a still higher temperature, and thereby obtaining a higher efficiency. There again, it seemed to me it called for an application of that same method that I have mentioned before: that if you can not get a thing that you want to get, because it seems too difficult, do the opposite and learn to know the fundamental factors involved, so that you can conclude with certainty what would happen if you did get the result that you had not been able to get, by the direct process. I knew it was impossible to get a perfect vacuum (and nothing but a perfect vacuum would satisfy Dr. Whitney). Since it was impossible to get a perfect vacuum, it seemed to me much better to put in gases and see what happened.

That is what made me feel that it would be a good thing to put gases into a lamp having as good a vacuum as I could get; deliberately put in specific gases. I put in oxygen and then I would put in hydrogen, and then in another lamp I would put in nitrogen, carbon-dioxide and carbon monoxide, and I even went so far as to put in hydrochloric acid gas and bromine and iodine and sulphur and phosphorus and almost anything I could get into the form of gas, into lamps, in order to see what effects they could produce; not to see whether they could improve the lamp, but to see what happened to the gases and the filaments. I did it, not in order directly to improve the lamps, because I did not have that definitely in mind, but simply out of scientific curiosity to find out what would happen with these different gases.

Now, in order to do this work, it became first necessary to have pure gases which I could add. Then it became necessary to know whether the gases that I put into the lamps stayed pure. Now, the amounts of gas that I put in varied usually from five microns pressure up to 100 microns. I do not think I ever went above 100 microns, about one-tenth of a millimeter pressure, one ten-thousandth of an atmosphere, or something like that; so that the amounts of gas were not very large. After this gas had been let in, I frequently found that the composition changed, or I suspected the composition changed, so I needed a method of analyzing those small quantities of gas. So I devised a piece of apparatus, by which, finally, I was able, along about the middle of 1910 or 1911, I think it was, I was able to make a complete or pratically complete quantitative chemical analysis of a quantity of gas, which at atmospheric pressure would be about one cubic millimeter or something like the volume on the head of a pin. I could made a quanitative chemical analysis of this gas and determine in it the amount of hydrogen, the amount of oxygen, the amount of nitrogen and carbon dioxide and carbon monoxide, and in some cases such gases as methane.

This was done by use of a mercury pump, on the Toepler pump principle, by which the gas was pumped over into very small capillary tubes in which the gases could be analyzed by bringing them in contact either with platinum filaments or with tungsten filaments. With the platinum filament, you could cause combustions to take place. By mixing oxygen and hydrogen, and heating them in contact with a platinum filament, I could cause them to react and observe the gas contraction in the vacuum system, by measuring the same amount of gas on the McLeod gauge before and after. The reduction in pressure would then show the contraction of volume of gas that resulted from the combustion that had taken place in this little volume. In all this work, it was very important to get rid of the effects due to moisture from the glass, or any other gases that might come off the glass.

Having this apparatus to measure and analyze gases, I wanted to find out what gases did come off the glass, so I heated some bulbs first to 100 degrees,. then to 200, 300, and 360 degrees, and measured the amounts of water vapor, and other gases that came off during the heating to different temperatures, and was particularly interested to see if the action continued, and how long it was necessary to heat the bulb at each temperature in order to get off all the gas that would come off at that temperature.

I found for example that on heating a bulb to 360 degrees, I got—I am just giving this from memory—something like three to four hundred cubic millimeters of water vapor (measuring it as if it were an ideal gas), twenty or thirty cubic millimeters of carbon dioxide, and perhaps six cubic millimeters of nitrogen, and I could not find any other gases. I never was able to detect any oxygen or any hydrogen.

In connection with the study of these methods of exhaust to get gases out of the glass, I wanted to go to as high a temperature as possible, and it occurred to me that the factor which prevented our going above about 400 degrees in heating the bulb was that the atmospheric pressure of fifteen pounds per square inch on the outside of the bulb tended to collapse the bulb. Although the bulb was really pretty strong at these high temperatures it could not stand a pressure such as that, and gradually collapsed. I thought that if I could remove this external pressure from the bulb, I ought to be able to go to a good deal higher temperature before the bulb would become deformed; so I devised a vacuum oven in which I was able to produce a rough vacuum on the outside of the bulb, and a good vacuum inside of it.

Q. 18. I believe you obtained a patent on that, did you not?

A. Yes, I do not remember the number of the patent. It is in the record.

Q. 19. In the Interference record?

A. In the Interference record, yes. Another source of gas within the lamps that needed to be taken into account was the gas from the metal filament, and the lead-in wires.

In the beginning I stated that my first experiments had shown that a tungsten filament seemed to have given off seven thousand times its own volume of gas, without any signs that the limit was being reached. When I removed as completely as possible the water vapor and hydrocarbon vapors from the vacuum system, I found that the amount of gas which the filament gave off on heating to normal operating temperature, such as a brilliant white heat, instead of being several thousand times the volume of the filament volume, was only about five or six times its volume, and that this gas came off immediately within a few seconds. Certainly within a minute. Practically all that gas would come off from an ordinary incandescent filament at say 2400 degrees, but below 1500 degrees it came off extremely slowly.

Now, 1500 degrees, of course, is 1200 degrees C., roughly, which is a good bright yellow heat, or above the melting point of copper and gold. Only a few metals will stand heating to such a high temperature.

Q. 20. How does it compare, Doctor, with the melting point of platinum?

A. The melting point of platinum is about 2050 degrees on that same scale. In this work on the introduction of gases into the lamp vacuum, in the presence of a tungsten filament, I found that the phenomena involved were extremely varied, that no two gases acted the same way at all. Oxygen reacted with a tungsten filament to form a compound which deposited on the bulb. That was simple, but there were many interesting factors in connection with it which I studied and I published a paper on the results.

Then I undertook the effect of hydrogen, and there, I ran across extremely interesting phenomena; the hydrogen disappeared; but only a limited amount would disappear, and after a very detailed study of that, which extended really over three or four years, off and on, but most of it was in 1911, I think, 1911 and 1912, early in 1912, I found that the hydrogen became dissociated into atoms.

You remember the hydrogen molecule consists of two atoms H_2. I found at high temperatures, such as those of the tungsten filament, the molecule is broken up into its two atoms, and the atoms stick to the glass, forming a single layer of atoms. You can not get more than one layer on the surface of the glass, because if you do, the atoms adjacent to each other react and take the molecular form; but if they are single, there is nothing for them to react with. The fact that they are so active makes them stick to the glass, and that accounts for the disappearance of this hydrogen. That hydrogen was in a very active form chemically, which I do not think interests us very much here.

Now, nitrogen would not react with the tungsten filament directly but would react instantaneously and quantitatively with any tungsten vapor that came off the filament. At normal operating temperature, 2400 degrees, the amount of vapor that came off was absolutely negligible, so that it would have taken hundreds of hours to get any measurable disappearance of nitrogen.

Q. 21. Always absolute temperatures?

A. Always absolute at these high temperatures. It is almost universally the custom to refer to filament temperatures in terms of the absolute scale. At normal operating temperature of the tungsten filament, the rate at which nitrogen and carbon monoxide will react with the filament is negligible. At 2700 or 2800 degrees, which is a temperature at which the filament would have a very short life, measuring only an hour or so, the vapor comes off the filament fairly fast and reacts with either nitrogen or carbon monoxide as fast as it comes in contact with it, and forms chemical compounds which deposit on the bulb.

In this work, it was necessary to distinguish between the effects due to the evaporation of the tungsten filament as such (due to its temperature), and the effect due to electric discharges in the bulb. So I studied those two phenomena separately. In the first place, by using a low voltage filament with twenty or fifteen volts across it, like a hairpin, so as not to get appreciable electric discharges through the gas which was introduced like the nitrogen, for example. Then later, really beginning in 1912, I deliberately used high voltages for the purpose of studying what effect the electric discharges in the gas would have; (and by high voltages, I mean now, say from 50 volts up to 250 volts), what effect the electric discharges that might occur from a hot filament in the gas might have on these same phenomena, namely, the disappearance of the nitrogen or hydrogen, or whatever gas I was studying.

From time to time the question kept arising as to what would happen if you had a perfect vacuum, and I began to have an answer. In the first place, I had found that the disintegration of the tungsten filament and blackening of the bulb were not due, as had been generally supposed, to electric discharges taking place in the lamp, if the lamp was well exhausted; certainly not. It was not due to chemical attack, but was due, in a well-made lamp, to perfectly normal evaporation from the filament, such an evaporation as you might have in a piece of camphor in the air. But if water vapor were present, there was a cyclic action which was quite unique. The water vapor would be decomposed in contact with the filament and would liberate hydrogen in the form of atomic hydrogen, and form tungsten oxide which would deposit on the bulb. The atomic hydrogen would react with that oxide accumulated on the bulb, reduce it to metallic tungsten, forming again water vapor, which would come back and attack the filament again. Thus with a very minute amount of water vapor, you would carry over to the bulb an amount of tungsten which was all out of proportion to it.

Now, if you had hydrogen alone in the bulb, there was no deleterious effect, that is, an amount of hydrogen which, in the presence of water vapor would be very serious, was not harmful in affecting the life of the lamp, neither was a similar amount of oxygen, but the two together would be fatal to the lamp.

Now, no gas that I had studied outside of water vapor, produced a really harmful effect on the filament of the lamp, in the absence of electric discharges, and electric discharges such as attacked the filament seriously with ionization that would cause a bombardment of the filament in serious amounts did not occur to a serious degree in the ordinary well-exhausted tungsten lamp.

Now, feeling that no single pure gas was distinctly harmful in the lamp, and that the loss of tungsten from the filament was due to evaporation, I now could reason that if I had an absolutely perfect vacuum, the life of the lamp would not be appreciably better. That could not be directly proved, because you never could get a perfect vacuum. But to go as far as I could in that direction, I made some life tests of lamps in which I ran the lamp during life test completely immersed in liquid air, the whole lamp during its life ran under the surface of liquid air, and was taken out from time to time in order to see whether the candle-power was maintaining itself. Exactly similar lamps were run at room temperature, and I found the lives of these lamps were substantially the same. There was no improvement in the life of the lamp by immersing the bulb in liquid air.

Q. 22. What was the exhaust schedule?

A. They were carefully exhausted on our own vacuum system, with removal of vapors, such as mercury vapor and hydrocarbon vapors. In all of these vacuum systems that we worked with, or I worked with personally, we had no stopcocks or anything of that sort that could give us off any impurities, because we wanted a clean vacuum, and one that we knew all about.

Now, many experiments before that time had indicated to me, that when you immerse the bulb in liquid air, the clean-up phenomena that can go on is entirely irreversible. That is, if the gas is once cleaned up and the bulb is in liquid air, there is no danger of its (the gas) coming back again; whereas, if you have a lamp at room temperature, and you put in, for instance, nitrogen or hydrogen, or some other gas, and allow that gas to be cleaned up by the heating of the filament, or the use of high voltages, together with an electric discharge, then although you will in general get a clean-up, the very discharge itself decomposes the products (that are formed on the bulb) which contain the gas that has been cleaned up, so that the reaction goes both ways. If, for example, you put a higher voltage on, you may find the gas cleans up, and when you lower the voltage it will come back again, but very large amounts of it may come back again as you lower the voltage.

In fact, I made a very extensive series of experiments of that nature, changing the voltage continually, and watching the change of pressure on the McLeod gauge every time I changed the pressure (this I think was due to the hydrogen in the lamp). The first work of that sort was done early in 1910, where we changed the voltage on the lamp, no other factor taking place, and every time we raised the voltage, the pressure would go down so that we could go up and down in pressure by lowering or raising the voltage of the lamp. Then the other fact was very striking, that if we had introduced into a lamp such things as water vapor (as, for example, in our work on the blackening of the bulbs, by deliberately having water vapor present), that in those lamps an electric discharge would usually cause the *evolution* of large amounts of gas, instead of causing the disappearance of gas, and gases would be evolved,—gases which were on the glass would be evolved,—because of the positive ions which would strike the glass, positive ions would bombard the glass, and knock off the gases that were there, so that the vacuum would get much worse. There is only one other thing, I think, up to the summer of 1912 that I need talk about, and that is our methods of measuring the pressure.

Q. 23. I was going to ask you, Doctor, what you did in the way of manometers or gauges, or what your apparatus was in that respect?

A. When I first came to the laboratory, I found they were using McLeod gauges very extensively. Of course, they introduced mercury vapor into the apparatus and that gave a pressure of about one or two microns. As soon as I started the use of liquid air, that trouble could easily be avoided, just as it could have been by using solid carbon dioxide, because it was frozen out in the trap between the McLeod gauge and the rest of the system. At first I was rather skeptical about whether that was a justifiable thing to do, because from the very fact that you have a steady stream of mercury vapor going from the mercury in the McLeod gauge, into the liquid air trap, you might think that that would help to pump gases out of the McLeod gauge. But experiments at that time, as well as theoretical work which I did, showed that at these low pressures, the molecules travel such long distances before colliding with other molecules that they practically only collide with the walls, so that the mercury vapor molecule bounces from wall to wall and does not hit the other molecules, and therefore has no effect in driving out the other molecules. When you come to much higher pressures than that of the two microns of mercury vapor, one gas will carry along another gas, and this fact has been made use of in the various mercury vapor pumps that are now usually used for producing high vacuum.

So we found, I found by my own experiments, that the McLeod gauge was thoroughly reliable, even when used with a liquid air trap to eliminate the mercury vapor. I might say that after I used the liquid air machine, the first time, along in the fall of 1909, and got the machine going within a very short time after that, the machine was running every day and has been in operation, and we have had a steady supply of liquid air in the laboratory ever since that time. Its value is so great in enabling us to obtain high vacuum, that we have always had a supply of liquid air on hand. Now, when you come to study——

Q. 24. Before you proceed, Doctor, I will ask you if you had occasion at any time to make any study of radiometers?

A. I think I would mention that in connection with the matter of measuring pressures.

Q. 25. And would you give the details?

A. The McLeod gauge, I said, gives an accurate measure of pressures when used with the liquid air trap, but I do not mean, of course, by that, that the McLeod gauge measures the mercury vapor itself. If, for instance, you have a system with a vacuum tube in which there is mercury vapor and connect it to the McLeod gauge, it only gives you the pressure of the gases which do not condense in the liquid air, if you have the liquid air trap, because any gas that does condense, does not get into the McLeod gauge, and the mercury vapor itself in the McLeod gauge condenses as soon as you raise the mercury to measure the volume of the other gases. You understand the principle?

THE COURT: I thought I did, but your last statement throws me off again.

A. The McLeod gauge is a very simple and useful device. It is a bulb which is usually of two or three hundred cubic centimeters, or sometimes even up to a liter in volume, a liter being about a quart, and 200 cubic centimeters being about one-fifth of that. The bulb is elongated in a vertical direction, and at the top of it it is narrowed down into a capillary tube of about one millimeter internal bore. Now, the mercury in the bulb is lowered to the bottom of the bulb and a side tube from the tube that supplies the mercury, then makes connection between that McLeod gauge bulb and the vacuum system in which you want to measure the pressure; so that that bulb contains the gas at the same pressure as the apparatus which you want to study. You now raise the mercury, and the first thing the mercury does is to seal off that bulb from the rest of the system, and then the mercury rises in the large bulb, and all the gas in that bulb, which was originally at the low pressure, is driven into the little capillary tube at the top, so that its volume can be measured accurately. The gas in that tube is not measured at atmospheric pressure, but the tube that communicates with the bottom of the bulb and the vacuum system to be measured, rises vertically by the side of this bulb; so that as the mercury rises in the bulb, it also rises in the tube by the side of it, and finally, when all the gas in the bulb has been driven into the little capillary at the top of the McLeod gauge of the bulb, the mercury outside is raised to the level of the upper end of the capillary tube.

Suppose, for example, that the mercury rises in the outside tube to a level corresponding to the upper end of the capillary, and inside, that is, inside the capillary, the mercury level is twenty millimeters lower, that represents the volume of gas in that little capillary. But the pressure in that capillary is only due to the little head of mercury of twenty millimeters between the surface of the mercury inside and outside, so that you are only measuring it at a low pressure; and therefore, that volume is very much greater than it would be if measured the ordinary way of atmospheric pressure. Because of the compression of the gas into the capillary of the McLeod gauge, it is possible to measure pressures, or conveniently to measure pressures as low as one one-hundredth of a micron, and by pushing things to an extreme, as was illustrated particularly in an article by Gaede, which I have not the reference to at present, but it is possible by using a very large bulb and taking precautions to heat the mercury in the capillary tube so as to prevent the sticking of the mercury on the sides of the tube by variations in capillary force, it is possible under these conditions to measure pressures by the McLeod gauge as low as one one-thousandth of a micron.

Although the McLeod gauge is extremely satisfactory for measuring pressures under these conditions and is by far the most useful device in its general application for this purpose, it is frequently desirable to have a gauge which would indicate also the presence of water vapor and mercury vapor or any other vapors which would not be indicated on the McLeod gauge. Also, there is a desire for a gauge that might be more sensitive than the McLeod gauge, with pressures lower than a thousandth of a micron. I think in 1910, there was a man working in our laboratory, Dr. Hale, who spent about a year developing a hot-wire manometer for measurements to be made as accurately as possible on gases in vacuum, by studying the cooling effect of gases acting on a very fine platinum wire, as has already been described, I think, in Arnold's testimony, pretty much the same kind of gauge, I imagine. We used that gauge quite a little to study vacuum in incandescent lamps so that we could seal the gauge onto the lamp and study the changes in pressures in the lamp during its life.

The McLeod gauge is not suitable for that. It is hardly a portable piece of apparatus and in order not to get mercury vapor into the lamp you would have to have liquid air continually there.

So the Hale gauge was used for that purpose. It was not satisfactory below one-tenth of a micron, not very sensitive.

A more satisfactory, but only roughly quantitative gauge, was used, I think, at Dr. Whitney's suggestion in the form of a radiometer; I think that was used even before I came to the laboratory. I remember its being used by a Mr. Ruder, probably in 1911, or early in 1912, who worked on it very extensively while I was in the laboratory at that time.

The old radiometer that we see in jewelers' windows, which has a set of rotating vanes, which is made to spin by the action of sunlight, depends upon the presence of a considerable amount of gas. One side of each vane becomes heated, because one side is black and the other side is bright. The hot side sets the molecules of gas into more rapid motion, so that the gas is repelled, and this sets the vane into motion because of this temperature condition. We found that that was not sensitive enough, and that the phenomenon entirely disappeared when we came to the lower pressures, such as we were using in the laboratory in connection with lamps. But then it was found that if such a radiometer which is a little structure consisting of four vanes, mounted on a needle so that it can spin, was set into rotation by shaking the device by hand, that in a very good vacuum, it might continue to rotate for an hour or an hour and a half, but if the vacuum were a little poorer, it might stop in fifteen or twenty minutes; so that although there was nothing quantitative about that gauge used in that way, it did serve as an extremely useful, and a very sensitive means of detecting changes in pressure in sealed off lamps during their life.

Now, there were two modifications of that principle, which I devised in the laboratory and used to a considerable extent; the first one was what we call the quartz fibre gauge. If a little quartz fibre much less than the diameter of a hair is fastened firmly to one end, so that the other end can swing freely, and this is mounted in a lamp bulb, and a very high vacuum is produced by tapping the bulb, this little fibre is set into vibration very much like a pendulum, only an elastic force is the force that causes its return to its normal position.

This gauge is quite sensitive. It can be used down to about one-hundredth of a micron and can be calibrated, the idea being that the longer the time that it continues to vibrate—if set in motion, it will continue to vibrate for a certain length of time—the higher the gas pressure the more rapidly its motion, will slow down and finally stop, or come to one-half the amplitude that it had at a definite time. By measuring that time you can get a quantitative indication of the pressure. We have used that considerably, in order to follow changes in the pressures in lamps.

Then finally in the summer of 1912, I worked with what I called the molecular gauge, in which a rotating disc of aluminum was mounted just below a suspended mica disc to which a mirror was attached, and that whole structure was suspended from a quartz fibre, which is like a galvanometer suspension. The aluminum disc underneath could be operated by a rotating magnetic field, so as to rotate. Some, I think, were used about 15,000 revolutions per minute and at this high speed of rotation, the frictional force in the gas tended to drag around the suspended circular disc of mica which was placed just above it. The extent of that frictional force could be measured by the angular deflection of the mica disc, as measured by the beam of light reflected by the mirror, just as in the case of a galvanometer. That proved to be an extremely sensitive gauge.

I might show your Honor some of these things I have been talking about in a photograph of a room in which most of this work was done. This is Exhibit Langmuir Priority Exhibit L, I think (indicating).

Q. 26. Just a moment, Doctor. That corresponds does it not, to Plaintiff's Exhibit No. 122? I think it does.

The Clerk: Yes.

A. It is printed on page 2096 of the Interference record.

Q. 27. The Interference record, Doctor?

A. The transcript of record in the Interference, yes. You will notice that just in front of the window there is a high object, that is a large cylinder which can be raised or lowered; that is the vacuum oven that I spoke to you about that could be used for exhausting lamps, and only the pressure outside the lamp could be reduced to say the pressure of a centimeter.

Q. 28. Doctor, may I interrupt you? Will you mark on the photograph with ink, the parts you are referring to?

A. Shall I use letters?

Q. 29. Yes, use letters.

A. I will mark this oven A. That was electrically heated, and could be lowered down over the lamp, and could be heated to 600 degrees C., and was frequently used in our work, along in 1911, I think particularly, when we wanted to get a very high vacuum. As a matter of fact, we found that we did not gain very much by going above 360 or 400 degrees C., so later on we did not use that as much as we did earlier, because we could obtain vacuum in other ways, and it would be just as high.

There is on this photograph a complicated motor-driven device which I will mark B, which is the electric commutator used for operating the rotating part of the molecule gauge that Dr. Dushman and I—I do not know that he worked on it at that time—I think at that time I was working alone, but later on he did some work on it. I think the first work was done by myself; but there is the apparatus set up ready for use. The device which I will mark by the letter C is the McLeod gauge which we used in this apparatus in connection with the apparatus for measuring and analyzing small quantities of gas.

This apparatus for making this quantitative analysis is included in the circle that I have drawn at D. That contained the little bulbs in which combustion analyses could be made. It also includes the bulb of the Toepler pump, which is the larger bulb seen at that place. That was the bulb containing about a liter and a half of mercury, I think, in which the mercury could be raised or lowered by letting either air or the rough vacuum into the mercury contained in the bulb, which I will mark E, so that the Toepler pump could be operated very easily without lifting very heavy weights, as was usually the case when they were operated, the heavy masses of mercury had to be lifted by hand. In this case it was raised by atmospheric pressure and lowered by using vacuum. You will notice in this photograph also that there were two other ovens for baking out lamps. One I will mark with F, which is a gas heated oven that is capable of exhausting six lamps at a time, and then behind the tall frame at the left-hand edge of the picture, there was another oven which cannot be very directly seen in the picture.

The Court: Recess until 2.15 P. M.

After Recess.

Q. 30. Will you continue, Doctor, your description of your work up to the summer of 1912?

A. I spoke of the introduction of a series of different gases into a well evacuated lamp in order to study the effects that would be produced thereby and I mentioned that in the case of hydrogen there was evidence that a peculiar effect took place, that is, that the hydrogen molecules became dissociated into atoms.

In order to study this more in detail and see if I could make a real measurement of the extent or the fraction of the hydrogen molecules that would be broken up into atoms at any given temperature and pressure, I needed to make experiments covering a much wider range of pressures up to atmospheric presure.

So I heated some tungsten filaments by passing current through them in hydrogen at different pressures, using temperatures up to melting point of the tungsten wire which is about 3660 degrees absolute.

The dissociation of the hydrogen into atoms then manifested itself by an abnormally high heat conductivity of the gas which carried away much more heat at the high temperature than you would have expected from the curve obtained at lower temperatures. In order to see if this was due to dissociation of hydrogen, I made some other experiments in which I heated the filaments under similar conditions in nitrogen instead of hydrogen. It was this work, done for the purpose of studying the dissociation of hydrogen, in other words, in order to settle a fundamental scientific point, that led to the discovery that you could use high pressures of gas to build a better tungsten lamp, because that work, resulted in the gas-filled tungsten lamp that has greatly increased the efficiency of all the larger sizes of tungsten lamps.

The work was done mostly during the early part of 1912. I think a patent for that was filed about April, 1913, but most of the experimental work was done in the early part and during the summer of 1912.

One other thing I would like to point out is that beginning quite early in 1910 (since I wanted to do quantitative work on studies of everything that was going on in lamps), I needed to have a good temperature scale so that I could measure the temperature of filaments. That work continued along, beginning 1910, into 1912 and right on until 1916. We continually were working on better methods for measuring accurately the temperatures of filaments at these extremely high temperatures. It is quite a difficult problem.

For that we needed to study the properties of the filaments right up to the melting point and we wanted to see whether as you changed the voltage, or whether you used a long filament or a short filament you could rely upon the characteristics of the filament being the same for a given current; whether a given current would heat a long filament to just the same temperature that it would heat a short filament.

That question arose because it seemed as though if you had a long filament in a vacuum the voltage drop between the ends of the filament would cause a considerable quantity of current to flow through the vacuum itself which would thus not really pass through the filament, and therefore the temperature of the filament would be different from what it would be if you had the same current passing through a short filament where nearly all the current would pass through the filament itself.

So we looked for that kind of an effect and were not able to detect it at all. We knew then, from that that the current flowing from one end of the filament to the other, even with 110 or 250 volts, and sometimes more, across the terminals of the filament, that those currents were quite negligible compared to the current going through the filament itself. At that time, we found that. It was quite early, when I came to realize the rather remarkable nature of that result more fully. As time went on——

Q. 31. May I ask you, Doctor, if that effect is well known or has any definite name, I mean, when carried to an extreme?

A. Which effect?

Q. 32. Is that the same effect as is called the Edison effect?

A. It is the relative absence of the Edison effect that came to my attention. But the Edison effect that occurs in a poor vacuum, always has given trouble in lamps when abnormally high voltages were used and gave trouble in tungsten filament lamps at 110 volts, if the vacuum were poor.

The first year that I was in the laboratory an assistant of Dr. Whitney's continued experiments for a great many months (I do not know just how many, but several months), on measuring how big these leakage currents were in an ordinary lamp. He put into tungsten filament lamps an extra filament or an extra electrode in the form of a platinum wire and put different potentials on that, connecting to the source of potential which was the same as that of the positive end of the filament and measured the current through the galvanometer. During the course of the life of the lamp he followed the change of current and it was noted that if the vacuum became very poor these currents rose to high values and as you got better vacuum the currents became smaller. Every one knew that the vacuum was not perfect and as they got better vacuum they always got less current. Dr. Whitney particularly seemed to think that that indicated or suggested to him that if you got a perfect vacuum perhaps those currents themselves would disappear.

At any rate, all the experimental indications were that those currents would become very small. They were of the order of magnitude of a milliampere, one or two milliamperes is the amount of current that was obtained.

That fact was in accord with the fact that the characteristics of the filaments showed the substantial absence of Edison effect, at least to the extent that the current flowing from one end to the other in good vacuum was negligible compared to that flowing through the filament itself. I speak of filaments such as in forty-watt lamps which will take four-tenths of an ampere and a ten-watt lamp which will take one-tenth of an ampere.

Certainly the currents that were flowing across the space were very small and negligible compared with 100 milliamperes.

The peculiar thing about that, that was in my mind, lay in the fact that these filaments were running way up to temperatures over 3000 or 3500 degrees. During the measurements of these characteristics we ran up to such high temperatures.

The work of Richardson was well known, according to which the electron emission from a filament increased with the temperature very rapidly like the vapor pressure of a substance, and followed the same mathematical law that the vapor pressure of substances in general follow, increasing as you raise the temperature.

There had been no measurements, or no measurements available, on the electron emission from tungsten, but there were for other metals, particularly platinum. Platinum and tungsten might have been presumed, and I did presume, that they were approximately the same or gave electron emissions that were about the same. As a matter of fact, I was not very far wrong as subsequent measurements have shown.

Putting into the equations that Richardson had derived the factors obtained for platinum and using, for instance, a temperature of 3000 degrees or 3500 degrees, you can calculate that the electron emission should have been hundreds of amperes per square centimeter of surface. Such large currents, of course, had never been observed, because with platinum filaments it was not possible to go to such high temperatures and at that temperature the emission was not very large, so that nearly all of the work that had been published on the electron emission from pure metals involved very small currents, usually microamperes and sometimes milliamperes. Only from the Wehneit cathode were large currents reported.

So it seemed as though if Richardson's theory was right you should get hundreds of amperes passing at high temperatures between the two ends of the filament, and it was therefore a striking fact that the current actually must have been down to the order of one milliampere. I had not thought of any explanation of the phenomena at all by the summer of 1913.

Q. 33. Do you mean 1913?

A. 1912, I mean, and simply looked upon it as one of these unexplained peculiar phenomena, and one that was in close relationship with these experiments that had been made in 1909 and 1910 by this assistant of Dr. Whitney.

I had always looked upon Richardson's theory of electron emission, that is, evaporation of electrons from the metal, as being a most reasonable theory and one that was very attractive and one that you would like to see established because of its great simplicity. It is one that you would naturally hope would be true, but I had not made any definite experiments myself on it, so that I did not know what to believe.

In the literature of that time, 1912, there were quite a large number of papers being published—I mean not only in 1912 but up to 1912, quite a large number of papers were being published which expressed great scepticism or doubt as to the possibility of getting electrons out of a metal in the perfect vacuum. Perhaps I had better go into that in a little more detail later, but that was the state of my mind at 1912, that I did not know. I had not read these papers in very much detail, I had read Soddy's paper, which I think was in 1906 or 1907, in which he had a Wehnelt oxide cathode, and as he got a better vacuum the current fell to zero according to his statement and no current could pass.

I never repeated that experiment, but it certainly was in line with the observation in the laboratory that these currents were extremely small in very high vacuum.

I think it was in 1911 that I had an assistant of mine work for several months on electric discharges from a hot filament to a nickel anode in mercury vapor with the mercury vapor at two microns pressure and up to perhaps ten or fifteen microns pressure,—very low pressures of mercury vapor. Nothing came of it, but we had the blue glow phenomena and we were simply getting familiar with the phenomena and we studied the rectifying properties of this device and I was studying the electron emission from the filament as a function of temperature in the presence of mercury vapor and I knew from my own experience that you did get, as you raised the temperature unlimited current and there was no trouble at all, in that mercury vapor, in following Richardson's equation up to high current values. It was entirely different from the conditions that you found with the pure tungsten filament in high vacuum. But with mercury vapor you would have, if you raised the filament temperature to 3,000 degrees, a dead short filament and it would have melted the filament and the leads. So that I knew there was nothing abnormal about tungsten. Tungsten emitted electrons extremely easily at high temperatures.

I forgot to mention this morning that along in 1912, in studying the clean-up of gases by passing discharges between a hot electrode and a cold electrode that the gas that disappeared was deposited on the bulb or in some case was driven into the glass a short distance and I found that such gases sometimes came back off the glass.

In studying this phenomenon, it was my custom for perhaps a year,—I had right in the laboratory by the side of our exhaust system a high frequency coil, a Terla coil, that would give sparks about an inch or two long. By a wire from one of the terminals the potential could be brought up to the surface of the bulb and the sparks be made to play over the outside surface of the glass. When that happened, if there was any appreciable gas pressure, say five or six microns or more, a glow would appear inside of the bulb and the bulb was being clearly bombarded by positive ions and electrons because of the sudden changes in potential. In this way I studied the effect of discharges in a bulb, very often with cold electrodes,—usually with cold electrodes. This discharge caused either the clean-up of gases and the evolution of gases and I found that such discharges were just about as likely to knock gases off the bulb as to knock it into the glass of the bulb. Thus it sometimes caused an increase and sometimes a decrease in the pressure.

On the same floor that I was working, there was a good deal of work being done on the study of mercury arc rectifiers,—6,000 volt rectifiers. Such rectifiers were being baked out by a man that I frequently saw at work. I might tell you, your Honor, the particularly characteristic thing about our laboratory is the fact that there are no doors to the rooms. Every man is supposed to know what every other man is doing. That was brought about through the personality of Dr. Whitney and there was a great spirit of coöperation. So that when this man was working on rectifiers I would talk to him and watch him and he would suggest things. That was characteristic of the work that was going on in our laboratory.

One other point that I meant to mention, and forgot to, was in connection with the exhaust of tungsten lamps as compared with the carbon lamps. Before I came to the laboratory and before we had tungsten as a material to use for filaments, Dr. Whitney and others in the laboratory had done a great deal of work on carbon filaments, in fact it was that work which led to the metallized carbon filament, which was a considerable improvement over the old Edison carbon filament lamp.

So that we had exhausted carbon lamps for years before they had exhausted the tungsten lamps. The exhaust of the tungsten lamps I was told was quite a different problem from exhausting of carbon lamps. The differences, as I learned later from my own understanding of the thing,—one of the essential differences is that the carbon lamp is run at such a low temperature that the electron emission from the filament is so small that even if you get the saturation current at the operating temperature it would not cause a discharge that would be serious in the lamp. So that it was not necessary to have a vacuum so good that (as we express it now), currents were limited by space charge. The emission was small and that was enough to keep the current down to low value.

The carbon filament would surround itself with an atmosphere of gas with which it was in equilibrium. So that, unless the gas pressure rose to such a value that it cooled the filament and therefore lowered the efficiency of the lamp, the gas was not a serious factor in the usefulness of the carbon filament lamp. But with the tungsten filament, the matter became entirely different, because there the temperature was so high that if a blue glow started, that is, if there was sufficient gas to allow the current to be limited only by the saturation of the filament, then the positive ion in bombardment was so great at one end of the filament that that end would get hot, and, as it got hotter, it would emit more electrons which would cause more ionization and that would cause still more positive bombardment. Thus the filament would be unstable and go up in temperature and the current would flow without limit, which would lead to a sudden arcing of the lamp.

Q. 34. Is that the same thing as the Edison effect?

A. Yes, but exaggerated,—so much exaggerated as to be fatal. That thing happened in tungsten lamps. It was a very serious problem to get the vacuum down so low that it would not happen, but with the old carbon lamps that did not happen. In the carbon lamps, in the exhaust with the Malignani process, phosphorus was distilled into the bulb and the voltage was raised far above the normal operating voltage, so that then the electron emission became sufficient to start ionization and cause a glow discharge in the gas in the lamp and it was this discharge that caused the ionization of the gas and those ions would then react with the phosphorus vapor to form compounds of various kinds which deposited in the bulb. Without the ionization the phosphorus does not clean up the gas in the old phosphorus exhaust. For example, the Malignani process was not successful on low voltage carbon lamps because they could not raise the voltage to the point where they would get the glow. Distilling phosphorus into the lamp would not cause the improvement in the vacuum.

Q. 35. Did you reach any particular conclusions as a result of the work you have described?

A. I might summarize the work that I had done up to the middle of 1912, in so far as it relates to methods of obtaining and maintaining in lamps such high vacuum that the remaining impurities had no appreciable effect on the operation of the lamps.

The facts that I had learned to appreciate were first, the gas which can be liberated from a glass surface is extremely serious unless very great precautions are taken to bake out the glass at a very high temperature. And a very small portion of glass which has not been baked out may be very important.

For example, if a lamp is exhausted, connected with a piece of tubing and the tubing has not been baked out and the rest of the lamp has, the lamp will very rapidly go bad. And the same is true if the said tubing has been heated to 100 degrees and the lamp is operated at room temperature. That is, if a glass surface has been heated to 100 degrees for we will say an hour it continues to give off gas at room temperature for long, long periods of time at low pressure and those effects in the lamp are cumulative in the presence of a hot filament. Without the hot filament those difficulties do not exist at all, but in the presence of the hot filament a gas like water vapor is decomposed, causing a steady generation of hydrogen which accumulates within the bulb and forms an atomic hydrogen film on the glass and then you have a hydrogen atmosphere in the lamp. And in the same way, if there are electric discharges, as there always are with any case of a hot filament at 100 volts, the walls are being bombarded by positive ions and this liberates other gases like carbon monoxide and we find this frequently by analysis. The work that we did showed carbon monoxide and carbon dioxide which are present in contact with the hot filament.

Large surfaces of metal in a bulb were always carefully avoided. We made the leads of wires of as small size as possible. We were afraid to have large metal surfaces anywhere in the lamp. We knew we could not exhaust them and get satisfactory lamps.

And then although we had found that if you do take these precautions to get gases (from the bulb) removed completely, that the gas from the filament comes off very rapidly. The gas does not come rapidly unless you can heat the filament to such temperatures as 2000 degrees. Unless you can get to a bright white heat you have evolution from metal surfaces that persists even at temperatures far below those at which they were originally heated.

It is not safe at all to heat a lamp to 400 degrees during exhaust and then think that you can run that lamp at room temperature in the presence of large metal surfaces, because the metal surfaces although they had been heated to 400 degrees will give off gas at room temperature which will interfere with the operation of the lamp. That kind of thing I was thoroughly familiar with. Now, another thing that had impressed itself upon me——

Q. 36. May I ask, Doctor, if there is any illustration of this in your work on the gas-filled lamp?

A. Yes, indeed. At first it might not seem to your Honor that the gas-filled lamps that had atmospheric pressure of nitrogen or argon were very closely related to these high pressure devices that I speak of, but as a matter of fact they are extremely closely related.

Q. 37. Did you mean high pressure devices?

A. I meant high vacuum devices.

A. (Continuing.) When we first started to put nitrogen at atmospheric pressure into tungsten filament lamps, we had very serious difficulties. I had found at that time that nitrogen did not attack the tungsten filament and argon did not attack the tungsten filament at any pressure. Nitrogen at all pressures combined with tungsten vapor as fast as vapor evaporated from the filament and it formed a compound which consisted of one atom of tungsten and one molecule of nitrogen, WN_2, W being the symbol of tungsten and N of nitrogen.

And that compound had a brown color, a rather light brown color, so that when we ran a tungsten filament in nitrogen at very low pressure, we got a brown deposit on the bulb in place of the black deposit that you get if you run the tungsten filament in high vacuum, for example, and let the tungsten deposit on the bulb. It was rather fortunate for me that I had made that observation, because otherwise, we might never have succeeded in making the gas-filled lamp. The reason is this:

We had, in making gas-filled lamps, to use a filament of large diameter. The heat losses, the cooling effect of the gas is relatively very much more important in a small diameter filament than in a large diameter filament, so that if you take a standard forty-watt tungsten lamp and put gas in it, you could not operate that much better than about four times lower efficiency than if you had not put the gas in. But if you take a filament having several times that diameter, a filament that takes ten amperes of current and then put gas in, the cooling effect of the gas is not very great in proportion to the total amount. That is one of the fundamental principles that has been made use of in the design of gas-filled lamps.

So that we could not operate with small lamps but we had to use fairly large lamps, 100 watts or so, and more, two or three hundred watts usually.

We realized that we had to make very large bulbs—we used bulbs even larger than we had used for the same wattages in a vacuum lamp, because we did not want to have the bulbs overheated.

But we did not realize that the convection current in the gas would localize on the surface of the bulb and heat the bulb somewhat hotter than you would normally get in a vacuum. That is one effect. The other is, that in order not to get heat generated at one point on the bulb by the convection currents, we needed to put the filament low down in the bulb, as far as possible from the top, and thus we had long leads which were carrying the current down from the top of the bulb,—down to the filament, which might be six inches below the top and these were filament leads that carried ten amperes of current. And so we found that the heated convection current, rising past those wires, gave great trouble in causing evolution of gas from those metal wires.

Now, when we first made such lamps, we first exhausted the lamps as well as we knew how. By that time we started to use Pyrex glass because ordinary glass could not be heated hot enough in the oven and we used Pyrex glass and heated them to a much higher temperature, and we used tungsten and molybdenum wires for supports so as to get as free from gas as possible.

When we had good indications that by such construction we might be able to gain efficiency in making lamps,—reduce the rate of blacking, by using nitrogen at atmospheric pressure,—our first lamps were hopelessly bad, they blackened up in a much shorter time than if we did not have nitrogen there.

That is just exactly what everybody else had found prior to that time whenever gases had been tried in lamps. Edison put nitrogen in lamps in 1880, and he found that they failed.

So in a way, that is what was to be expected, because the gas cooled off the filaments so much that you had to increase the current to make up for it, and although the gas might decrease the rate of evaporation, it increased the energy loss so much that you could not tell which one would over-weigh the other. So that if it blackened more rapidly, you would say you had not been able to offset the loss in efficiency due to the cooling effect of the gas by the decrease in the rate of evaporation.

So we were fortunate in having studied at low pressures just what happened when the filament is heated in nitrogen. In our first gas-filled lamps we found a black deposit, and that indicated to me that the nitrogen could not have remained pure notwithstanding the fact that we had taken precautions which I think were far greater than any one had taken in purifying nitrogen before. We had dried the nitrogen by passing it through tubing two feet long filled with phosphorous pentoxide. We had exhausted the bulbs better than ever before and yet we found that water vapor, when we finally investigated it, was still causing the failure of these lamps.

And when we took additional precautions to bake out our bulbs and went further than before and designed our bulbs so that parts of the glass would not be too much overheated, we found that the deposit on the bulb became brown instead of black, and we were then for the first time able to make a successful gas-filled lamp.

In other words, the preliminary treatment that these lamps had to receive was far greater than any treatment we had ever been required to give, both in regard to the baking out of the bulbs and to the choice of materials and the design of the metal parts that would be heated and must unavoidably be heated in the operation of the bulb.

Q. 38. Did you investigate the clean-up of nitrogen by passing a thermionic current between a hot cathode and a cold anode, and if so, when?

A. Early in the spring of 1912, I made some measurements of that kind in which I used two single loop filaments (in a bulb) arranged in series and three terminals, three lead-in wires, were brought out; one of those was connected to the middle point of this filament; that is the point between the two loops.

In this way, with these three terminals we could run these two filaments in parallel or in series and in that way without changing the temperature of the filament, could double the voltage. If you parallel these filaments you would get thirty volts, and if you put them in series you would get sixty volts, and with the sixty volts you would get an Edison current or a current flowing across the terminals, that would produce a greater effect on the clean-up of nitrogen.

I discovered that the voltage had a great deal to do with the rate of disappearance of the nitrogen. And therefore, at the end of July, 1912, I devised an experiment in which I had two separate loops of filament side by side within the bulb, so that I could heat one and get electrons which could pass over to the other. Now, that was at a time that we were right in the middle of our development of the gas-filled lamp and were studying all of these problems and getting better exhaust than we had ever gotten before and getting metal parts free of gas.

I knew at that time that in such experiments as this, if I am going to pass electric discharges through this bulb, I must have all my electrodes incapable of giving off gas of their own accord. So I chose not just a piece of tungsten wire as the anode of this discharge, but I chose two filaments alike, two separate filaments both of which could be heated to practically any desired temperature during the exhaust of the lamp so as to get both of them in the condition that our best filaments are in, that is perfectly free from gas by being able to heat them and age them at very high temperature before starting the real experiment.

Q. 39. Is this a matter that you testified about in the Interference record?

A. I have, yes.

Q. 40. You may refer to the testimony which you gave in this transcript and explain to the Court perhaps in a more general way or more general terms, the substance of that testimony, which, by the way, is rather complicated and goes into considerable detail and just how you reached the conclusions which you there reached?

Mr. Haight: That is a most unusual suggestion to a witness that he interpret the testimony that he gave in another cause, and I think I must object to it.

The Court: I will hear you, Mr. Lunt.

Mr. Lunt: If your Honor please, the testimony is very complicated and it is rather tedious.

The Court: I am wondering whether Judge Haight's objection goes to anything more than the form of your question. I am inclined to agree with Judge Haight that here you can not ask him in a general way to put a general explanation upon his previous testimony, but you may ask him here to give such testimony as you desire so that I take it instead of letting Dr. Langmuir cover the field covered by him in the Interference, that you better address specific questions to him to bring out any facts which you want.

Q. 41. I will ask you to explain in a general way what the nature of this experiment was and the results secured, and will say that you may refer to this testimony and also to the Exhibit 79, and experiment 291, which I understand is now Plaintiff's Exhibit 99, being the records on which that testimony was given or based?

Mr. Haight: I will object to the witness referring to the testimony that he gave in the Interference record, because that will eventually lead to exactly the same evil that I sought to overcome by the other objection.

(Discussion.)

A. The experiments that were carried out beginning at the end of July, 1912, for the purpose that you have mentioned, were performed for me by Mr. Sweetser who was my assistant, and he is still my assistant, in carrying out the things that I am personally interested in. I have always had Mr. Sweetser working in the same room in which I worked. You will notice in this photograph——

By Mr. Lunt:

Q. 42. You are referring to what photograph?

The Court: I think you did not put this in before recess. Did you intend to?

Mr. Lunt: That is in now.

The Court: This is one of the list of your exhibits?

Mr. Lunt: One of our exhibits. It is 122 but it has not been marked. It has been offered. It is a photograph of Langmuir's laboratory which was formerly Exhibit L in the Interference record and it is now Exhibit 122.

A. (Continued.) The vacuum system that I spoke of this morning which is connected to the Toepler pump which is shown in the circle marked D, was always used and operated by Mr. Sweetser and myself. Mr. Sweetser's desk in this photograph is right behind the large lamp in the left foreground. My own desk was in front of the chair which is in the left central foreground. The little table directly above the chair just mentioned in the photograph, on which there are some notes, is the table on which Mr. Sweetser always kept his notes. The notes that were taken during July and August and part of September on the experiments that I wish to speak of, are included in Mr. Sweetser's note marked "Experiment 291" in Exhibit No. 79.

Q. 43. Just a moment, Doctor. It is now Exhibit 99?

A. Yes. On the first page of these notes marked S-1146——

Mr. Haight: May I inquire, are you going to refer to some one else's notes, Doctor? Are you referring to Mr. Sweetser's notes?

The Witness: Yes.

(Discussion.)

The Court: I do not know where we are until you put your specific question with respect to these notes. I think that the defendant is entitled to have you do that, Mr. Lunt.

By Mr. Lunt:

Q. 44. I will ask you, Doctor, to describe the experiment and make such reference to the notes as you may wish to do?

A. I wonder if I can refer also to my notebook 413——

Q. 45-47. May I interrupt, Doctor? Will you give us the date or dates?

A. May I also refer to my notebook 413, which is marked "Langmuir Exhibit No. 81"?

The Court: The entries were made by you in that notebook?

The Witness: Yes.

Mr. Lunt: I would like to state to your Honor that that is now known as Exhibit 101.

The Court: All right.

Mr. Lunt: In that connection, if I may, I would like to state that at the first, the offer of that exhibit, was limited to pages 1 to 145; and that apparently it has been so offered here in the offer of that exhibit; but I find that there is a stipulation in the Interference record that the whole book may go in, including all the pages and therefore I would like to have leave to amend our offer to include the entire book.

(Discussion.)

A. On this page S-1146, which showed entries made and experiments started on July 20, 1912, and that its object was to study the clean-up of nitrogen. May I ask anything off the record?

The Court: Yes.

A. The particular pages that I have been expecting to refer to in this—in order to find the pages that I want to refer to here——

On Page S-1148 there is a description of the exhaust procedure used for this lamp. I might say in turning back to the first page, that is 1146, that it is stated that the "filament in two loops, each with independent lead wires, in order that by interposing a resistance between the loops, a larger difference of potential between the terminals could be made without a necessarily high temperature of filament." That refers to what I spoke of before, where the two filaments were actually in series, so that the voltage difference between the two legs could only be obtained by putting a higher current through the filament and therefore higher temperature. Here, there are two entirely separated filaments, each with its own pair of leads.

Coming back to page 1148-A, the lamp bulb was heated for a period of over two hours at a temperature over 250 degrees C. for about an hour and a quarter and at a temperature of about 350 degrees for about forty-five minutes. On the notes themselves we see at 10.35 on the morning of July 23, exhaustion of the lamp was started with the rough pump, that means that the pressure was pumped down to about twenty millimeters presure. At 10.45 the rotary pump was started. That refers to the rotary oil pump which I designate by the letter G on exhibit——

The Court: What is the number of this photograph exhibit?

Mr. Lunt: Plaintiff's Exhibit No. 122, formerly Exhibit L in the Interference record.

A. One hour later, exhaustion was started by means of the Toepler pump. After seven minutes, liquid air was placed upon an appendix to the system, which is designated by the letter N. That means not directly below the lamp but at some distance from it, was a little side tube or blind-ended tube which was cooled in liquid air in order to take care of larger quantities of water vapor coming off the lamp bulb when it was being heated. Then the pumping was continued with the Toepler pump until 2.53 in the afternoon. By that time, the pressure, as marked by the McLeod gauge was 0.43 microns, and then the oven was started, at 3.47, the temperature in the oven had risen to 254 degrees, and then at 4.15 it was 332 degrees, and it reached 351 degrees at 4.25, and was kept going at 350 degrees or thereabouts, until five o'clock, when the heating current was turned off, and the lamp was allowed to cool.

During that time, the Toepler pump was operated at intervals, and at 4.36 and continuing steadily thereafter, liquid air was applied to a liquid air trap placed directly below the lamp outside the oven, just as close to the lamp as it was possible to have it. There was no constriction between the lamp and the liquid air trap; so that gases coming off from the glass could pass rapidly and completely, (that is, the condensible gases), into the liquid air trap, where they could be condensed. And then it was our practice, and it is indicated in the notes, that the liquid air was kept day and night on that trap during the rest of the experiment, unless some accident happened, in which case it was always our practice to bake out the whole bulb again to remove condensible gases. I do not know that that happened anywhere in this experiment. The liquid air was kept on day and night and also over week-ends on this liquid air trap.

I notice that twice during this exhaust, the filaments were lighted, both sections of the filament, A and B, being lighted for fifteen to twenty seconds at a temperature of 1770 or 1973 degrees. The next day, without the lamp being in an oven, thus with the bulb at room temperature, the filament was aged at 2380 degrees for about half an hour.

Now, after that, experiments were made with this lamp from July 26th on through August, in which quantities of nitrogen were let into the lamp, and then different voltages were applied between the two filaments while one of them was heated so as to emit electrons, and an electric discharge made to pass through the nitrogen, for the purpose of studying the changes in pressure that occurred in the nitrogen. In other words, I was studying the clean-up of nitrogen, not by the tungsten that is evaporated from the tungsten filament by the heat alone, but by the effect of the electric discharge.

Now, on August 19, 1912, in my notebook 413, on page 22, I summarized some of this work of Sweetser's that he had been carrying on for me under my immediate direction, and I say "Sweetser's work shows apparently three kinds of clean-up of nitrogen," and then I go on to enumerate these:

"1. Chemical, in which N_2 combines with the electrically neutral W vapor coming from the filament," and so forth, and

"2. Electro-chemical. When filament is heated to only 2,000° K, and another cold filament in bulb is charged to +250 volts and there is present about 100 microns, of N_2, the N_2 disappears at a constant rate," and so on.

And I show that this is due to the formation of a compound, WN_2; due to the fact that the electric discharge disintegrates the tungsten and causes it to evaporate at a temperature at which it would not otherwise evaporate, and the tungsten that is caused to sputter off the filament in that way combines with the nitrogen just as though the filament had been heated to a high temperature. Actually the temperature of the filament was 500 or 600 degrees lower than that at which vaporization of tungsten would take place at any appreciable rate.

Now, finally on page 25, I speak of the "electrical clean-up. A third kind of clean-up seems to occur at very low pressures when the voltage is 50 volts or more. It seems to consist in the driving of N_2 molecules onto the glass. Part of this nitrogen can be recovered," and the experiments in these notes show distinctly that nitrogen can both be cleaned up and can come back again as result of this, what we call low discharges or clean-up effects, by raising the voltage nitrogen disappears and by lowering the voltage nitrogen tends to come back. At the end of these notes, I note——

Q. 48. Are you referring to your notebook?

A. My own notebook under date of August 19th says "Sweetser will soon investigate this more fully," that is the low pressure clean-up which is denoted as the electrical clean-up.

Now, turning to Sweetser's notes again, under date of August 20th, which is the next day after I made my entry, that Sweetser would study electrical clean-up at low pressures, and I see that Sweetser, (who, up to that time, had been working with fairly high pressures of nitrogen, such as 83 microns, I notice on page S-1174, and 28 microns in the middle of S-1176), made the entry, "lower pressure, same connection"; and he then pumps the nitrogen down to 4.9 microns and lights the filament to a temperature of 2100 degrees K, and applies a voltage of 186 volts. On the next page, S-1177——

Q. 49. You are now referring, Doctor, to Plaintiff's Exhibit No. 99?

A. Yes, on page S-1177, beginning at 2.45 in the afternoon of August 20th, a milliammeter is substituted for the voltmeter, which had previously been used for measuring the Edison current, a voltage of 250 volts is applied between the two filaments. This is shown by the little sketch at the right-hand edge, which shows the terminals of the 250-volt direct-current line, one filament being connected to the negative end, and the other one through a small resistance to the positive end. These resistances were merely relatively low resistances to prevent a dead short-circuit in case leads should be wrongly connected or anything of that sort. Now, the current as measured on a milliammeter reading 150 milliamperes for the whole scale, was eighteen, and it stayed about that until suddenly it changed to five.

I would like now to present these data in the form of this curve——

A. On the curve which is marked "Run 1," the uppermost point shows the milliamperes, which was eighteen milliamperes at something over five microns pressure. The readings were taken at three-minute intervals, but the currents were not taken at every interval, so that whenever the current was measured, I have indicated the current in terms of circles and have interpolated the volts in between at which the pressure only was read, but not the current, by means of little crosses. The milliamperes changed from eighteen gradually in the course of about thirty-two minutes to sixteen milliamperes, and the pressure had by that time fallen to about 0.53 microns. That is due to the clean-up phenomenon that was going on as a result of the electrical discharge taking place between those two terminals at a difference of potential of 250 volts. And then a very remarkable phenomenon took place in that the current dropped suddenly from sixteen to fifteen and then to five, up to fifteen, down to five, and then stayed at five milliamperes.

This is indicated in the diagram by the line that doubles back on itself.

The pressure at the next reading was 0.37 microns, and in the next reading 0.34 microns, and at the next reading, three minutes after that, the pressure was 0.29 but no current reading was taken at that time; the current was turned off.

On the next page of the notes, S-1178, beginning at 11.01, on August 21, a similar set of readings were taken, but with a lower filament temperature. I may have stated this wrong. I guess I did not give the temperature before with this one. In this Run 1, the temperature of the filament was 2225 degrees; in this

Run 2, which was taken from page S-1178, the temperature of the filament was 2105 degrees, about 120 degrees lower temperature, so that the electron emission was considerably smaller and the current, when the pressure was about five microns, at the beginning of the run, was 4.2 milliamperes, and the current stayed about constant, as the pressure decreased. For the two determinations at the pressures of 1.2 and 0.82 microns, the current is exactly four milliamperes without any tendency to decrease, but in the next reading, where the pressure was about 0.54, which is about the same as that at which the discontinuity occurred in the Run 1, the reading is lower, and is down to 3.2 milliamperes, and then as the pressure falls to 0.43 microns the milliamperes fall to 3.0 milliamperes. At that time the currents were read not with the milliammeter, but with a voltmeter as is shown in the notes, and the voltmeter resistance caused a drop of fifty volts across its terminals, which made the voltage on the electrode only 200 volts instead of 250 volts. These I have marked on the curves to show that the anode volts at the end of Run 2 is 201 volts, whereas at the end of Run 1, it is 250 volts.

The Court: We will take a short recess.

(After a short recess.)

Mr. Lunt: If your Honor please, I would like to offer in evidence an explanatory diagram produced by the witness, and have the same marked "Explanatory Diagram, Plaintiff's Exhibit No. 163."

(Received in evidence and marked "Plaintiff's Exhibit No. 163." *See Volume IV, Plaintiff's Exhibits, page 45.*)

The Court: Have you some other question, Mr. Lunt?

Mr. Lunt: Had you finished your answer?

The Witness: No, I had not finished.

A. (Continued.) With the pressure at five microns, the currents were substantially independent of the pressure and the ratio of the currents at those two temperatures is entirely in accord, in fact, exactly in accord with our present-day knowledge of the electron emission at those two temperatures. For example, our present-day knowledge of the electron emission from tungsten filaments gives at a temperature of 2105 degrees, an electron emission of 3.7 milliamperes per square centimeter, and at 2225 degrees sixteen milliamperes per square centimeter, the ratio in those figures being 4.32.

Now, if we take the 18 milliamperes that we observed in these experiments of August, 1912, at 2225 and divide by 4.32, which is the ratio which I have just mentioned, we get 4.17 as against 4.2 for the electron emission at 5 milliamperes at the lower filament temperature. There is no doubt, therefore, from what we know about discharges at present, that those currents were limited by emission from the filament and not by space charge. As the pressure decreased below 0.5 micron, a discontinuous sudden change occurred so that at 0.4 micron or thereabouts, or at lower pressures, there was a current of 4.5 milliamperes at the high filament temperature, which is only 25 per cent. of the emission of the filament at that temperature.

Now, with the filament at the lower temperature, a change occurred at practically the same pressure, but the current only went down to 3 milliamperes. But that difference between 3 milliamperes and 4.5 is in first-class agreement with what we would calculate on the basis of the space charge equation, the 3/2 power law. As is illustrated in this diagram, which is in the Interference record on page 2091, Langmuir priority Exhibit No. 5, the full line shows the 3/2 power law, the slope being 3/2 at 200 volts. If we have 3 milliamperes, we therefore should have at 250 volts, about 4.3 milliamperes, whereas, it was observed at 4.5. Considering the fact that the voltages were not absolutely definitely known, because the shop line was used, which may have varied a few volts either way, a voltage change of about five or six volts out of the 250, would account for that difference. So that within the experimental error, or the probable experimental error, the ratio of those two currents observed at 0.4 of a micron corresponds with what we would now expect for a device of exactly that character at that pressure, when the current is limited by space charge.

In my opinion, there cannot be the slightest doubt but that the currents at these lower pressures in this device at that time, were currents from 3 to 5 milliamperes with 200 to 250 volts, in which the current was limited by space charge, and was not substantially affected by ionization of the gas. Not only do these results as they stand show that conclusively in my opinion, but in experiments made in December, 1912, with filaments of the same size and shape, in which the pressures were made very much lower, pressures down to one-tenth of a micron being used, it was found that the currents were almost exactly the same as those found here, when the current was limited by space charge. In other words——

Mr. Haight: Go ahead.

A. (Continued.) This is discussed on page 1565 of the Interference record. Such a result would, I believe, have been entirely impossible under these conditions if I had not had both electrodes thoroughly freed from gas by the very high temperature treatment that they received at about 2400 degrees for half an hour at the beginning of the experiment.

Furthermore, it would only have been possible with the bulb thoroughly baked out, so as to prevent the generation and continued liberation of gas during the operation of the device.

I might say that this device was not connected to the pump during these experiments; that is, after the nitrogen was let in and when the notes show that the pumping has ceased, the lamp was sealed off from the rest of the system by a mercury seal, that is, by a U-tube or a tube like a Y in which mercury can be raised into the two branches of the U-tube so as to form a complete separation of the gas in the lamp system from that in the pump system, and liquid air in the trap below the lamp prevented the mercury vapor from such seal getting into the lamp.

Now, the following experiments made during the next week dealt with the clean-up of nitrogen while the bulb was heated. The bulb was heated to 100 degrees C., to see whether the clean-up of nitrogen would proceed as rapidly at that temperature, or whether gas would be evolved from the nitrogen that was on the bulb in the form of compounds. That work was completed by August 28th, and on page S-1186 of these notes, the work at low pressure was again continued with the bulb cold, that is, at room temperature, the object then being to compare the rates of clean-up which were then obtained with those that had been obtained previously with the bulb hot. Low pressures were again employed, and a little lower down on this page, beginning at 3.08 o'clock a run was started, again at a temperature of 2225 degrees, and the nitrogen cleaned up almost exactly as it did in this Run 1, which I have just been describing. Again the current which was obtained with 250 volts on the anode, and with the use of a milliammeter to measure the current, changed from 5 to 17, and then suddenly to 5 milliamperes at almost exactly the same pressure that was recorded before. That is, the pressure at the first reading that gave 5 milliamperes, the pressure was 0.4 micron.

Now, by the side of these notes is the statement that when the current was seventeen milliamperes, there was "pronounced purple glow," and when the current was five milliamperes, there was "no glow." The pronounced purple glow was characteristic of a discharge in nitrogen, and when the pressure got down to 0.4 micron, although there were five milliamperes of current at 250 volts, there was no glow.

Right after that, a little more nitrogen was let in, and again, with 250 volts, and with the same filament temperature, 2,225, when the current was eighteen milliamperes, there is the note "purple glow." The current falls to seventeen, stays at seventeen, while the pressure falls down to 1.2 microns and at 1.2 microns seventeen milliamperes, there is the note "strong glow."

At the next reading, taken four and a half minutes later, with the pressure of 0.52 microns; the current has fallen to five milliamperes and there is the note "no glow."

This is just another illustration of this same fact, that we had passed from the condition where there was a space charge which was eliminated by the presence of positive ions, so that the current was limited by saturation, and suddenly, when the pressure reached below a certain point, the supply of ions was no longer sufficient to neutralize the space charge, and the current became limited by space charge.

Now, these pressures of 0.4 micron are a good deal higher than the pressures that were used or ordinarily exist in pure electron devices today; but they are pressures that can be duplicated at any time with a device of this kind at present and give pure electron discharge under these conditions.

The reason that the positive ions at this pressure of 0.4 micron play no part in the neutralizing of the space charge, is that the positive ions go to the walls of the tube. The walls of the tube completely surround this discharge. The two filaments I might say, were two hairpin filaments, single loop filaments, I think each one 3½ inches in total length, that is, each loop was about an inch and three-quarters long, and were placed side by side in a bulb, a fairly large bulb, I think about four inches in diameter.

Now, the filaments were close together, and the electrons could pass across from one to the other. Very few electrons would pass out to large distances from the filaments in this latter case at the low pressures. The positive ions would be formed and travel out—they may be attracted towards the negatively charged cathode, but they do not hit it because it is of such small area, and they fly past it and strike the bulb because the bulb is always negatively charged. This is because the electrons have a higher velocity and are able to carry so much more current because of greater velocity that they always charge the bulb negatively and the positive ions are dissipated over the relatively large surface of the bulb. If the anode had entirely surrounded the filament and the anode had been positive, the positive ions would have had to keep on circulating around the filament, and if they had past by and missed it, they could not get out of the anode, because the anode is positively charged and would have repelled them. Therefore they would keep on circulating and build up a positive space charge; and in fact, this phenomenon has been used in our laboratory in the last four or five years, and has been studied in great detail,—what we call the trapping of positive ions. When you have a space in which, all surfaces surrounding the discharge, are positively charged, then any positive ions formed, keep on doing the work of neutralizing space charge over and over again; whereas, if you have a negatively charged surface, particularly a large negatively charged surface, the positive ions only neutralize the charge while they fly across the space once and then they are gone by discharging themselves on the bulb.

Q. 49a. Have you finished your consideration of the record?

A. Yes.

Q. 49b. Now, were those results that you have testified to surprising to you at the time you secured the results?

A. No. These data that we obtained at that time were entirely in accord with what I have already stated as our general experience in that field. That is, as the vacuum got better, the currents decreased to small values of the order of milliamperes. Those were like the currents that we had learned to become familiar with in this work of Dr. Whitney's assistant that I mentioned before, and also my own observations on the absence of large Edison currents in well exhausted tungsten lamps, as, for example, observed when measuring the characteristics of the filament.

Q. 50. Are you acquainted with Richardson, the author of the so-called Richardson law?

THE COURT: I missed that.

Q. 51. Are you acquainted with Richardson, the so-called author of the Richardson law?

THE COURT: The author of the so-called——

Q. 52. The so-called, yes.

MR. HAIGHT: Can I have that?

(Q. 50. repeated as recorded.)

A. Yes, I met Professor Richardson, I think, for the first time, in October, 1912. I had not known him personally before that time.

Q. 53. Did you have occasion to discuss your work with him or any of it?

A. I think it was probably early in October when——

Q. 54. Will you answer that yes or no?

A. Yes.

Q. 55. What was your conversation with him?

A. I went down to New York, I think it was, on October 12, 1912, to a meeting of the American Physical Society, at Columbia University,—particularly for the purpose of meeting Professor Richardson and talking with him about several things connected with electron emission, which were puzzling me very much at that time, and these were the subjects that I discussed particularly with Professor Richardson. We spent the whole afternoon after the meeting sitting on a bench, I think, out on the campus at Columbia University, discussing these matters, and I remember the conversations, or most of them, very well. Certainly, the subject-matter of them.

One of the subjects was this thing that I have mentioned several times about these relatively low currents that were obtained when the vacuum was good; why it was that the currents obtained in good vacuum were so very small compared with what you would expect to get on the basis of Richardson's equation. Again, I did not realize that these results represented a limiting value of the current. That is when the current decreased from a higher value where it had the normal value in the presence of gas, to the smaller value, I did not know whether or not these currents would disappear if a really perfect vacuum were obtained. There was some considerable amount of evidence that indicated to us or suggested to us in the laboratory that they really would disappear.

Now, there were: these facts that I have mentioned, particularly the old experiments that Dr. Whitney had started; and the fact that the characteristics of the tungsten filament show no appreciable current running parallel with the filament out in the space even up at the melting point of tungsten, and finally some experiments that Dr. Coolidge had been making these were things that impressed me very greatly; and I discussed these also with Professor Richardson.

After Coolidge had made drawn tungsten wire, and it was in use in lamps as filaments, he turned to other applications of wrought tungsten. He made, for example, tungsten contacts for spark coils. But, then he himself was particularly interested in applying the use of tungsten to the targets of X-ray tubes, where previously platinum was the only suitable material, and where Coolidge felt that tungsten would not only be very much cheaper, but would be enormously better, because it could stand a higher temperature, and would enable X-ray tubes of much more power to be built. So he, for I think at least a year, or a year and half before the summer of 1912, had been making X-ray tubes, that is, of the old-fashioned kind, with cold cathodes, and had been running them with tungsten as an anode material. He had also tried tungsten as a cathode material; and in some cases, he had both the anode and the cathode made of tungsten.

Now, he had high voltage apparatus that gave him probably 100,000 volts, and several kilowatts of energy for the operation of these X-ray tubes and the anodes would become white hot, but the cathodes oridinarily did not run very hot; ordinarily they would use aluminum cathodes.

Now, he found, if he took a piece of tungsten as a cathode, a thin tungsten circular dish, that it easily became heated by the discharge, and finally, it ceased entirely to function as an X-ray tube. Even with 50,000 or 100,000 volts, the tube passed no discharge whatever. This was a thing which was very much more striking in tubes with tungsten cathodes than with any other tubes he had ever observed.

Q. 56. Did you see this work of Coolidge?

A. I saw it repeatedly, yes. I saw dozens of tubes, I suppose, in Coolidge's room when I was with him, watching him applying those high voltages, and talking with him, about the results he was getting, and the phenomenon he was observing; and I saw myself these cathodes and anodes heated up to a white heat. Now, it was along in the middle of 1912, I suppose, probably about August or September, that Coolidge had a particularly striking demonstration of the difficulty of working an X-ray tube with a tungsten cathode, with a flat tungsten cathode, used in the way of the old-fashioned X-ray tube. He had two of these electrodes, one, his cathode, and one his anode, and they were both running up to a dazzling white heat. I did not see this particular experiment, but he told me about it, though, probably the next day after it happened. Both electrodes were running a dazzling white heat, and he said that while they were both white hot, the whole thing simply stopped, and he could not get any discharge through with 100,000 volts. Then, from that time on, you could not pass any current through the tube, and the surprising thing to him was that even if they let in considerable amounts of hydrogen such as, I think, about eight or nine microns of hydrogen, it did not improve matters; he still could not pass the discharge through. When those electrodes were relatively freed from gas, I said relatively—they would probably be nowhere near as free as those he worked with later, but they were much more freed from gas than any he worked with up to that time.

Now, neither Coolidge nor myself at that time saw the explanation of that, what looked like to us as an extraordinary fact. When you think of it, in view of the present-day knowledge, it is obvious what happened. At that time, Coolidge said that tube stopped while the electrodes were at a dazzling white heat, and he believed that he would have a better vacuum than ever before. He said that if that thing had emitted electrons, it would not have stopped. So he believed that there he had another little piece of evidence that [illegible] current flowed in the highest possible vacuum, such as he had learned to work with—because he also, all during this time, was using the same technique that I was; in all the high vacuum work we were both working altogether with liquid air and bombarding electrodes, and heating tubes to a very high temperature, and he was heating the electrodes by these high voltage discharges, but always in a low pressure gas discharge, but he never had been able to do what I was doing by heating the anode by passing currents through it.

Well, I told those things to Richardson, and I said: "How do you account for this phenomenon?" I had thought that Richardson probably knew more than any one in the world about the phenomena of this kind in general, but I found that Richardson's experience had been entirely different from that. He had worked with usually very minute currents, usually less than a milliampere, sometimes only 10-8, sometimes 10-12 ampere currents, that could be measured only with electrometers. He had never worked with tungsten filaments and did not know anything about the larger currents that we had been working with, currents of milliamperes, 10 and 15 milliamperes, in high vacuum.

Further than that, practically all his work seemed to have been at relatively high gas pressures, more of the order of 100 microns. He asked me, I remember, whether these currents were saturated, and he said: "Well, suppose the voltage were a little different, would you get more current or less?" I said, "Well, I have not measured that particularly," but I said, "Can you imagine that with 100 or 200 or 250 volts, as we have, those currents are not saturated? How much voltage does it take to saturate a current, what do you use?" He said, "Twenty volts ought to be enough, 50 volts, or something of that order certainly ought to saturate the current''; so he did not conceive it possible, that is my recollection, distinct recollection.

Mr. Haight: I object to that——

The Court: I do not see any principle upon which that is admissible. I will hear you, Mr. Lunt. You cannot get those in directly, can you? Are you not in the hearsay rule now, in introducing testimony that is purely not under oath?

Mr. Lunt: I am not so much trying to prove the actual fact or the truth of this, I mean the correctness of this, but as leading up to a subsequent visit of Richardson to the laboratory.

The Court: I wonder if you had not better put another question which you want.

Mr. Davis: I do not quite understand, if your Honor please, as your Honor just remarked, that the defendants can produce testimony of a talk with Dr. Millikan, that Dr. Millikan had with Professor Rutherford in Cambridge, as to the state of scientific knowledge, and at the same time, object to the proof which we have of this state of scientific knowledge, and that is all this witness is testifying to. Here was the greatest expert in the world; he did or did not know certain things, and did or did not understand certain phenomena, and could not account for certain phenomena, which seems to me of the highest evidential value, as to what the knowledge of the art was at that time. It is evidently more important than the fact that Professor Rutherford did or did not believe Pring & Parker were right or wrong, which Dr. Millikan was allowed to testify to, without our objection.

The Court: It means Judge Haight's objection restricts him to, well, I do not know what to call it—the conclusions of this witness as to conversations with Professor Richardson, that is, he is not stating—he is passing now from the substance of the conversations to impressions which he gathered, which is different.

Mr. Lunt: I wonder if I can cure that by another question.

Q. 57. Doctor, what did Professor Richardson say to you in response to what you told him?

Mr. Haight: As I understand it, and then he summed up his conversation by his conclusion of what——

The Court: You are stating inferences which he drew from the conversation, which is not within the jurisdiction of the witness.

Mr. Lunt: Well, if he has completed his response to that particular aspect of it, I will go on to the next point.

Q. 58. Did Professor Richardson ever visit the laboratory?

The Court: Did what?

Q. 59. Did Professor Richardson ever visit the laboratory, the laboratory of the General Electric Company?

A. I was very much interested in having Professor Richardson visit the laboratory, and I think he was also, when he heard what I told him in October, so it was arranged that he would come in November, to give us a colloquialium, that is, to talk to the laboratory force on a Saturday morning. I think it was about the end of November he was to come to the laboratory, and I forget the exact date, but it was probably about the last Saturday in November that he came, and saw what we were doing at that time.

Q. 60. What did you do in anticipation of his visit?

A. I said that I expected that Richardson would be able to help me out of the difficulties that I felt existed in our understanding of this phenomena, but when I met him, it did not seem to me that he had been able to offer any concrete suggestions as to the cause of the phenomenon that we had observed; and I therefore made up mind, right after seeing him, and knowing that he was coming to the laboratory, that I would make some definite experiments with the object of measuring the electron emission from tungsten filaments, in the best vacuum, or at least, a very good vacuum. But other matters prevented my doing this in any systematic way. I normally would have done it, by having Mr. Sweetser start a series of experiments, to make a careful study of this important phenomenon. But as Sweetser was busy with another experiment that I did not want to break into (along, I think about the 18th of November), and knowing that Richardson would be there rather soon, I decided to make some experiments myself.

Q. 61. What year was this, Doctor?

A. 1912. I decided to make some experiments myself, but in a very simple way, and I believe that without taking the trouble to have really formal experiments started, say by Mr. Sweetser, that I could get results by utilizing some of the principles and the methods of exhaust, that I had become familiar with in our laboratory. So I wanted something that I could do quickly and easily, and I remembered that I had a whole set of lamps that had been made up about a year before, for special experimental work, that had never been used. They were unexhausted lamps, so I got those down from the shelf in the room that I was working in, Room No. 24, off the shelf, and had three of them exhausted with the regular lamp exhaust treatment. Those were probably exhausted on the oil pump, using phosphorus pentoxide, and so on, and were sealed off and were aged in the regular way.

Q. 62. What do you mean by "aging," Doctor?

A. I think I mentioned it a little this morning. They are running for several hours at this—I am not quite sure about this, I would have to refer to my notebook to see what aging treatment they were given, but usually the filaments are run at very high temperature, or sometimes at normal temperature for twenty-four hours, in order to bring filaments into a steady condition, and get rid of any gases that might be evolved in the first hours of operation. Those lamps, that I had, I said were special experimental lamps. They were like ordinary 110-volt tungsten lamps, except that instead of having two leads, they had four leads. The ordinary tungsten lamp at that time had six loops. In the ordinary tungsten lamp, the filament, went back and forth in the lamp in the form of a zigzag, making six hairpin loops out of the same filament. These particular lamps differed from those in that the lead was brought in to the end of one loop, and another lead was connected with the filament at the beginning of the third loop, and another one brought into the filament at the beginning of the fifth loop. Thus by putting on a voltage, or passing a current through the first pair of these leads, the first two loops could be lighted; with the second pair, the next two loops could be lighted, and by the third pair, the next two loops, so that we have the six loops with four leads.

I chose these lamps for this purpose for the experiment, because it occurred to me that I could burn out the middle loop, by passing a heavy current through it, and at the same time I could use the vaporization of tungsten which I had been working with. That is I used the vaporization from that middle loop for the purpose of cleaning up the vacuum, and getting a very high vacuum.

Now, I realized that these lamps had not been given any better exhaust treatment wher I got them from Mr. Robinson than the ordinary tungsten lamps of that kind; but then I proceeded to heat the central portion of that filament to a very high temperature, and vaporized the tungsten, so as to clean up the vacuum, and at the same time, the burned-out filament was ultimately heated to the melting point, or until it failed, and when that happened, I then would have two separate filaments (separated from one another), that I could heat individually, and then I could apply a voltage difference between them, just as I had in the experiment 291 that Sweetser had carried out under my direction.

Now, this work that was done at that time is described in this notebook 413 (indicating).

Q. 63. Plaintiff's Exhibit No. 101?

A. Yes, on page 123, under the date of November 18th, I worked out Richardson's equation as applied to platinum, and simply state this fact, which I had repeatedly thought of in a more or less qualitative way, where I had not written down the actual equations, but here I worked out what the electron emission from platinum would be at 3500 degrees, and I got thirty-three amperes per square centimeter.

THE COURT: Platinum?

THE WITNESS: Yes. This is all from a book by Wilson, simply from a book in the library, and "according to Richardson, since tungsten is more electro-positive than platinum, the current should be still larger."

Q. 64. Are you reading that?

A. "Yes. We know, however, that the currents are really very small."

THE COURT: I thought platinum fused.

A. This is calculated from an equation that shows the relation between the electron emission and the temperature, and you can substitute in that equation temperatures which are far above the melting point of platinum. The equation, however, is determined by the measurements on platinum. The justification for using platinum is that Richardson had told me that he expected that tungsten would be more electro-positive than platinum, and therefore the currents from tungsten would be higher. I had never applied this particular equation, to measurements of tungsten, so I do not know the exact value of these constants.

On the next page, 124, under the date of November 20th, I referred to the work that had been done the day previously, that is, November 19th, on the Edison effect, and then there followed some twenty pages of notes, which were all written up, I think, on November 20th, describing the experiments that I had made the day before.

These experiments, summarizing them briefly first, were made by taking these three lamps and burning out the middle sections of the filaments for the double purpose of getting two separate electrodes, and also for vaporizing tungsten, to bring about the clean-up in the way that I had done almost repeatedly during the preceding years, and studying then the electron emission, as a function of temperature, to see what the electron emission really would be in a very good vacuum, and to see whether it increased, according to Richardson's law, and under what conditions it did so.

Now, in order to see whether gas is still having some effect, there were two things I tried to do, applying this principle I have spoken of repeatedly, if you cannot get a perfect vacuum, try to make it worse and see what happens. I tried both. I tried first to get a vacuum better. First of all I tried to get it good by vaporizing tungsten. Then I tried to make it better by immersing part of the bulb in liquid air, because I knew from previous experience that enormously increased the degree of vacuum that could be obtained. And then, secondly, I deliberately heated the bulb with an alcohol flame, to drive gas off, and to compare the results that I obtained in the relatively poor vacuum with what I had just previously obtained in the good vacuum, so as to understand what effect gas made in the phenomena I was observing.

Now, a description of these experiments has been given in a great deal of detail in the record of the interference case beginning, I think, on page 1571, and running through to page 1577, and also in the priority record on page 2097 to 2108, and I merely would like to summarize those briefly, and point out to your Honor the original entries in the notebook that referred to these data.

Mr. Haight: I have no objection to the reference to the notebook, but I do object to Dr. Langmuir summarizing his own testimony in another case.

The Court: That is what we discussed before, and if he wants to connect the testimony given in the Interference with the entries in the notebook, then Judge Haight makes no objection to that.

Mr. Lunt: That is all I wish to do.

Q. 65. Doctor, please state generally what the results were which you secured?

A. There were three lamps, two of them contained thoriated filaments and another one which was marked No. 2 contained a pure tungsten filament. They were about 120-volt lamps, 40 watt, .37 amperes. I studied these lamps in succession.

The first lamp showed a typical temperature saturation curve, that is, I tried to measure the variation of electron current with temperature, raising the filament temperature from 1740, where I first got a current of 0.4 milliampere, up to 2170, and then as the temperature was raised way up to 2550, 2740 and even up to 3220, the current did not increase beyond the temperature of about 2550, although the electron emission if extrapolated along the curve increasing at the rate at which it was in the beginning, it would have gone very high.

These data as we see them now indicate that the filament in the vacuum obtained in this way was operating largely as a thoriated tungsten filament. We never would get from a pure tungsten filament any such currents as 0.4 milliampere with a temperature as low as 1740 degrees and attention is called to these facts in the notes.

Then in lamp 6 which was another thoriated filament lamp the middle section was burned out as before and then voltages of 250 volts were applied to the anode. (I would like to say that voltages of 180 to 250 volts were applied to the anode of the first lamp.) These results indicate a poor vacuum. When later on page 129 of this notebook liquid air was applied to the tip of the bulb, sudden flashes of blue glow occurred, and they had also occurred previously to that while the vacuum was poor, and then "the current dropped to .003 and could not again be raised to its former value," that is, with the liquid air on the tip of the bulb, and also "allowing the bulb to warm up again had no effect."

Then some readings are given, raising the temperature to 2830 degrees, showing that the current did not increase between 2280 and 2830. It was a typical curve showing limitation of current by space charge because the electron emission actually was enormous at these temperatures, but only a very small current flowed, that current being limited by space charge.

Now, I calculated in the last column, extrapolating from the lower figures, how the current should have increased according to Richardson's equation. If it continued to increase as it does at the lower temperatures, you ought to get a current of 1.9 amperes instead of 0.4 milliamperes. So that is a very minute fraction, 1/400 or so of what it would be if the current were limited by saturation.

Now, going for a moment to No. 2, which had a pure tungsten filament and which gave by far the best data because the results were not variable, because of the changes in the thorium content of the surface. At that time I knew nothing about the conditions necessary for getting thoriated filament into good condition. With lamp No. 2 several runs were made at different voltages at 125 volts and 250 volts. In this lamp an accident had happened during the exhaustion of the lamp by which the three sections—there were originally three sections of the filament, each section consisting of two loops—in the aging of that lamp the third section (the four leads being marked A, B, C and D) the filament that was mounted between C and D, was burned out.

When I burned out the section between B and C, in order to do what I had done with the other lamps, I then had one cathode consisting of a pair of filament loops and I had two anodes or two electrodes, one connected with the lead C and one consisting of lead D plus the portion of the filament which was still attached to it.

Then, I varied the temperature of the remaining double loop filament and put 125 or 250 volts on the portions of the filament that were connected to C and D and varied those currents and then plotted the result in the form of curves, plotting against the temperature of the filament as abscissæ and the electron current as ordinates. On the curves that are on page 133 and 134 it can be seen that as the temperature rose above a certain definite value, different however for each different curve, the current remained absolutely constant, within the limits of the accuracy with which the currents could be read.

When the current was small as it was in curve 5 it reached the limiting value at about 2100 degrees, whereas, when the current was much larger, as it was in curve 4, it did not reach the limit until 2400 degrees. The flat part of the curve we now know corresponds to the current limited by space charge.

(Whereupon at 4.55 P. M., an adjournment was taken until Monday, November 1, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del.,
Monday, November 1, 1926, 10 o'clock A. M.

THIRTEENTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Richmond: Your Honor, here is a tube bearing the number X-5928, which is closely the same in structure with the nitrogren-filled tube as to which Dr. Kelly testified; but it is now said to contain helium, and I understand it was asked for to show the structure of the nitrogen-filled tube.

(Discussion.)

Mr. Davis: May I have it marked for identication?

The Court: Yes.

(Received and marked "Plaintiff's Exhibit E for Identification."

The Court: Let us see. Who is on the stand —Dr. Langmuir.

Irving Langmuir, resumes the stand.

Direct Examination (Continued).

By Mr. Lunt:

Q. 66. Referring to the work on the bulbs in which the filaments were burned out, about which you have testified, was any photograph ever taken showing the progress of that work at any time?

A. Yes. This photograph which is Exhibit No. 122, and which has already been discussed, was taken on November 19, 1912, which is the very day that those experiments were made with the three lamps which I discussed last Friday. In this photograph there is one of the three bulbs shown at the right-hand side of the picture at a place marked by the arrow. This photograph was probably taken during the noon hour, which was the time when photographs were usually taken. The instrument marked M is the milliammeter which was used in that work and further to the right is the voltmeter.

The Court: Will you mark it?

The Witness: Which I now mark with the letter V. It was used in this work to measure the currents at certain times. That is, sometimes the milliammeter was used, and at other times the currents were read by means of the voltmeter.

Q. 67. Have you anything further to say as to the treatment you gave these bulbs and the data you took with respect thereto?

A. The lamp No. 2 which is the one that contained the pure tungsten filament, and in which two sections of the filament had been burned out, one section being burned out accidentally, the other one deliberately, showed particularly good vacuum conditions. In my notebook 413, on page 130, in describing the measurements taken with this lamp, it was stated:

> "At these very high temperatures the current was absolutely constant (independent of the temperature) and surprisingly independent of all external conditions, gas pressure, temperature of bulb. etc."
>
> "This limiting current was approximtely proportional to the voltage on anode and to area of anode."

The reference to the area of the anode is in connection with the use of the two sections of the filament, which were used as anodes, one section being conected to the lead C, and the other one being connected to the lead D. Sometimes C was used alone as an anode, and sometimes D, and sometimes C and D were connected together as anodes, and with each of these connections, both 125 and 250 volts were used as the anode potential. The curves that I referred to last week are on pages 133 and 134, and show the variation of current with each of these connections with filament temperatures, and in each case above a certain filament temperature the curent became constant, showing that the currents were limited by space charge and were independent of the temperature filament.

After having obtained these results, various effects were studied as to what influence gas was having if any and for this purpose electric discharges were passed over the outside of the bulb by means of the high frequency coil so as to bombard the inner surface of the bulb by electrons and positive ions. It was noted that the presence of the high frequency coil often made the discharge stop entirely so that no current could be obtained between the electrodes even with 250 volts on the anode. Gradually, however, or after a certain period of time, however, the current started up again but started abruptly and stopped abruptly, not passing slowly from one value to the other.

The effect also was tried of applying potentials on the outside of the bulb by taking hold of the bulb with one hand and with the other hand touching the two or three terminals of the direct current "shop" line used in the laboratory. The conduction of the current through the body caused the potential of the hand that was holding the bulb to change and that acted as a grid does in an audion to stop or start the current between the other electrodes, and it was found in this way that the current could be stopped or started.

Such phenomena were sometimes observed in the audion but only at very low voltages, voltages where ionization plays no appreciable part.

The fact that at 250 volts the current could be controlled by the potential on the outside of the bulb in this manner, we now know is proof that positive ion effects were practically entirely absent because in the presence of ionization you cannot control the discharge in that manner, that is, in the presence of appreciable ionization.

On page 137 of the notebook it is stated that with lamp No. 2 the temperature of the bulb seemed to have no effect on the Edison current. This probably refers to immersing the bulb in liquid air and moderate warming. Lower down on the page it is stated:

> "Tried heating bulb very strongly. It increased E. C. from 25 to 35 or even to 40, but this would return rapidly to 25."

The figures given, twenty-five to forty, are not milliamperes but are voltmeter readings which should be divided by fifteen in order to convert them to milliamperes.

Q. 68. Pardon me. Will you explain just how you use a voltmeter to measure current?

A. A voltmeter is essentially a milliammeter, in which a very high resistance is placed. In this case

15,100 ohms. Therefore, the current that flows is proportional to the voltage across the terminals of the instrument and because of the high resistance even with say 100 volts, the current that flows is within the range of the instrument. Such a voltmeter therefore, can be used as a milliammeter, but it must be realized when the use is made in that way that the instrument consumes or has across its terminals a voltage which is indicated by the reading of the scale. For example, if the voltmeter is used as a milliammeter and it reads twenty-five volts, it means then that the voltmeter really consumes twenty-five volts if it is placed in series with the lamp on the 250 volts line. There is then 250 volts minus 25 on the lamp itself because the twenty-five volts is consumed in the voltmeter. The current through the instrument is then equal to the voltmeter reading divided by the resistance, that is, 25 in this case, divided by 15,100.

Q. 69. Now, will you proceed with your previous answer?

A. This statement of "heating the bulb strongly" refers to the use of the alcohol flame which was described on the preceding pages. The current of 25 as read on the voltmeter corresponds to the figures obtained on page 132, with 250 volts on the anodes C and D, that is, the two electrodes connected in parallel and this current is the maximum current that is observed at the highest filament temperatures and is therefore the current that is limited by space charge.

The rising of the current from 25 to 35 or even to 40, therefore, indicates the presence of sufficient gas to partially neutralize the space charge and thus allow a larger current to flow. On cooling the bulb, however, the current returned automatically and rapidly back to its original value of 25, showing that the vacuum had not been permanently impaired.

However, later, the bulb was sparked strongly with the high frequency coil and then the readings show distinctly that gas had been liberated in sufficient quantity to produce blue glow with 125 volts and currents of about one-half milliampere or even less.

These effects, however, were produced deliberately for the purpose of getting a more fundamental knowledge of the nature of the discharge. It should be noticed that sparking on the bulb in most cases spoiled the vacuum.

On pages 139 and 140 there is a general summary of the results with the three lamps that were studied on November 19th. Two stages are recognized. The first stage corresponding to relatively poor vacuum conditions which were first observed in connection with lamps No. 3 and 6, and the second high vacuum condition, called the second stage.

It is stated in these notes:

> "No blue glow during 2nd stage. 2nd stage characterized by reproductibility especially of the max. current."

The maximum current referring to the current observed with the maximum filament temperatures, which is the current which is limited by space charge independently of ionization.

> "The E. c. is approximately proportional at high temperatures to the anode surface. At low temperatures seems to be nearly independent of it. The E. c. is approximately proportional to anode voltage at high temperatures but independent of it at low temperatures."

Thus it is recognized that in the flat portion of the current temperature curve, which we now know is the space charge portion, the current varies with the voltage and surface of the anode, but with low filament temperatures where the current is affected by electron emission of the filament, neither the voltage of the anode, nor its surface has an appreciable effect on the current. That is, two distinct parts of the curve are recognized that follow entirely different logs.

Under date of November 22d, on page 144 of this notebook, is a discussion of a theory of these effects. This theory is a clear statement in a qualitative way of the space charge theory of these currents obtained with the highest filament temperature. I will read from the notebook:

> "New Theory of Edison Current. The velocity of electrons in a conductor corresponds to that produced by a fall thru a potential diff. of only a few tenths of a volt. Electrons leaving a filament will leave irrespective of the presence of a field. But they will only travel a very short distance if there is an electric field of only 0.1 volt per centimeter against them. Hence around filament there is an atmosphere of electrons in equilibrium with the filament. Below a certain temperature the potential is determined by wires only."

That refers to the electrodes, which in this case were wire, those filaments.

> "Above a certain temperature the concentration of electrons becomes so great that they determine the field. Hence two laws: Richardson's at low and some other at high temperatures."

Mr. Haight: I submit, if you read the part of that statement and quote it that you should read the balance. There are three or four lines more of that particular statement, as I understand it.

A. (Continued.) On the following page, 145, it says:

> "Cooling bulb has no effect when no gas molecules present, but if gas is there the molecules collide with electrons (which have same velocities as those in filament) and slow them up and make them more readily absorbed by anode wires."

That was an attempt to explain the fact that the presence of gas increased the current. That we now know is not a correct theory of that effect, but the increase in current when gas is present at high voltages is due to the fact that the positive ions formed neutralized the space charge and therefore removed that limitation of current and allow the current to rise toward the saturation value.

Q. 70. You have referred to certain curves. I am sorry I do not remember whether you stated the pages on which those occurred, the pages of your notebook. Will you do so if you have not?

A. Pages 133 and 134.

Q. 71. You have stated, I believe, that on a portion of these curves the current was limited by space charge. How do you arrive at that conclusion or how did you arrive at that conclusion?

A. At that time I reached that conclusion from the fact that the currents were independent of the electron emission from the filament and varied with the voltage and with the size of the anode surface. It is possible now or was possible after the mathematical laws were worked out to apply the 3/2 power law test which is characteristic of the flow of electric current in high vacuum when the current is limited by the space charge of the electrons independently of positive ionization. I have taken the data obtained in this way and have plotted curves on logarithmic paper to show how these currents vary with the voltage and found that they agreed excellently with the 3/2 power law. That plot is in the record on the priority. This plot is in the Interference record on page 2101.

Q. 72. The Interference record?

A. The Interference record, page 2101. On the opposite page 2100 is a table containing the data which are plotted on this logarithmic plot. There are six experimentally determined values of the current which are taken from the currents observed in the flat portion of the curves on 133 and 134. That is, the currents on these flat portions on 133 were 9, 6 and 1. These are given in the fifth column of the table on 110.

And similarly the other three points are taken from the maximum currents of the curves at page 134 of my notebook. The sixth column gives the voltages that were on the anode at that time, these being measured from the mid-point of the hot cathode and correction was made for the voltage drop through the voltmeter used to measure the current; so that in this fifth we have the currents, not in milliamperes, for those observed values must be divided by 15.1 in order to convert them to milliamperes; and in the sixth column are the voltages. These currents and voltages are then plotted in the figure on the opposite page, page 2101. It will be noticed that when electrodes C and D were connected together, which corresponds to the points that lie near the upper line, the increase of current with the voltage checks excellently with the straight line, which has the slope 3/2 and corresponds to the 3/2 power law. That is, I would like to point out to your Honor that the slope of this line is not arbitrary. The 3/2 power law must be drawn with a fixed slope, that is, the slope is not determined from these experiments, but is determined from the theoretical equation.

THE COURT: Yes.

A. (Continuing.) The points obtained when D was anode, check also and agree excellently with the equation, with the theoretical line, the points corresponding to the use of the electrode C as anode have been multiplied by two in this case, which of course since both are multiplied by two, does not affect the slope of the curve. This multiplication by two is simply for the purpose of getting the whole curve within the range of the logarithmic paper. The straight line was drawn through the upper point and it is seen it does not go through the lower point, which is the point marked by the little cross, but it goes lower than that. The circle indicating where it should be, to be on the line. That difference between the cross and the circle corresponds to a difference of one-quarter of a volt on the voltmeter reading. Because of the use of logarithmic paper, it looks quite a distance here, but actually that same interval of one-quarter volt on the upper curves would be practically negligible, because of the crowding together of the lines as you go higher up on the logarithmic plot.

Q. 73. May I ask how large are the gradations that indicate one volt on the voltmeter?

A. Those are certain divisions on the scale of the voltmeter.

Q. 74. How large are they, or how wide?

A. About one-twenty-fifth of an inch, and this error corresponds to about one-quarter of a division. There is one other test that can be applied to these data in order to see whether they agree with the theoretical requirements of a pure electron discharge in a device of this character, and that test is to see whether the current that flows when C and D are connected together agrees with that which would be calculated from the currents that are obtained with C alone and D alone. It will be noticed by reference to the table that with C alone at 125 volts, the current is 1 and with D alone it is 6. The sum of these is 7. The observed current was 9. In other words, when two electrodes are used together, the current is more than the sum of the two currents taken separately. Now, that result is to be expected on the basis of the 3/2 power law, and it is possible to make an analysis to see whether that increase of the 9 over the sum which would be 7, is in accordance with what I would have expected on the basis of the 3/2 power law. We have already seen from Dr. Kelly's testimony that stating that current varies with the 3/2 power of the voltage is equivalent to saying that the voltage varies as the 2/3 power of the current. When we have three electrodes in a high vacuum tube, as we do in this case, you can test the 3/2 power law, if you only have one voltage difference. For example, if you have one of the electrodes at the same potential as the cathode, and put a certain voltage on the third one, for example, if you have C at zero potential and put 100 volts on D, or put a voltage on D and then vary it, you can find that the current varies with the 3/2 power of the voltage, or you can use the other electrode C and put a voltage on that. But if you have voltages on both electrodes, there are evidently two voltages that need to be taken into account, and in the ordinary form of the 3/2 power law, there is only one voltage in the equation.

Now, it is well known that the electric field produced by a series of separate electrodes can be obtained by summing the effects due to each one. That is, in high vacuum with cold electrodes. So if we have two electrodes and put different potentials on them, their combined effect can be found by taking the average or effective potential for the two, which is obtained by the ordinary methods of averaging. That is, in place of a voltage which we will say is E_C on electrode C, and a voltage E_D on electrode D, we will get the effective potential of the two in a case of this sort, by multiplying the potential E_C by a constant K_c and the potential E_D by the constant K_D. So that in the 2/3 power law, we derive the equation

$$I^{2/3} = K_cE_c + K_DE_D.$$

In case either of these voltages become zero the equation reduces to the ordinary form where the 2/3 power of the current is proportional to the voltage on the other electrode, but in case both potentials are different from zero, then the above form of the equation is the logical extension or generalization of the 3/2 power law, to a device that has more than two electrodes.

This theory is well recognized today, and has been used very extensively in the theory of vacuum tubes. Now, if we apply that equation to these data, we see that we have two unknown quantities: the two constants K_c and K_D, and in the case of D, and we have *six* experimentally determined points from which we can determine these two unknown quantities. We can pick out any two of the points, any two out of the six points of these curves, and from them derive two equations. For example, suppose we should pick out the first point in this table, we would have a current of 9 and a voltage of 98.5. If we substituted those values into this equation for the current and the voltage, (in this case, for example, E_c and E_D would be both equal to 98.5), we would then get one equation which would have two unknown quantities, K_C and K_D. And then if we take the second point, we will get a second equation, and from the two equations we can determine the two unknown quantities K_c and K_D.

If now having determined these two co-efficients or constants in that way, we use this equation to calculate the current for a given voltage, say at the third point marked on the third line in this table, and we find that the calculated current agrees with the observed, it proves that there is a law, and this particular law is the law of that discharge, in so far as that particular value goes. That is, it is a confirmation of the correctness of the equation.

Now, actually what I have done in this case is to determine the two constants from different pairs of values, and take the average values of these constants, which is the normal scientific procedure for testing out whether an equation applies to experimental results, and I have obtained the values of the constants:

$$K_c = 0.0083$$
$$K_D = 0.0327$$

so that the whole equation becomes

$$1^{1} = 0.0083\ E_c + 0.327\ E_D$$

and from that equation I have thus calculated the currents for each of the six conditions given in this table, and in the last column, column 7 is a table of the calculated currents. These are to be compared with the observed currents in column 5. The agreement is, I believe, within the probable experimental errors of the measurements. An average error of 3 per cent. in the voltage would account for all the deviations between those observed and calculated values, and since no measurement of the shop line voltage was taken at the time, but it was merely assumed to be 125 and 250, which was its average value, I think that these results are as close as can reasonably be expected. The fact that the *six* points on the curve agree with an equation that has only *two* constants, is the essential point to be considered. If we only had two experimental points, of course it would be reasoning merely in a circle to calculate back these two points from the two points used to determine the constants, but we have four more points than we need to fix the values of the constants and the agreement of those with the calculated values shows that the currents in this tube did vary in accordance with the modern theory of currents, limited by space charge, independently of positive ionization, and at voltages as high as 250 volts. The maximum current in this case was 1.66 milliamperes.

Q. 75. You have referred to certain curves with flat tops appearing on pages 133 and 134 of your notebook 413. Was the phenomena indicated by the flatness of the tops of those curves well known phenomena at that time?

A. No. I think it is entirely new. As far as I know I was the first person to observe an effect of this kind, with a device of this character.

Q. 76. Would you consider the work which you have just described, important?

A. I considered it very important. It seemed to me it threw an entirely new light on the whole theory of very high vacuum discharges from hot cathodes. It seemed to me to give a complete answer to the questions that had been raised so frequently during the preceding years, as to whether electrons could escape from hot cathodes in extremely high vacuum. This showed me why it was in the past that the currents in such devices as those that I had in August, 1912, and in the earlier work with incandescent lamps—why it was that in such cases, large currents did not flow in spite of the fact that large currents would be indicated by Richardson's equation.

I recognize now that when the vacuum is high an entirely new factor limits the current, namely, the space charge of the electrons which no longer can be neutralized by the positive ions of the ordinary gas discharge. And I saw that the current under these conditions becomes governed by entirely new factors from those that were usually considered or had been considered in connection with thermionic currents in vacuum.

The importance that I attached to it is not only shown by the fact that I wrote twenty pages of notes the day I described this work, the day following the measurements, but from the fact that I set Mr. Sweetser to work on November 21st, immediately thereafter, to make a detailed study of the laws governing this phenomenon under thoroughly good vacuum conditions.

Mr. Haight: I ask that the latter part of this answer which is purely argumentative in its nature, be stricken out. I do not care so much for this particular answer as to guard against the future, because I appreciate that the witness will, unless warned of the limitations to which he may go, continue to do the same thing.

The Court: I think it is not responsive to the question in any event, but I will hear you, Mr. Lunt, or Mr. Davis, or both.

Mr. Lunt: It seems to me that that brings out, at any rate, I sought to bring out what his conclusions were at the time as to what he had accomplished.

The Court: I think that is not responsive to that question and I strike it out on that ground. If you want it so as to bring this issue out you will have to put another question in order to bring it out. I am not saying that I will rule for you or against you later, but you may ask the question.

Q. 77-78. Will you state what were the conclusions arrived by you at that time?

Mr. Haight: My objection was to Dr. Langmuir taking certain things which he said that he did and using those to assert a conclusion which he now gives that he attributed particular importance to certain things. He proceeds to state the facts and then to argue his case.

Q. 79. I was about to ask you, Doctor, just what it was that you had done, that you considered important?

Mr. Haight: I think the witness has answered that.

The Court: I think he has, but may be that

Mr. Lunt is leading up to another thing and I think the repetition is not particularly harmful.

Mr. Haight: That is a matter of discretion with your Honor, of course.

The Court: You may answer that, Dr. Langmuir.

A. I believe I had observed a new phenomenon and worked with what seemed a new type of electric discharge which led me to a particularly clear understanding of the nature of electric currents from hot cathodes in very high vacuum.

Q. 80. You have stated that the burning out of a loop on the filament in a lamp or lamps was influential in effecting a vacuum, I believe. Was this an old scheme in vacuum production technique so far as you know?

A. I had used this method for some time previously to obtain very high vacuum. I do not know of it ever having been used prior to that time by any one else outside of our laboratory.

Q. 81. Did you obtain a patent on it?

A. I did.

Q. 82. Is this the patent or a copy of it to which you refer, patent to Langmuir 1,237,210, on page 2433, Plaintiff's Exhibit No. 160, in this case?

Mr. Richmond: Of course, the patent speaks for itself as to what it is a patent on and I prefer to have that followed instead of the witness's statement.

The Court: As I understand it there is no question pending now, Mr. Richmond. Your objection is rather an anticipatory one.

Mr. Richmond: He was asked if he had obtained a patent on it and the patent is quite limited so that the scope of the patent is determined from itself instead of from his answer.

THE COURT: You object to the witness thus indirectly putting a construction on the patent?

MR. RICHMOND: Yes, sir.

THE COURT: What have you to say, Mr. Lunt?

MR. LUNT: I simply wish to identify the patent and do not wish to go into it any further.

THE COURT: The objection is overruled.

A. Yes. I would like to say in connection with the question just preceding that you spoke of the production of a high vacuum by the burning out of the filament. It is not the burning out of the filament in itself which is the important feature, but the vaporization of the tungsten that occurs preceding the burning out of the filament. The heating of the filament to such high temperature that it vaporizes is the important element. When that action is carried to an extreme it frequently results in the burning out of the filament, but it is not an inherent part of the process.

Q. 83. If you did any further work along the line of thermionic devices and in anticipation of the expected visit to the research laboratory of Professor Richardson, which I think you mentioned, will you please describe this in very general terms and when it took place?

A. The work that I have described on November 19th, was started primarily at that particular time for the purpose of having information on the subject which I could discuss with Professor Richardson. My interest in the results which I obtained were such, however, that I wanted to continue the work immediately and I do not believe that this later work was done for the purpose of having any data to show Professor Richardson.

On November 21st, I had Mr. Sweetser start in to exhaust a tube under the best vacuum conditions. I realized that this work that I had done on November 19th was of a very preliminary nature. I had desired especially to get results quickly and easily and I had produced the vacuum by the vaporization of tungsten and by cooling the bulb in liquid air, but up to that time I had not given, that is, preceding these two treatments, had not given the bulb a particularly good exhaust treatment. So I asked Mr. Sweetser to construct a tube having an anode and cathode both in the form of filaments which could be heated to 2400 degrees or higher during exhaust treatment so as to free them thoroughly from gas while the lamp was connected to the pump, so that the gases evolved in this way could be removed by the pump.

And then I of course wanted him to give the regular exhaust treatment that he had been using in baking out the bulb at very high temperature in the oven that he used for this purpose, using a liquid air trap immediately below the lamp to remove traces of water vapor and carbondioxide.

But particularly I asked him to make the bulb of sufficiently small size so that the entire bulb could be immersed in liquid air and for this purpose, instead of having the tube connecting the bulb with the pumping system come out at the lower end of the bulb I had it brought out from the top of the bulb in the form of a gooseneck so that it came out of the top of the bulb and then bent down at the side of the bulb and passed out of the oven to the liquid air trap, which was placed below the oven.

The object of this was to be able to immerse the entire bulb in liquid air and thereby still further improve the vacuum so as to be absolutely sure that the results that I had obtained on the 19th would still persist as I thought they would in a vacuum probably many times better than that which I had obtained on the 19th.

And at the same time following out this general policy which I had so often made use of, I wanted to check up the whole theory by getting a fundamental knowledge of the effects of gases by deliberately putting in gases of various kinds and I suggested trying nitrogen, hydrogen, mercury vapor and argon and in this experiment these gases were tried.

The object was to find to what extent the electron emission from tungsten was influenced by the presence of these different gases and also to find what pressures of gases and under what conditions this new phenomena of the limitation of current by the space charge took place, and what laws were followed, not only with regard to the voltages of the anode, but to such effects as that of a magnetic field and the presence of different amounts of different gases.

This work was started by Mr. Sweetser on the 21st of November, and was carried on for several weeks after that and all his data were recorded in what we called Experiment 317. I do not think I need to go into details in that as I did in Experiment 291, but the exhaust treatment was practically the same as it was in that work of August, with the addition, however, of immersing the entire bulb in liquid air during part of the readings, during the taking of a good many of the readings.

Q. 84. What part did you personally take in this work?

A. I took a very active part. For the first couple of weeks I worked with Sweetser. I was making the measurements and he recorded the notes.

Q. 85. Did you use alternating current or direct current?

A. Both.

Q. 86. Would you mind stating what the voltages were, approximately?

A. With direct current we used ordinarily 125 and 250 volts and there were several things I did with alternating current. In the first place, I wanted to make sure that the passage of the electric current through the filament itself had nothing to do with the electron emission and for that purpose I heated the filament with alternating current and applied the voltage to the anode either in phase, that is, either simultaneously with the current through the anode, or out of phase with it, so that the current to the anode flowed at a different time from the current through the filament to see if that made any difference whatever. I found it made none, showing that neither the magnetic field of the current flowing through the filament, nor the mere fact of the passage of the current through the filament in any way influenced the electron emission current.

That is one thing that I did with alternating current. The other thing was to go up to higher voltages. I did not have available any direct current voltage higher than 250. To go to higher voltages I used a transformer that gave me alternating current potentials I think up to 1300 volts and measured the current with a direct current voltmeter as I have already described, the tube of course rectifying the alternating current voltage, so that the negative part of the alternating current voltage was ineffective in producing any current.

Then I varied the alternating current voltage from low values up to the maximum limit that I could get. I said I used voltages up to 1800 volts. That is what the transformer gave, but most of that voltage, or a large part of it, was consumed in the voltmeter itself, so that after correcting for the voltage drop in the voltmeter, the voltage that I actually had was 480 volts, up to 480 volts, and as I varied those voltages the current agreed closely with the 3/2 power law.

Plotting the results now that were obtained at that time and making a correction in a little better way than I did at that time, I find that they agree almost perfectly with the 3/2 power law. At that time, however, in the end of November or early part of December, we plotted the results that we obtained without making quite the proper correction, but substantially the correct correction and found that the current plotted on logarithmic paper increased with the 1.7 power of the voltage. I can see now that it was closer than the 1.5 power to that and the difference is not due to any real characteristic of the discharge, but was due to deviating causes resulting from the fact that we used alternating current.

Q. 87. I believe you have testified in some detail as to this work in the Interference record, and I will therefore ask you if you will identify the pages on which that testimony occurs.

Mr. Haight: Is that within your Honor's previous ruling?

Mr. Lunt: I will withdraw the question.

Q. 88. Professor Richardson visited at the Research Laboratory that it was planned that he should do?

A. Yes, he visited the Research Laboratory on November 29th and 30th and gave a lecture or talk to the laboratory forces on Saturday, November ~~30th~~.

Q. 89. What if anything did you show him on the occasion of his visit?

A. I showed him the work that I was doing with Sweetser at that time and told him of the work that we had done on November 19th, and had confirmed and checked up this work by Experiment 317, that is, I told him how the current increased at first in accordance with Richardson's law up to a certain temperature and then the current became limited by another factor which was presumably or believed at that time to be space charge, and that under these conditions the current was effected by the voltages on the electrodes, was independent of the temperature of the filament, but was dependent on the voltage and size of the anodes and such factors as magnetic field.

There were two things particularly (I think I have already mentioned them), that I wanted to have Professor Richardson see in the laboratory when I met him in New York on October 12th. These were the phenomena connected with the low currents with high filament temperatures that were observable in very high vacuum, and secondly the phenomenon that Coolidge had shown me about the 1st of October in which the current stopped in his old type of X-ray tube while both electrodes, anode and cathode, were equally heated and both were at bright white heat, the cathode being just about as hot as the anode, but of course, due to positive ion bombardment, that is, due to gaseous discharge.

I believe Professor Richardson saw both of these things when he came to our laboratory in Schenectady, Coolidge showed him that work with the X-ray tube where he had both electrodes heated by the discharge; both electrodes being made of tungsten, but the cathode was in the form of a disc as well as the anode and the other phenomenon of course I showed him in connection with the work I was doing with Sweetser, that is, the phenomenon connected with the passage of current from a heated cathode in a high vacuum.

Q. 90. Did Professor Richardson indicate any surprise at what you then showed him?

Mr. Haight: I object to that. It calls for the witness's interpretation of Richardson's emotions.

The Court: Do you want to change the form of your question, Mr. Lunt?

Q. 91. Did Professor Richardson express any surprise at what you showed him?

Mr. Haight: That is the same thing.

The Court: What you are inquiring, I suppose, is what did Professor Richardson say or do when he saw these demonstrations?

Q. 92-93. What did Professor Richardson say if you can remember as to the phenomenon which you exhibited to him?

Mr. Haight: I object to that question, because I think it is irrelevant and immaterial what another person may have said in respect to what Dr. Langmuir exhibited to him.

(Discussion.)

The Court: Without a citation of authority, I have been at a loss to determine whether that hearsay rule seems to have pertinence here. It fails to dominate the situation and the state of the art, if the rule begins to allow oral statements made by those skilled in the art. Here we are assuming, I assume, Mr. Davis to have disclosed a statement by Professor Richardson of England, made in a laboratory of the General Electric to Dr. Langmuir upon his demonstration. Now, assume Professor Richardson says: "That is an entirely new phenomenon to me, I have not conceived of it and I have not heard of it." Suppose he said the most he could say under the circumstances, and favorable to Dr. Langmuir's contention, why is not that hearsay?

Mr. Davis: If your Honor please, I was under the impression, and in these matters I speak with the greatest deference—I was under the impression that a spontaneous expression of that sort was usually evidential, a cry of pain, for instance——

(Discussion.)

Mr. Lunt: We withdraw the question.

Mr. Davis: Because the matter is already covered on page 1586 of the Interference record and Dr. Richardson had an opportunity to rebut it.

The Court: Very well.

By Mr. Lunt:

Q. 94. What was your next step in your work on thermionic devices? You may refer to your notebook, if you want.

A. On December 10th——

Q. 95. What year, please?

A. 1912. These experiments that I had been making with Sweetser, his Experiment 317 had progressed so far that I wrote up a summary of the results that we had obtained on pages 154 and 155 of my notebook 413, and then I went down to Coolidge, whose laboratory was on the first floor of the same building, and told him all about these results, and discussed them very fully in connection with their bearing on the X-ray tube that he had been working on. I might say that Coolidge up to that time had been working with X-ray tubes of the gas type, the old-fashioned X-ray tube, which required for its operation the presence of gas to produce positive ions, which bombarded the cathode, and released the electrons in that way. In the operation of these tubes, he had used the tungsten anodes and cathodes in some cases, that is, usually tungsten anodes and in a few cases tungsten cathodes, and he found that as the vacuum got better, the cathode became more and more highly heated, particularly when the tungsten cathodes were used; and I have discussed the work that he did about the first of October.

Q. 96. Did you see this work?

A. Yes, I saw the work. On the first of October, I saw these experiments in which he had the cathode and anode both running at bright incandescence and I had been with Coolidge a great deal during the preceding year and had seen a large number of his experiments, and had talked over his results with him.

Now, on December 10th, I suggested to Coolidge that he use a hot cathode which could be heated by electric current for the purpose of getting electrons in his

X-ray tubes and I told him the evidence that I had that even in the very highest vacuum, that such a cathode would function properly; that there would be no disintegration of the cathode, and that the control of the current from such a cathode, even in the highest vacuum, could be accomplished by controlling the current passing through the filament. On page 156 of this notebook, I would like to read the following:

Mr. Haight: I object. I think the witness can testify, using his notebook to refresh his recollection, but to read into the record an extract from a notebook detailing his impressions, or things of that kind, I think is improper.

Q. 97. I will ask you, Doctor, in place of that question, what your recollection is, or whether you recall what is referred to in the notebook?

A. I remember very distinctly this conversation with Coolidge, and what I told him——

Q. 98. Then, please state it?

A. Without reference to this?

Q. 99. Yes.

The Court: If you need that to refresh your recollection as to details, you may refer to it, if, at the time you made the entry, you knew the entry was correct.

The Witness: I certainly knew the entry was correct at the time I made it. I remember making the entry very distinctly, just after coming back from Coolidge's room and telling him these things.

The Court: You may testify now.

Mr. Haight: Pardon me. May I ask Mr. Lunt to point out wherein the conversation that Dr. Langmuir may have had with Dr. Coolidge, is going to bear on any of the issues in this case?

The Court: I will hear you, Mr. Lunt.

Mr. Lunt: There has been some confusion as to just what it was that Dr. Coolidge showed to Dr. Langmuir, and I wanted to clear up that point.

THE COURT: Is there any defense that Dr. Langmuir was not the inventor so far as the General Electric Company's status is concerned?

MR. LUNT: So far as the General Electric Company is concerned, no; but I do not know what defense may be brought up here.

THE COURT: There is no suggestion here that Dr. Langmuir was not the particular inventor or anything of that sort, if the invention was made in the laboratories of the General Electric is there?

MR. DAVIS: If your Honor please, so far as the answer goes, no such defense has yet been suggested, and we do not anticipate there will be. It is simply that we have the Coolidge patent in here, put in by the defendants and its history; and of course, if Dr. Langmuir did disclose to Dr. Coolidge an invention, which he, Dr. Langmuir, made, and if Dr. Coolidge carried that invention forward and developed it and did something with it, then it is of importance in the case in two ways, it seems to us. First, I can not imagine any contribution which an inventor can make by his invention, any greater than to stimulate another inventor to make a great and useful invention. We have heard a great deal in this case about the transcontinental line, everything that Dr. Arnold thought of, every idea in his head assumes enormous importance because it is going to be used in the transcontinental line, and that Langmuir is a scientist in a closet who has no ideas of practical value, and who is making scientific experiments that have been made over and over again. Now, we propose to show in this case that no less than three very important inventions were made within a few months after November 19, 1912, because of disclosures by Dr. Langmuir to various people, and Dr. Coolidge is one of them. I can not imagine as I have said, that as a practical matter of importance to the world, Langmuir could have done anything more important than to stimulate Coolidge for the X-ray tube.

Mr. Davis: It is, I suppose, elementary that if Dr. Langmuir disclosed something to his associate Coolidge, in the same laboratory, and Coolidge then proceeded with that disclosure, to go ahead, and build the thing, and that thing was a reduction to practice of the thing which Dr. Langmuir disclosed, then Coolidge is reducing to practice Dr. Langmuir's invention. That has been held over and over again, particularly by the Court of Appeals of the District of Columbia, and it is thoroughly settled law down there. It is not necessary that they should be employer or employee, or principal and assistant. As a matter of fact, they may be co-workers. If A, having made an invention, discloses the invention to B, and B proceeds to reduce it to practice, the reduction to practice enures to the benefit of A. That is my point. It is necessary, of course, to show the disclosure before you can argue about reduction to practice, and this is one of the reasons why we are introducing this disclosure.

Mr. Haight: I had not supposed that the purpose of this testimony was to show at a certain time Dr. Langmuir disclosed this invention, which is the subject-matter of this controversy, to Dr. Coolidge. If that is the purpose of the testimony——

The Court: Then your objection is withdrawn?

Mr. Haight: My objection would be withdrawn.

The Court: You may answer the question.

Mr. Haight: I want it to be understood that that is the purpose of the testimony. I did not understand Mr. Lunt to state that.

The Court: No. Mr. Davis did. You may answer the question.

The Witness: Read the question.

(Question repeated as recorded.)

A. I told Coolidge that even in the highest vacuum, electrons were emitted from tungsten filaments, and that a pure electron discharge could be obtained at voltages at least up to 500 volts, in which there was no appreciable bombardment of the cathode by positive ions, and no injury to the cathode resulting from the passage of the current through the device; that for this purpose it was necessary to use a very much higher vacuum than had ordinarily been used with hot cathodes; that the reason that high curents had not been obtained from hot cathodes in high vacuum previously, was due to the fact that gas interfered with and prevented the limitation of current by space charge; that when a very high vacuum was obtained, so that there was no appreciable ionization, that the current that could flow from a given cathode was limited by space charge, but that at high voltages, large currents could be obtained, even when the current was limited by space charge, and that I thought that these facts that I had discovered should be applicable to the construction of an X-ray tube, and should prove particularly useful in connection with such an X-ray tube, because such a tube would operate in the highest vacuum as distinguished from the old-fashioned X-ray tubes, which ceased to function as soon as the vacuum became too good.

Furthermore, that by using the hot cathode in this way he would have a separate control of the current through the tube and the voltage on the tube, because the current through the tube would be determined by the temperature of the cathode and the voltage could be determined by the voltage delivered by the transformer that he used to obtain the potential for the anode.

I suggested that the anode and the cathode should be put very close together and so that the charges on the walls would not unduly influence the current between the electrodes.

As I have already said I summarized to him and discussed with him the data that I had obtained in the last few weeks with Sweetser on the laws that govern the discharge in very high vacuum and the effects that were brought about by the introduction of gases at low pressures. I pointed out particularly that all the gases which I had introduced with the exception of argon had the effect of decreasing rather than increasing the electron emission from the tungsten and that the results in the past which seemed to indicate the opposite, namely, that larger currents were obtained in the presence of gases than without them were due to the fact that in the past people had not understood and taken into account the space charge effect that occurred in very high vacuum, and by space charge I mean space charge of electrons substantially free from effects of positive ions. The space charge in general was quite an old phenomenon.

The Court: Mr. Lunt, have I been told why the old tube ceased to function when the vacuum became high? If I had been told that, it slipped my memory and if I had not been told that and there was no reason for telling me that, pass it right up.

Mr. Lunt: I do not think specifically it may have been mentioned, but I do not think specifically it has been explained.

Q. 100. Will you explain it, Doctor?

A. In the old-fashioned X-ray tube, which is a modified form of Crooke's tube, there are two electrodes, anode and cathode, that is, essentially; frequently, however, a third electrode was used but it was really never necessary to use that third electrode. The three were called the cathode and the anode and the anti-cathode, but the anode could very well be left out or combined with the anti-cathode without affecting the operation of the tube. The cathode was usually in the form of a disc which was slightly concave on the side facing the anti-cathode.

A high positive voltage was placed on the anode usually from an induction coil and with that high voltage some ions that were formed, presumably by residual radio activity in the air or radio active bodies in the surroundings, produced a few ions in the tube, and these positive ions were drawn towards the negatively charged cathode and struck it with such very high velocity that the positive ions knocked electrons out of the metal of the cathode. Those electrons would be drawn by the positive field of the anti-cathode away from the cathode and would be made to impinge on the anti-cathode or target, as it was sometimes called.

On the way across the space from the cathode to the target or anti-cathode, those electrons might strike gas molecules and the gas molecules would have the electrons knocked out of them by that process, one or more electrons, producing a new positive ion which again would be drawn towards the cathode and strike the cathode and knock out more electrons.

It is very obvious when we consider that mechanism, that in order to maintain the discharge you must produce by bombardment of the positive ions against the surface of the cathode, a sufficient number of electrons to carry on the discharge by producing enough positive ions to produce again the number of electrons that are needed to maintain the discharge.

I may make this clearer by taking a numerical example. Let us suppose that the gas pressure is such that while an electron passes from the cathode to the anti-cathode, one electron out of five makes a collision with a gas molecule and ionizes that gas molecule. If we have then five electrons leaving the cathode, on the average one new positive ion will be formed. That positive ion will be drawn back towards the cathode and will hit the cathode. If that positive ion should produce only four new electrons, there will not be enough electrons produced to keep the discharge going, because from those four electrons in general there will not be produced one more positive ion, only one out of five resulting in the formation of a positive ion. In order to maintain the discharge, if the chance is only one out of five that the electrons will hit a gas molecule, then it is necessary that a positive ion striking the cathode should produce five electrons at least in order to keep the discharge going because those five will be sufficient to produce one more ion and that one ion will produce five electrons, and so on, indefinitely.

If, however, the gas pressure is raised to double that, then an electron going across the tube will produce two positive ions and they, in coming back, will produce five electrons each and you thus have ten electrons where you previously had five. The next time you will have again twice as many, so that the current will tend to increase indefinitely.

On the other hand, if you lower the pressure so that the collisions become less probable, so that you do not get quite one ion out of five electrons, then the discharge stops entirely, because there is not enough ionization to keep up the needed supply of positive ions at the cathode.

The Court: May I ask one more question at this point that I lost sight of? Perhaps it is of no importance, and if it is just disregard it. Why did the old tubes cease to function in high vacuum and the Coolidge new tube functioned better in a high vacuum?

Q. 101. Will you explain that, Doctor?

A. The old tube ceased to function at a very critical pressure. If you lowered the pressure below a certain value the old tube stopped functioning, because the number of positive ions formed could not produce enough electrons at the cathode.

By The Court:

Q. 102. As you have just explained?

A. Yes, to maintain the discharge. And therefore the tube ceased usually quite abruptly and it did not do much good to raise the voltage, because as you raised the voltage the clean-up phenomena were more marked and the vacuum would become still better and the thing would operate still less.

The only reason the old tube operated at all was because they used an induction coil whose voltage varied a great deal according to the current that was drawn from it and it was in that way that they could get the tube to operate for any definite length of time.

There is one other factor, and that is you had in that device no separate control over the current that flowed. For instance, if you raised the voltage, if you had a constant voltage you would get a dead short circuit which would carry an indefinitely large current. You had to limit the current by the reactance of the coil. Then the voltage was indefinite. If you passed a certain current through, the voltage would depend entirely on the gas pressure so that you had no way of controlling the operation of the tube except to modify the gas pressure. As you lowered the gas pressure you got a higher voltage across the tube and vice versa. Therefore, with higher gas pressure, you got softer X-rays or less penetrating X-rays.

With the new Coolidge tube on the other hand you have got your electrons from the hot filament. You needed no positive ions to give you the electrons. They came more from the hot cathode because of the temperature of the cathode and the number of electrons was determined by the temperature of the cathode. Positive ions——

Q. 103. Was not that the principle of operation of the cathode in the other at all?

A. No.

Q. 104. The temperature had nothing to do with it?

A. No. The temperature was not even perceptibly warm in the old tube. The cathode was quite cold. The first time that cathodes became really highly heated were in these experiments of Coolidge. And in those the heating of the cathode was due to positive ion bombardment, and as soon as the gas pressure got below a certain point, the positive ion bombardment stopped and the cathode cooled off. We did not understand it at that time. We knew afterwards that that was the reason why that tube had failed. Alhough the cathode was hot there was no way of maintaining the temperature after the gas was gone.

In the new Coolidge X-ray tube the current that can flow through the tube is determined by the electron emission from the cathode and nothing else is of importance. The voltage is the voltage that you apply and you can determine each of those factors separately.

Gas was extremely harmful in the new Coolidge X-ray tube. The cathode was in the center of a little focusing device which caused the electrons from the cathode not to spread out all over the bulb and strike the glass, but the negative charge on the shield around the cathode caused the electrons to pass over in a more or less definite line or path and strike a definite spot on the opposing electrode, which was called the target. That target became very highly heated.

Q. 105. Is this the old or new?

A. This is the new type of Coolidge X-ray tube (referring to Interference Exhibit No. 22, Plaintiff's Exhibit No. 42 in this case) with a massive block of tungsten which is the target or anti-cathode. The cathode consists of a little flat coil of tungsten wire surrounded by a little tube called the focusing shield, a little spiral filament, that is the whole coil. The large mass of tungsten in the center of the tube is the anti-cathode.

The cathode is the little coil of wire which can be heated by current passing through it. This little coil becomes brilliantly incandescent and emits electrons and the positive charge of the anti-cathode draws the electrons across and they are focused and you can see the spot on the anti-cathode or anode on which the electrons have been striking and which has heated that anode to brilliant incandescence.

Positive ions in such a tube are very deleterious even at a pressure far lower than the pressure—100 or 1000 times lower than the pressures—that were needed for the operation of the old-fashioned X-ray tube would be distinctly harmful in this tube, because the positive ions formed by the passage of the electrons across are drawn back and hit the cathode. The cathode consists of little wires which become heated to a higher temperature by the bombardment of the positive ions and as the temperature rises the current increases and the tube tends to run away, that is, the current rises above the value which should be fixed by the temperature of the cathode. That is one effect.

A still more serious effect is that the positive ions that come back and hit the cathode would disintegrate the cathode and give the tube a very short life, especially at the high voltages of 30,000, 50,000 or 100,000 volts. The positive ions that strike the cathode would knock the tungsten atoms off its surface and give a short life to the cathode. In the old-fashioned X-ray tube the surface of the cathode became pitted. If such an effect should happen with the Coolidge X-ray tube it would spoil it. The new type of tube has an unusually long life. The old-fashioned X-ray tube ran for about twenty-five hours while these new tubes run for thousands of hours.

By Mr. Lunt:

Q. 106. May I ask the number of the exhibit in the Interference record that you have been talking about?

A. Exhibit 22.

Mr. Lunt: I will state that this appears to be Plaintiff's Exhibit No. 42 in this case.

Q. 107. Will you now state what was the next subject which you investigated in connection with your work?

A. Sweetser continued under my direction the experiments with electron currents in high vacuum and also continued the study of the effect of gases. In January, about the middle of January, 1913, I had several talks with Mr. Alexanderson who told me about the DeForest audion which he saw in visiting the laboratories of John Hayes Hammond, Jr., and he learned a great deal about the operation of the audion in his consultations with Mr. Hammond. He told me what he wished to do, what he would like to do with the audion. He had the idea that if he could obtain an audion that was not——

Mr. Haight: I think this is immaterial. I have no objection to his statement that Alexanderson told him what he wanted to do with the audion, provided that was followed up by experiments by Dr. Langmuir.

THE COURT: I understand this is leading up to that.

MR. LUNT: That is exactly it.

MR. HAIGHT: But they are going around to get there.

THE COURT: I think not too far to make clear the particular thing that Alexanderson desired to do. I think, just now the objection will be overruled.

MR. HAIGHT: Yes, sir.

A. (Continued.) Mr. Alexanderson had the idea that if he could obtain——

By THE COURT:

Q. 108. Do you mean "he told me"?

A. Yes. Perhaps my statement was a non-legal way of expressing what I mean. Mr. Alexanderson told me that he wanted to use an audion if an audion could be obtained that was not "sluggish" in its action, for the purpose of using what he called tuning in geometrical progression. He wished to use a series of audions, the grid circuit of each one except the first being coupled with the plate circuit of the preceding one in such a way that the audions could be used to amplify the radio frequency impulses received from the antenna. And it was his intention to tune each of these circuits, each of the plate circuits, in such a way as to get additional selectivity. He wanted to get a radio receiving system which would be more selective than any that had been used up to that time. He believed that that could not be done with the ordinary audion because he had heard that it was very sluggish in its action.

I told him of the work that we had been doing with high vacuum discharges and that in devices that we had made there were no positive ions that affected the operation of the discharge and that in our device or the tubes that I had made the current was carried solely by electrons and the current would respond to voltages on the electrodes practically instantaneously.

I thought and told him that any sluggishness that might exist in the audion would be due to positive ion effect, a gas effect, for I knew that the masses of the positive ions were so much greater than those of the electrons that they would be slow to respond,—comparatively slow to respond to electrical impulses.

Alexanderson said that he wished I could help him in this problem by building for him tubes that he could use which would respond to the high frequency or the radio frequency currents that he wished to amplify.

I might say that this thing that Alexanderson described to me in the middle of January is now spoken of as radio frequency amplification and is used in a very large proportion of the radio receiving sets today. Mr. Alexanderson offered to get me an audion from Mr. Hammond so that I could see how it was made and study its operation——

By Mr. Lunt:

Q. 109. May I interrupt you, Doctor? When was the date of this conversation?

A. About the middle of January, 1913. That is, there were two or three conversations I had. On February 4, 1913, I received a copy of a letter from Mr. Alexanderson describing in some detail the circuits that he intended to use for this tuning in geometrical progression, this highly selective system and at the same time, and certainly within a day of that time, I received the audion which——

Q. 110. May I interrupt you? What kind of an audion was this?

A. A regular DeForest audion which had been obtained by Mr. Alexanderson from Mr. John Hayes

Hammond, Jr. I had Mr. W. C. White test out this audion, study its characteristics, and I worked with him at that time in observing the characteristics of this audion.

I realized that the type of discharge made use of in that audion was very different indeed from that which I had been using in the tubes that I had made in November and in August, 1912. So during the early part of February, I decided that we would make some audions which would operate with the same pure electron discharge that I had become familiar with. I wanted to do this not only for Alexanderson but also to use in connection with the photo-electric cell which Dr. Dushman had been working with in the laboratory for some time previously.

I arranged that Mr. White should be transferred from the work that he had been doing, which I think was in connection with mercury rectifiers, so that he could spend all his time on the practical development of high vacuum audion.

Q. 111. What was the first device that you built?

A. Before Mr. White could exhaust such a tube it was necessary that he should put together an exhausting system for his own use. This would have taken a week or so and in the meantime my interest in the audions was such that I thought I would start a preliminary experiment with Mr. Sweetser, that is, I asked Mr. Sweetser to exhaust a tube which I had designed and had made up, which was very much like the DeForest audion that I had seen, that is, it had metal plates and a metal grid in the form of a zigzag wire and a nickel plate, but I wanted to get the gas out of the electrodes by heating them very hot during the exhaust.

I had seen Coolidge heat his electrodes to a dazzling white incandescence in his work with the old-fashioned X-ray tube and Coolidge was also working now with the hot cathode tube and heating his electrodes white hot by electron bombardment and I wished to do more or less the same thing, but my difficulty was that I could not draw large currents from the cathode.

So I realized that I needed high voltages, that is, high voltages compared with those with which I intended to operate the tube. However, I did not have available any such voltages that Coolidge had. He worked normally with 50,000 to 100,000 volts. I planned this tube in such a way that I could apply much higher voltages between these electrodes than would be possible with the DeForest audion and in the DeForest audion that I had, the terminals of all of the electrodes came out of a single glass tube side by side and close together so that it would not be practical to apply voltages of 100,000 volts. There would be too much danger of short circuit.

I built a tube which had four separate electrodes one filament, one grid and two plates and it was purely an experimental tube in order to get information. I brought the terminals for the four electrodes out at four opposite sides of the bulb. On page 228 of my notebook 413 is a sketch of the tube which I had made up on February 11, 1913, and in this tube, as I stated, the leads from each of these four parts come to bases at four different sides of the bulb, so that high voltages may be applied without sparking over.

As I say in my notes, that tube was made up for White to test out. I wanted to see whether it was going to be a practical matter to exhaust a tube of that character, with metal plate electrodes such as were used in the audion, but by improving the method of exhaust by going to high voltages. That tube was made up and I have a note of it on February 25, 1913, on page 305.

On February 25th I note that "Sweetser has been testing out the experimental relay tube" and on this afternoon I tested it out and then describe the test that I had made. At the end of that page it says, "This tube was exhausted three times to 425 degrees (one hour) the first time the filament burned out due to running too much as cathode in a vacuum of about one micron and with 1200 volts a. c. The blue glow discharge this time, as always, produced a disintegration of the filament. My audion experience thus far has been that a discharge in which there is a glow is always accompanied by more or less severe attack of the filament. On the other hand a straight non-luminous discharge (electrons only) does not injure the filament in the slightest."

The results obtained with this tube were very bad. We did not succeed in exhausting it even with 1200 volts and heating the electrodes red hot during the exhaust, we did not succeed in exhausting it to a point where it interested me at all and so we did practically nothing more with the tube.

I speak of the different exhaust treatments. On page 308 I said:

> "The third time the lamp was exhausted to 0.1 microns, then nitrogen at about 1 millimeter was let in and a D. C. (rectified A. C.) current from 1400 volt source was used between electrodes to heat them each to redness for a few minutes. Then the whole was pumped again to 0.1 microns and the filament heated (this time a five mill filament was used). It was found that if no voltage was applied to the plates (that is no Edison current) that the vacuum would remain indefinitely at 0.1 microns while the filament was being heated. But if the voltage (positive) was applied to any of the plates (or grid) that the pressure would immediately rise even when very small currents flowed and blue glow also appeared when the voltage was 250 volts."

I heated the electrodes red hot by a discharge from the hot cathode in nitrogen in order to get sufficiently large currents. That is, I put in gas for the purpose of getting large currents to heat the electrodes with the voltages available. I got the electrodes red hot, exhausted down to one-tenth of a micron and found that the filament could be run without any increase in gas pressure, but just as soon as I put voltage on the electrodes the pressure as indicated by the gauge rose to too high a value and blue glow appeared at 250 volts, which showed me very clearly that this was about as poor a method of exhausting a tube as we would well want to use, so that I made no further attempts at that time to build a tube of that character.

Instead of that I decided to use an anode which could be freed from gas by passing a current through it such as I had used in the work in August and in the different experiments that were made in November.

Q. 112. Let me ask you if and when you had occasion to work out the 3/2 power law?

A. About February 12, 1913, my notebook on page 287, then off and on to page 321, gives the derivation of the space charge equation for parallel plain electrodes and also for concentric cylinder electrodes. The first derivation which deals with the flow of current between parallel plain electrodes is the same as that which was derived in 1911 by Professor Child and published in the *Physical Review*. At that time, of course, I was not aware of Child's work. The second part of the derivation, however, which deals with concentric cylinders was new, that is as far as I know, nobody had worked it out. I published the result before anyone else had written about it or any one else had published it.

Q. 113. I now hand you Plaintiff's Exhibit 105.

A. I would like to add something to the last answer.

Q. 114. You may go ahead.

A. I said that this was worked out on February 12th, but the entries, the description of it was made on February 18th according to the notebook.

Q. 115. I now hand you Plaintiff's Exhibit 105. This was known as Exhibit 85 in the Interference, tungsten wire audion No. 2. Do you recognize it?

A. Yes, I recognize this tube.

Q. 116. What can you tell us of its origin?

A. It was the first tube that was made which involved the use of an anode which could be heated to very high temperature to free it from gas. I made this tube myself with the help of a glassblower and have made an entry to that effect in my notebook 558, under date of May 12, 1913. On pages 9 and 10 of this notebook are sketches and data describing the construction of this tube which was designated as tube No. 2. At the beginning of these entries is the statement in the notebook, "Improved form of audion. Yesterday and today I made up with Lindsley the following improved form of audion." Then follows a description of the tube and sketches.

By Mr. Lunt:

Q. 117. When was the construction of this tube completed?

A. Why, within a very few days after that, the tube was exhausted by Mr. White and myself with the new vacuum system which White had constructed for the purpose. On page 11 of my notebook under the date of March 14th is the entry:

> "Yesterday we completed the improved audion described on pages 9-10 and sealed onto new pumping system."

Q. 118. I would like to have you briefly describe the audion, the construction of it?

Mr. Haight: Describe what audion?

Mr. Lunt: This audion.

A. The filament——

Mr. Haight: I was wondering whether that was not all in the notebook and I do not object to the reference to the notebook for that very purpose. I thought that would save time, and it would be in there more compactly than the other way.

The Witness: May I read it?

Mr. Lunt: You may refer to your notebook.

Mr. Haight: If that is just there, anybody can read it at any time.

Mr. Lunt: Very well.

Q. 119. Will you please explain what the present condition of Exhibit 105 is?

A. Evidently it has received a very severe jar, for the glass frame holding the electrodes in position has been broken in many places. I would like to add the point in connection with this tube which I do not believe is described in the notes, and that is, that all the wires connecting to the filament and the terminals of the electrodes are made of platinum.

Q. 120. I understood you to say that you had this tested?

A. Mr. White and I tested this tube. I think just as soon as it was exhausted.

Q. 121. And you were present at the tests?

A. Most of them.

Q. 122. Yes. Were any records made of that test?

A. Mr. White had kept the notes of the tests that were made and the characteristics obtained.

Q. 123. Have they been preserved?

A. In my own notebook on page 29, I made an entry:

"White has been testing out tube No. 2, and determined the characteristics. I think we can obtain simple relations and can express all the features of an audion by three or four constants."

Q. 124. Have these records been preserved; if so, please produce them?

Mr. Haight: What records do you mean, Mr. Lunt?

Mr. Lunt: The records of the test.

Mr. Haight: Made by Dr. Langmuir?

Mr. Lunt: Yes.

A. These notes were not recorded by me. They were recorded by Mr. White.

Q. 125. Those were the records, I understand it, of the test made by you and Mr. White together? You worked together?

A. We worked together in obtaining this data.

Mr. Haight: The data is recorded by Mr. White, you say?

The Witness: These are all Mr. White's notes, yes.

Mr. Haight: And you have no independent recollection of the results of the tests?

The Witness: Not the figures.

Mr. Haight: That is what I mean. I understand——

The Court: That seems to bring out a new factor. Do you press or withdraw your objection?

Mr. Haight: I am not objecting. I understand from Mr. Davis that they are going to produce Mr. White to substantiate and verify these notes, and upon that assurance I have no objection to Dr Langmuir referring to them and giving his scientific conclusions therefrom, if that is the purpose of the question now.

The Court: All right.

AFTER RECESS.

MR. LUNT: I think it has been stated, your Honor, that to take care of the question of order which now arises, we propose later to call Mr. White, who made the records.

THE COURT: Very well.

MR. LUNT: I presume these records may be put in.

THE COURT: And you will satisfy them by establishing Mr. White's testimony later.

By MR. LUNT:

Q. 126. I will now ask you to explain in what way these test records of audion No. 2, Plaintiff's Exhibit No. 131 shed light on the condition of audion No. 2, when the tests were made. Before you begin your answer will you state how many pages there are in this record, and identify them so that we can have a record of what they consist?

A. These notes that cover the data that were taken on the characteristics of audion No. 2 and the description of the exhaust schedule to which this tube was subjected on the 13th and 14th of March, 1913——

Q. 127. What is the number of that sheet?

A. Are——

Q. 128. Are S. W. 77?

A. S. W.-77. The other sheets are 78, 79, 80 and 81, all these numbers being preceded by the letters "R. S. W.," which mean "Record Sheet, White." That is of White. There is also some data obtained with this same audion on May 23, 1913, which are recorded on R. S. W. 98.

MR. LUNT: I think through an oversight, there were no photostats made of them. I do not know how it happened.

THE COURT: I see.

The Witness: There are only one or two points on 98 that are important.

Q. 129. Will you proceed with your answer and explain what these sheets show and indicate to you as to the condition of audion No. 2, when the tests were made?

A. The tests were of several kinds in general. The plate voltage was held constant at some voltage up to 235 volts and the grid potential was changed in steps and the grid current and the plate current were measured, that is, these sheets contain operating data of the tube under conditions like those which were to be used in its operation.

There are also several sets of readings that show how the total current varied with the filament temperature. Those only give an indication of the emission from the filament and are not particularly significant as indicating the purity of the electron discharge. The data that were taken showing the variation of the plate and grid currents with the grid potential were practically all obtained while the filament temperature was close to 2500 degrees. That is, either 2480 degrees or 2500 degres. And at that temperature the emission was over thirty milliamperes, thirty to thirty-five milliamperes.

The first sheet R. S. W. 77 describes the exhaust of the tube showing that the tube was baked out at 350 degrees from eight o'clock in the morning, that is, the oven was started at eight o'clock in the morning and at half-past eight it had reached 330 degrees and from 8.40 until 11.15 the temperature was maintained at about 350 degrees. The pump was left running from nine o'clock on. While the lamp was hot or the bulb was hot' the pressure was about .02 micron and then the tube was finally sealed off at 0.05 micron after the plate filament, that is, the anode filament and the cathode filament had been "flashed well."

The data on the volt ampere characteristics of this filament, practically under operating conditions, have been summarized by a plot of the currents against the grid voltages which I present herewith. The abscissæ are grid voltages and as ordinates the space current, to the 2/3 power, is plotted. There are in all four curves at four different voltages, 50 volts, 75 volts, 115 volts and 235 volts on the plate.

In all except this last case the plate currents and the grid currents were both recorded and I have plotted in these cases the 2/3 power of the total currents, that is the sum of the currents to the grid and the plate. In the last case, however, when the plate voltage was 235 volts, measurements were taken only of the plate current, the grid current not being recorded.

According to the 3/2 power law, as modified or extended to cover a three-electrode tube, the two-thirds power of the total current should give a straight line when plotted either against the grid voltages or the plate voltages. We see in fact from these curves that the currents do vary in this way with the grid voltage, for the points at any given plate voltage lie very closely on a straight line, as close as could be expected in view of the fact that the plate voltages were obtained from the ordinary shop line which was subject to some fluctuation.

The curve for the highest plate voltage at 235 volts gives a straight line up to about twelve volts on the grid and then the currents are not quite as large as would be expected according to the straight line plot, but they fall too low, but the amounts by which they fall too low are just about what should be expected because of the fact that the total current is not recorded but only the plate current.

As an indication of this I have put on this curve, above the curves at the point over the abscissæ of about plus two volts, a note giving the magnitude of the grid current when the plate voltage was 115. It is seen that the magnitude of the grid current is just about enough when added to the current observed from the plate only, with the plate voltage at 235, to bring these points up on to a straight line.

The significant point about all these curves is: First, that they follow closely the 2/3 power law, which in a device of this sort is the law of a pure electron discharge in that these lines are straight; second, that these lines all have the same slope, they are parallel lines which again is in accordance with the law of the three-electrode tubes. And finally and perhaps most important of all, there is no upward bend of these curves which would be characteristic of ionization or the gradual elimination of space charge by ionization as the ionization increases with increase of voltage or increase of current.

I do not know whether that has been made clear to your Honor that the 3/2 power law or the 2/3 power law which gives, when plotted in a proper way, a straight line, is characteristic of the pure electron discharge in the absence of ionization where the currents are limited by space charge; and that if ionization is present it will be present in different amounts at different voltages.

As you raise the voltage and therefore raise the current there will be more ionization. Below the ionizing voltage there is no ionization at all. As you raise the voltage and raise the current there will be more and more ionization and therefore the departures from the 3/2 power law will always be in the positive direction, that is, the currents will be larger than you expect and more so the higher the voltage until you tend to get to saturation, and therefore, the characteristic effect of ionization will be an upward bending of the curves beginning somewhat above the ionizing voltage. Those effects are entirely absent in the characteristics of this tube.

Those facts prove to me conclusively that this tube operated with currents from ten to fifteen milliamperes with plate voltage up to 235 volts, in such a way that the currents were limited by space charge substantially independently of and free from the effects of positive ionization.

There are a few more tests that these characteristics can be put to. For example, we can plot certain of the data in the ordinary way on double logarithmic paper, that is not plotting the 2/3 power of the current but the logarithm of the current against the logarithm of the voltage and getting a straight line on double logarithmic paper. The line in that case would have a definite slope, 3/2. The only case in which plots can be made in this way, however, are when there is only one effective voltage on the tube, that is, either the plate must be connected to the grid so that there is in effect only one anode or either the plate or the grid must be connected to the cathode.

In all three of these cases, there is only one voltage that varies.

Now, from these curves we can read off and we can also obtain directly from the recorded values of the current and voltage, we can read off the currents that correspond to zero grid volts. That is, at zero grid volts, there are four points that would determine the current; 50, 75, 115 and 235 volts. So those four points can be plotted against the corresponding plate voltages on double logarithmic paper, and it will be seen that the four points which range then from 50 volts to 235, do lie on a straight line on double logarithmic paper; again indicating that there is no ionization in sufficient amount to affect the characteristics of the discharge and limited by space charge. Now, there is one other——

Mr. Lunt: To avoid confusion, I would like to offer in evidence at this time, the first plot produced, the 2/3 power plot, and have that marked as Plaintiff's exhibit.

(Received in evidence and marked "Plaintiff's Exhibit No. 164." *See Volume IV, Plaintiff's Exhibits, page 46.*)

Mr. Lunt: And the second plot produced, which I think is a 3/2 power plot, and have the same marked "Plaintiff's Exhibit No. 165."

(Received in evidence and marked "Plaintiff's Exhibit No. 165." *See Volume IV, Plaintiff's Exhibits, page 47.*)

The Witness: Might I add that on the margins of the first of these plots, the left-hand margin gives the ordinates in terms of the 2/3 power of the current, while on the right-hand margin are the figures of the milliamperes expressed directly, these of course not being arranged according to a uniform scale. But it is convenient for reference to indicate the magnitude of the currents at any point on the curves.

I have here also a third plot which you obtain from the data given on R.S.W. 78 taken on March 17, 1913. These were obtained with the plate and grid connected together electrically, so that they were at the same potential. However, the current recorded is the plate current only. Assuming as is generally justified in a case of this kind that the current divides itself in a fixed ratio between the grid and the plate circuits, we may plot the plate current as a function of the voltage on the plate and grid, and should obtain a straight line on double logarithmic paper whose slope is 3/2. It will be seen that the points do, in effect, go on the straight line when they are plotted in this way. The currents agree quite well with the 3/2 power law up to 50 volts, and a current of thirty-one milliamperes. Above that voltage and current the currents tend to become limited by saturation of the filament, these being rather large currents for a device of this size. There is a slight upward bend from forty to fifty volts which amounts to about 10 per cent. I do not believe that this is due to ionization in this tube, although the tube is being considerably overloaded in regard to current at that time. My reason for this is that the records show that as the voltage was raised to forty volts, the instrument reading the current was changed at that time to another instrument and by comparing the readings taken with the same instrument in other places on these records, I notice that when the change is made to that particular instrument, there is always a larger current; so I believe that the calibration of that instrument was in error by an amount that approximately is responsible in large part for the 10 per cent. increase in current on this point.

Q. 130. Where do you get that from on the record sheets themselves?

A. It occurs on the last of the four lines of R. S. W. 78. On the margin is marked "K is equal to 1"; whereas in the figures preceding that is the note: "K is equal to 1.07." Those values of K refer to the calibration constants of the two instruments that were used for measuring these plate and grid currents. There is also a third instrument used for measuring very much smaller currents, having a different value of K. It is clear from these notes that when the reading of forty volts was reached, the instrument was changed. I might say that I remember distinctly that at that time we were not using very carefully calibrated instruments, and further than that the instruments were not usually of uniform accuracy over the whole range of the scale, so that when we shifted from one instrument to another it was very common to observe a break in the curve.

Q. 131. Will you explain how you get the data of plotting Exhibit 165?

A. These points are obtained by picking out from the original data the currents that is, the plate currents corresponding to the four points on Exhibit 164 for which the grid volts were zero. These four points can also be obtained directly from the record sheets by picking out one point from each of the four runs, namely, the point at which the grid volts are zero.

For example, at the top of R. S. W. 79, the first line among the series of measurements for which the plate voltage was 115 was at grid volts of zero volts and current under the heading Edison current milliamperes is recorded as 0.963. That is the current that is plotted for the point at 115 volts on the Exhibit 165 and so on each of the other points obtained in a similar manner from the records at the voltage in question.

I might mention that the energies involved in this discharge were fairly large. For example, take the uppermost point when 235 volts was used on the plate, the plate current was a little over fifteen milliamperes so that corresponds to a wattage liberated at the anode of 3.5 watts. And that is the energy of the discharge in the plate circuit alone was 3½ watts.

When the anode and grid were connected together so that thirty milliamperes were obtained at fifty volts there is 1½ watts in the discharge. At these times, that is, when these currents and voltages were employed just mentioned, the currents were limited by space charge, that is, they were on the operating range of the audion, not currents limited by the emission of the filament.

Q. 132. How do you determine that?

A. From the fact that it is on the sloping part of the curve before the saturation has been reached where the currents are still following the 3/2 power law.

Q. 133. I do not remember that you have described how you obtained the points indicated by a cross on Exhibit 164. Will you please do so if you have not already done so?

A. All the points which are marked by small circles on these plots were taken from record sheets 78 to 81 and which were recorded on the days from the 17th to the 20th of March, 1913. I have not been able to find any subsequent determinations of the characteristics of this tube in a way in which I can plot on these same sheets for comparison except a point taken on record sheet 98, and even that is not strictly comparable for the voltage was then not 235 but 220. However, that voltage is sufficiently close to make a fairly good comparison.

The point marked by a cross on Exhibit 164 was obtained on the 23d of May as recorded on record sheet 98 and it is seen that the point fits in with the rest of the data showing that there has been no appreciable change in the characteristics of the tube during this time although the current is small, it is due to the relatively large negative voltage on the grid during the subsequent measurement, but it should be noted that the plate voltage is 220 volts, so that if ionization had been present in appreciable amounts the point would not have fitted on the curve as well as it does.

Mr. Lunt: I offer in evidence the last plot produced by the witness and ask that it be numbered Plaintiff's Exhibit 166, plot of volts on plate and grid against current.

(Received in evidence and marked "Plaintiff's Exhibit No. 166." *See Volume IV, Plaintiff's Exhibits, page 48.*)

Q. 134. Are there any other records of the testing and subsequent history of audion No. 2 so far as you know?

A. There are many references to the further use of audion No. 2 in Mr. White's notebook.

Q. 135. Are there any further references to it in your own notebook?

A. I think there are.

Q. 136. May I call your attention to your notebook No. 458, Plaintiff's Exhibit 131, and I will ask you whether pages 31, 34 and 36 have anything to do with this matter?

A. Yes. On page 31 of my notebook 458 I stated: "Day before yesterday White rigged up our tube No. 2 in this way." That was to test out this device as a detector for alternating current signals.

Q. 137. Will you give the dates, please, as you go along?

A. That entry was made on March 21, 1913. On page 35 of the same notebook under the same date I refer to this audion again and to explain the reference I must read a little of the preceding page in the notebook. I had stated on that page what was my general plan at that time, and that was to develop a new type of audion. I say, for example:

> "Now, what I intend to do is to construct an audion which will operate entirely and exclusively on the electron discharge. I shall attempt to get a vacuum so good that positive ions are present in neglible amounts. This means, of

> course, that we must also have the electrodes reasonably free from gas, so that the discharge follows the law."

And then follows the equation which we now speak of as the 3/2 power law, the coefficients of the equation being also given.

And then I say that to get as great sensitiveness as exists in the DeForest audion which depends upon gas effect, it will probably be necessary to redesign the tube. I state: "I expect to very greatly increase sensitiveness (this we have already done with No. 2 which appears to be three to four times more sensitive than the DeForest audion)."

I also discuss at that point the question of the sluggishness of the new device as compared with the audion and I point out that with electrons "moving with the velocity of about 10^8 centimeters per second (as we are) and with a path of only about one millimeter we should be able to make the audion respond to oscillation even as rapid as 10^9 cycles per second." That is one thousand million cycles per second. That was based on the theory which enabled me to calculate the velocity with which electrons moved in such a tube. Knowing that the electrons were the only carriers that needed to be considered and knowing how fast they could move I was able to calculate how rapidly they could respond to the voltages which would be applied to the electrodes.

I might mention that audions have been used to frequencies very nearly as high as that, that is, up to frequencies of several hundred million cycles per second.

Q. 138. I believe you have mentioned a notebook of Mr. White. Did this contain records relating to this general matter including records as to this audion No. 2?

A. Mr. White was my assistant during all these months, in fact, during that year, I think, and the year afterwards, and was testing all the circuits which I was interested in or which I devised and which I wished to have tested and the results of all such tests were recorded in his notebook. From time to time, for some reason, some of these data were given in my own notebook, but in most cases the details are in Mr. White's notebook.

Q. 139. Was it his duty to keep the notebook?

A. Yes, as part of his regular laboratory work.

Q. 140. I hand you a book. Do you recognize it?

A. Yes, this is Mr. White's notebook that was kept from January 28, 1913, to April 14, 1924.

Mr. Lunt: If your Honor please, we come again to a question of order and I would like to state that we expect to call Mr. White who will testify as to this notebook.

The Court: I will take, in the absence of objection, the witness's testimony based thereon, conditioned to the subsequent establishment of the accuracy of the notebook.

Mr. Lunt: Mr. White is not here in any event, and we did not like to bring him down just before Election Day.

Q. 141. I wish you would consult that notebook and refer to any statements therein which shed light upon the qualities and the history and general mode of operation of audion No. 2?

By Mr. Lunt:

Q. 142. Will you give the pages and the dates in the notebook as you go along?

A. This is notebook 452. On page 20, under date of Monday, February 10, 1913, there is the note: "Spent afternoon in conversation with Dr. Langmuir in regard to some experiments I am to try with the DeForest audion." I might say that up to that time Mr. White had been working mostly on mercury rectifiers and work that had nothing to do with any of my work. I remember at that time I was becoming very much interested in the audion. I just received the audion a few days before and had arranged with Dr. Whitney to have Dr. White spend his time in the study of this device and in making others which would help me with the ideas that I had developed the preceding month.

On page 43, under date of April 7th, there is a diagram of a circuit in which two audions are illustrated and one of these is marked audion No. 2. The diagram also shows that 250 volt shop is connected between the filament and the plate of this audion.

Q. 143. Pardon me, will you explain what is meant by shop?

A. By that we mean the direct current supply lines that were used throughout the laboratory as sources of power and for experimental purposes.

The other audion is marked No. 6, at the top of the page there is the entry: "Dr. Langmuir suggested a D C transformer. Used the following arrangement to step up D C voltage."

I might say that I was very much interested at that time in developing possibly ultimate power applications of audions, because I realized that there was now no upper limit to the voltage that I would be able to supply by such devices.

I was beginning to think of using 10,000, 50,000 and 100,000 volts on audions and I foresaw that with such voltages and the currents that I would then be able to get, that very large amounts of power could conceivably be controlled, and that meant that the conversion of direct current of one voltage to direct current on a higher voltage might be a very important application for these three-electrode tubes; and this was a circuit to test out on a small scale its effectiveness in such conversion of direct current of one voltage to direct current of another voltage. Then follow a great many details of the way the apparatus was set up. I do not want to go into that at all, but will simply indicate that the plate circuit was connected with one of the coils on a very high voltage transformer, a high inductance coil, and the plate current was sent through that coil, the idea being that by suddenly applying negative voltages to the grid, the current through the device could be suddenly stopped. That is, with a negative voltage on the grid, the current would no longer flow, and when you interrupt suddenly the current through a large inductance, you get a spark or a very high voltage developed across those terminals.

Now, we tried that out. I remember working with White on that circuit and seeing the results. He says at the bottom of page 43:

> "The higher voltage thus obtained would just about jump the smallest gap we could arrange so potential was probably about 350-400 volts. After a few tests blue glow began to appear, so discontinued these tests on these low voltage audions."

Now, I believe the voltage on the coil was a good deal higher than 400 volts that was produced by the interruption of this current; but even with that 400 volts, the tube was being obviously very seriously overloaded. It is more probable to believe that the voltages were over a thousand volts. Now, it was noted just after that, that that particular circular was discontinued. We continued, however, using that tube for the purpose of getting high voltages.

Q. 144. May I interrupt you? Did you give the page and the date?

A. Yes.

Q. 145. I did not get it.

A. On the next page, which is page 44, still under the date of April 7, is the note:

> "Tried the following arrangement suggested by Dr. Langmuir to get single high voltage impulses."

And then there follows another diagram showing audion No. 2 still used with 250 volt shop line, that is, 250 volts on the plate, and with a circuit by which instead of putting alternating current on the grid, as we had before, we put on high voltage surges of direct current, sixty volts negative and 180 volts positive to the grid (through a resistance of 30,000 ohms in each case, so that large currents would not flow), the object being to control the current to the plate.

Now, at the bottom of that page, the results are stated thus:

> "About twenty-five mil-amps was passed thru L when grid was positive."

That means that the plate current in the audion on the 250 volt circuit was twenty-five milliamperes and that that twenty-five milliamperes was passing through the large inductance L. Then it was stated really just above the last statement that I quoted, that when the grid potential was so altered by closing a switch and applying the negative potential to the grid:

> "Sparks of 0.3 mm. could be produced from the 250 V. shop."

That is, we were passing twenty-five milliamperes through the tube and were interrupting that current so suddenly that sparks of three-tenths of a millimeter were produced between wires that were spread apart that distance. I remember ~~these tests~~ distinctly and remember the sparks that we saw at that time. Voltages that will cause sparks to jump three-tenths of a millimeter between wires are of the order of 1,500 to 2,000 volts, probably well over 1,500 volts; but there is no mention in these notes of any further trouble from blue glow. However, whether it occurred or not, it seems to me is quite immaterial, because the tube had never been designed for 1,500 volts. It had been designed to operate on 250 volts. After using the tube, however in this way, with twenty-five milliamperes and voltages up to 1500 volts, the tube was continued in use almost indefinitely. That is, it was used for several months thereafter, on pretty nearly all the tests where we needed to use these audions. I will refer to several of these.

Just one other entry in the notebook although it does not relate to No. 2, I would like to mention if I may at this time.

Q. 146. All right.

A. And that is, on the bottom of page 46 is the statement:

> "Wired up a 10 K. V. A. 40,000 V. transformer with regulator (induction) and resistance in secondary, to be used on high voltage audion relays, ect."

I think it is "set." It looks like "etc." more than anything else, but I think it means "set." I remember the setting up of that transformer very well indeed and I remember the object for which I had it used. It was a large transformer that was over four feet long, and the tank part of it stood about three and one-half feet high with eight high voltage bushings that reached about five feet from the floor. This was a ten kilowatt transformer, and we spent some time in setting this up for the purpose of developing audions that would operate at voltages up to 40,000 volts, because I was interested in having audions that would really control large amounts of power. Although in White's original work with these small devices, he had been using, as a standard voltage of operation, 250 volts and currents up to five or ten or twenty-five milliamperes, I wanted to work with currents of hundreds of milliamperes and tens of thousands of volts. So we had this transformer installed, so that experiments could begin in the exhausting of these tubes and their operation at these high voltages.

I do not believe I gave the date of that last reference. That was the same date as those other references namely, the seventh of April, 1913.

Now, on page 57, under the date of April 28th to May 10th—I suppose that means that the notes were made on May 10th——

Q. 147. Still 1913?

A. Still 1913,—is the statement:

> "Made some tests on audion No. 2 to get total currents obtained from filament."

Now, on page 121 under the date of July 21, to July 26, 1913, is a description of a circuit to be used as a detector and at the bottom of the page is the statement:

> "With this arrangement tested out audion #2 as a multiplier of oscillations."

On the upper part of page 122 is the diagram of the circuit showing audion No. 2 labelled No. 2, connected to 240 volts and on the margin is a note:

"Written July 28th, 1913."

Now, lower down on that page, after describing the circuit in more detail, is the statement:

> "This method may be of value as the hot cathode bulb has so far proved to be a very good amplifier. No. 2 is not the best we have so that we should be able to increase the ratio to ten to one."

Of course, all through this notebook there are many references to other audions besides No. 2; but I am just picking out those that deal with No. 2. On page 125, under the date July 28 to August 2, 1913, is the statement:

> "Dushman has found that when an inductance is placed in grid circuit oscillations are set up which are amplified in the plate circuit, tried to detect these oscillations on one of our small audions #2."

And then follows a diagram of connections showing audion No. 2 again with 220 volts on the plate circuit. Then quoting again:

> "Found that this arrangement gave oscillations of 126,000 cycles per second."

I might say that this method of producing self-sustaining oscillations with the audion was worked out—we had worked up the circuits some months previously, and Dushman had used a very large power tube which produced these oscillations, and White was using his audion No. 2 in order to measure the frequency and the power of these oscillations, not measure the power quantitatively but to get a rough idea of it.

Now, on page 149, under the date August 11th to August 16th, 1913, there is a diagram of another circuit in which audion No. 2 itself was used to produce oscillations—no, I am wrong—I think there is a generator producing the oscillations, and this tube was used to detect the oscillations, on what is now known as the Armstrong regenerative coupling circuit. That is, he had the plate and the grid coupled together and this circuit diagram shows a plate voltage of 250 volts on audion No. 2. The audion was used to show the advantages of the coupling on the plate circuit with the grid circuit, the regenerative coupling, which is used so much in radio systems today.

Q. 148. Did you give the date?

A. Yes, I did. I think those are the only references I have been able to find to the use of audion No. 2. I might say that this audion was used for several months, and right up to the end of its life, it was a thoroughly reliable and good audion on 250 volts circuits. Of course, later on we had some others that would work with more current; but notwithstanding the fact that this tube had once shown blue glow—there is a statement there I would like to read here in which it is stated that that audion is the only one that had shown blue glow. I do not know what page it is.

(Here a short recess was taken.)

Q. 149. Have you finished your answer, and if not please proceed.

A. At page 66 of this notebook 452, there is the record of an unusual treatment that was given to the different audions. The different audions were placed in the interior of a coil of wire which was capable of giving quite a powerful magnetic field as is stated in the middle of page 66, and under these conditions the characteristics of the tube were studied particularly of their ability to detect radio signals or alternating currents.

No. 2 audion was tested in this way and on the following pages of the notebooks the results were discussed in some detail. Some very peculiar results were obtained.

On page 69, under date of May 27, 1913, it was stated: "Tested out all other available audions inside of a solenoid, but #2 was the only one that gave the discontinuity effect. Suspect the effect is due to positive ionization because"—and then follows a discussion of the reasons which make him think it is positive ionization, first that a kink occurs in the curve under certain conditions and that there is a lag effect —these are characteristics which it has in the magnetic field; and second: "For no apparent reason the effect will sometimes mysteriously disappear and later just as mysteriously appear again."

And then again it is stated:

> "This audion No. 2 is the only one which shows effect and is the only one we have which has shown blue glow since sealing off. Therefore vacuum poorest of lot. This being the case it is not advisable to follow this thing up at present."

Mr. Haight: I think that that statement should not be read into the record.

The Court: That is an expression of view rather than a statement of fact, as I interpret it. Is that your objection?

Mr. Haight: Yes, sir, and then the further statement: "This is the only one which has shown blue glow" or something to that effect.

Mr. Lunt: That is a statement of fact.

The Court: I think there is involved there a lot of expert conclusion on the part of Mr. White, is there not?

Mr. Lunt: It is an observation which he made as to whether the blue appearance took place in the bulb.

The Court: That appears to be a reading of the entry anyway. If you stop there—

The Witness: I have not quite finished.

The Court: As it now stands no value has been added to the exhibit by a portion of it being copied by the stenographer. Judge Haight must depend on what the witness said now as to whether the objection should be sustained or not.

Mr. Haight: Yes, sir.

The Court: May I say this to you, Dr. Langmuir, for your guidance. If it is your thought to say something which is based on an expression of opinion then that cannot be done. If you are predicating your conclusions upon a statement of fact by Mr. White that is all right.

A. (Continued) This phenomenon which was observed at this time was one which he studied in a good deal of detail some months later and it finally resulted in his taking out or filing a patent on a device which contained a very low pressure of mercury vapor. Those tubes made in that way did make use of the mercury vapor probably, because of the ionization produced by it. This tube showed this effect only in the presence of a small magnetic field and although it is my opinion that under these conditions the phenomenon that he had observed were due to minute traces of positive ionization, it is very clear to me that these did not affect the ordinary operation of the tube when it was not in the magnetic field, and from the fact that this tube was used repeatedly over long periods of time as an amplifier with 250 volts on the plate and chosen when other tubes were available for the tests of the various circuits which were used, proves that this tube operated as an amplifier as a pure electron device with these high voltages and currents.

I want to point out that 250 volts is a high voltage and with large currents of many milliamperes that we used, if there had been any appreciable amount of ionization it would have been a serious matter and would have prevented the operation of the tubes in the uses to which it was put.

For example, any even partial elimination of space charge would have caused the current to rise to the saturation value far below 250 volts and if that had occurred the tube could not have been used as an amplifier. For example, in the old DeForest audion the tube could ordinarily not be used as an amplifier or detector at voltages over 30 and sometimes at 25 volts or 40 volts the current would become limited by saturation because space charge would not be effective and the current would rise to the saturation value. The potential on the grid or plate would then not be able to control the current and its usefulness as an amplifier or detector would disappear.

Q. 150. Let us go back to your notebook No. 458, Plaintiff's Exhibit 131, and will you refer to page 48 of this notebook and tell us what is referred to therein and your recollection as to it.

A. On page 48, under date of April 7, 1913, I refer to White having tried out the D.C. transformer and I show the diagram with the audion connected to 250-volt shop line and a spark gap arranged across the terminal of the inductance. Then on the next page I describe the other circuit which White and I tried out, in which there is slightly different connection. I do not need to describe it in detail but say that White further tried out the following connection. I have just shown from White's notebook that it was audion No. 2 that was used in these two tests.

Q. 151-54. Will you refer to page 79 of the same notebook and I think you will find some reference to Wien. Please tell us who was Wien?

A. Professor Wilhelm Wien was a very well known Physicist who had received the Nobel Prize in 1911 for his work on Radiation of Light. He gave a series of lectures in Columbia University in the spring of 1913, and Dr. Dushman and I attended some of these lectures. I fix the date of this entry on page 79 under April 30, 1913:

> "On Monday went down to New York to the last of Wien's lectures. On the way back had talk with Dushman as result of which I saw Whitney yesterday and came to following decision, etc.: Dushman will work with White and me on D.C. transformer. Work to be arranged thus:
>
> "White will develop audions for wireless and relay for low voltages and low currents.
>
> "Dushman will take up work with the new Gaede pump and work on high voltage, hot cathode rectifier and relay."

And then further details are given as to the work that had been lined out for Dr. Dushman. I remember particularly the reason or the thing that made me get interested in having Dushman start work at this time, and that was in connection with these lectures of Professor Wien. After this lecture, we invited Professor Wien to the Manhattan Hotel in New York City. Dr. Dushman and I did, and we spent the evening with him and found him a most delightful man and had long conversations on scientific work, and the thing that impressed me particularly, after I had described the work that we had been doing in the laboratory to him, with pure electron current, . . .

[At this point the witness began to testify to a statement made by Prof. Wein, and thereupon counsel for defendant objected, and after argument, the question of admissibility of the testimony was laid over for further argument and consideration.]

By Mr. Lunt:

Q. 155. Now, will you refer to page 101 of this same notebook, No. 458, Exhibit 131, and explain the significance of the statement that you find there?

A. On page 101?

Q. 156. Page 101?

Mr. Haight: May we have a copy of that?

A. On page 101, under the date May 12, 1913, is the entry:

> "Today White and I tested out one of his new audions with high frequency currents (about 75,000 cycles).
>
> "The results were exactly as I had expected and help to prove the correctness of my theories as to the action of these relays."

And then there follows a diagram of the connections which were used for amplifying these radio frequency currents. Now, the object of this work was to try out Alexanderson's scheme of radio frequency amplification. The notebook on the preceding page refers to Alexanderson and Day having come over and I showed them several of the audions that we had made up.

After the diagram, there is a table which defines the different parts of the diagram, and the B battery, that is the plate battery, as marked by the symbol J, and on the next page, 102, it is stated that this battery J is a storage battery of 120 volts. These tests were not made in our laboratory. They were made in Alexderson's laboratory, which was in another place. I remember that very distinctly, using the Alexanderson alternator two kilowatt—100,000—cycle alternator as a source of power and amplifying the currents and reading them on a sensitive millivolt meter used as an ammeter.

On page 112 under the same date, May 12th, I give in more detail the diagram of the connections which were to be used for the test of the geometrical tuning circuits of Alexanderson. That circuit is described there.

Then on page 130, under the date of May 18th, is a summary of the work that we have just completed on Alexanderson's tuning in geometrical progression, and I stated there that it was demonstrated that the thing worked as predicted and lower down on the page it is stated:

"A hot cathode relay like that we have made responds perfectly to frequencies as high as 105,000 cycles. No sluggishness noticeable," and so forth. And then a statement that it would be good until ten million cycles.

Q. 157. What did you mean by the statement like that you had made?

A. The type of audions we had been using with White, that White had been making up like the audion No. 2. That was the type of audion used in these tests.

On page 131, continuing is a description of a further application of these tubes that is planned at that time. It is stated:

> "We can obtain A. C. of high frequency from a D. C. source of power by such a relay. Thus the batteries J supply the power for the A. C. current."

And then below a couple of sentences that are not pertinent and then:

> "It simply remains now to carry this out on a larger scale with higher voltages and higher currents and thus to obtain higher efficiencies. Dushman will carry on this work. Of course by a rectifier we can obtain D. C. from the A. C. circuit."

On page 132 it is stated:

> "Tuning by geometrical progression according to Alexanderson's scheme is an accomplished fact."

Q. 158. What did you mean by that?

A. We had just completed our tests with Alexanderson in which we had to study the selectivity of the system showing that by means of radio frequency amplification with the circuits in ~~each audion~~ tuned for the radio frequency we were able to obtain a selectivity for a given signal much higher than we had ever been able to obtain by any other circuits and together with the advantage that the system had a certain breadth of band in which it was sensitive. There was a certain range of frequencies for which the device had an unusually high sensitiveness and on both sides of that it was remarkably insensitive.

It is just those advantages that we found at that time and demonstrated that have made the radio frequency amplification so very important today in the radio field. This was done with audions of the character of audion No. 2 and I think would only have been possible with such audions. I do not think we could have made any of those tests, at least I thought so at the time, that I could not have been able to make any such tests without the character of audions that we were then using.

Q. 159. Was Dr. Alexanderson present at this demonstration of the geometrical tuning?

A. I do not think he was present at the last part of it. Those tests extended over several days and I think he was present at the first part before we completed them. I think he was present while we were showing that the audion could respond and could amplify radio frequency currents but at that time we did not have the whole set completed.

Q. 160. How long did this general demonstration take, or rather, over what period of time did it extend?

A. I think it was from about May 9th to May 18th.

Q. 161. Now, will you refer to page 138 of your notebook, Exhibit 131, and explain the significance of the entry on that page.

A. This describes a circuit in which a resistance is used in the plate circuit to couple one audion with the next following one. That is to couple the plate circuit of one audion with the grid circuit of the other one, a resistance coupling was used. Several other times before, such circuits had been used, but this is the most practical form of circuit and it was this work which led to our filing an application on that form of coupling. It involved the use of this same audion.

Q. 162. Can you give us the date of that entry or when the work was done?

A. The date was May 18, 1913.

Q. 163. I hand you a copy of your patent, No. 1,297,188. Is this the patent referred to?

A. Yes.

Mr. Lunt: I offer it in evidence.

Mr. Haight: I do not see the materiality of it.

(Discussion.)

The Court: I do not believe that would let it in. I think the objection is well taken.

Q. 164. Will you now refer to page 156, of this notebook of yours, Exhibit 131, and state what the significance of the entry there is?

A. This simply refers to the fact that I spent part of the afternoon looking over White's curve on D. C. characteristics of twelve different audions that he has made up. The curves show that there is a linear relationship between the plate voltage and the grid voltage, that is, that the effect of the grid and plate can be replaced by a properly chosen average of the two. This is an experimental verification of the fact that I made use of this morning in deriving the 2/3 power law as applied to a three-electrode tube.

Q. 165. I think I have inadvertently passed over something that I wanted to refer to. Will you go back to page 111 and explain the significance of the entry there.

A. There is an entry on page 111, under date of May 12th, which was made at the time that we were working on radio frequency amplification where we used one of these high voltage audions to measure the radio wave lengths or radio frequencies. I say, "This afternoon the contrast between the beautiful reliability and accuracy of this form of wave measurer as compared with the ordinary wave detector was very apparent."

Q. 166. What was the date of that?

A. May 12, 1913.

Q. 167. Will you refer to pages 176 and 177 of Exhibit 131 and state briefly what are the plans for the use of audions there referred to?

A. On page 176, under date of June 17, 1913, after speaking of a new man who had come to work with White on audions, this man's name being William Rogers, I state: "At present the program is 1. Try out Alexanderson's plan of using telefone to control high frequency current and thus send telefone messages by wireless. White will try this out for short distances, etc., with ordinary audion and then we will get larger one (I will ask Dushman to make up one) that will handle say 40,000 volts and 0.5 amp. and this can then be used for actual long distance sending."

The ordinary audion that I referred to there is the improved form of audion which White had been using of the type of audion No. 2.

Mr. Haight: I suppose it is understood that Dr. Langmuir endorses on the stand all of these statements that he has been reading. I mean by that that they refresh his recollection to the extent that he can swear to the things that appear there.

The Witness: Yes.

Mr. Haight: I make that observation because it seems to me that the form of my friend's questions were based on the idea that the book was primary evidence and not the testimony of the witness.

Q. 168. Without going into detail, was the plan of White subsequently carried out?

A. Yes.

Q. 169. Will you refer to page 185 and give your recollection as to the matter there referred to?

A. On page 185, under date of June 18, 1913, I made the entry: "Dushman has made fine progress. He has the large audion in good working order. It consists of two tungsten plates and grid of 1.5 mil tungsten wire wound on one-quarter-inch rod for support and a filament about three inches long. There seems to be no difficulty in operating it at 20,000-40,000 volts and 0.1 amp."—(that is 100 milliamperes)—"(probably even at 0.5 amp.)."

I might say that that tube at that time was still connected to the pump. I remember that we had these electrodes in a bulb which was about six or seven inches in diameter with side arms which contained the leads of the terminals to the electrodes and that this was connected with a very large diameter tube connected to the Gaede molecular pump, which is a very high speed pump, pumping about fifteen or twenty times faster than any pump we had up to that time, and in order to utilize the full benefit of the speed of this pump, we had a tube which was probably an inch and a quarter in diameter running right up to the big audion. So that we could operate this audion on the pump without making any attempt at that time to seal it off.

In this way we could study the characteristics of this audion at high voltages even though gas was still coming slowly out of the electrodes. The gas was being removed by the pump as fast as it was coming out.

Our intention was to get the gas out of the tube sufficient to seal it off but before we reached that condition we would at least know something of the practical operation of the device.

We had our high voltage transformer and all the electrical circuit connected up and the Gaede molecular pump right in front of it and a gateway or screen fence around the whole thing so that no one would get hurt or injured by the high voltage current,—because it could have easily killed any one who would have touched it,—so that we had a great many safety appliances in connection with it.

Q. 170. Will you refer to page 193 and state what recollection you may have as to the matter there referred to? Please also give the date of that entry.

A. At page 192 under date of June 19th, is a summary of the different things that I planned out for Dushman to do in the way of building tubes of special construction and the use of circuits. The intention is stated to use much larger currents.

On page 193 among the list of things that are planned is the following:

> "Build hot cathode rectifiers, two of them at least, one with two plates. These to be sealed off. This will require Dushman to get familiar with methods of getting gas out of anodes and etc., such as Coolidge has used."

The sealing off of the device will be much more difficult than operating on the Gaede molecular pump. But it is what I planned to have Dushman do.

On page 222——

Q. 171. May I ask you first to refer to page 200 and state your recollection as to the matter referred to in that entry?

A. On page 200 is a diagram of a circuit showing the use of the grid leak. There was a condenser connected to the grid which was shunted by a very high resistance and the object is stated there, there is also a battery "to keep the grid slightly positively charged enough so that a measurable current flows to the plate.

"Now, when signals are received the grid tends to become negatively charged. The resistance and the condenser should be so chosen that the condenser will discharge itself in say one 1/1000 of a sec. but yet not become more than very slightly charged in say 1/200,000 sec."

The use of the grid leak was a very important element in using tubes that we were then making as detectors. In the old DeForest audion, there was enough positive ionization under normal conditions to keep the grid from becoming negatively charged, so that grid leak was not very important. There was enough natural leakage in the tube itself due to positive ionization, so that the leak was not needed; but with the much higher vacuum that we were using, and with this pure electron discharge at high voltages, there was no appreciable positive ion current flowing to the grid. Whereas, when the grid became positively charged, as it did, when it received signals, it took up electrons, but unless there was a grid leak, you could never lose these electrons again, so that it became more and more charged and it was to overcome this defect that I devised the scheme for using the grid leak.

Q. 172. Did you obtain a patent along these lines?

A. Yes.

Q. 173. I show you a copy of Patent No. 1,282,439, and ask you whether this is the patent.

THE COURT: Applied for when, and issued when?

Q. 174. Will you answer that?

A. The application was filed October 29, 1913. Yes, this is the patent. It shows the use of the grid leak in the detector——

THE COURT: Just a moment while Mr. Richmond is looking at the patent.

MR. HAIGHT: We object to the patent.

THE COURT: Your reasons?

MR. HAIGHT: On the ground it is immaterial.

(Discussion.)

MR. DAVIS: If it is established that he did make this invention of the grid leak, and filed a patent application for it on a certain date, and that the patent is granted, that is all we are interested in.

The Court: Well, then the offer of the patent itself is withdrawn?

Mr. Davis: I think that is evidential. I think those facts are evidential.

The Court; I do not know just where that line should be drawn.

Mr. Davis: But the effect of the particular language of the patent I do not think is evidential.

The Court: No.

By **Mr. Lunt**:

Q. 175. I will now ask you to explain what your recollection is as to the entry on page 222 of your notebook, Plaintiff's Exhibit No. 131, and to explain particularly the statement reading as follows:

"Dushman has sealed off the first successful hot cathode relay."

The Court: Does that involve some minutes consideration, Dr. Langmuir?

The Witness: Not very long.

The Court: Very well.

The Witness: This refers to the relay or the audion which I had previously referred to. For example, the same one that was described on page 185 of this notebook. By that time we had for convenience come to give different designations to different types of devices. It was our custom at that time to speak of the tubes that White was making as audions, and the large power tubes, which Dushman was making, as hot cathode relays, although at an earlier date such a distinction was not usually drawn. It was simply a matter of convenience in nomenclature. The emphasis in this sentence, I think, should come on the fact that it has been sealed off. The tube had been operating for quite a while before that on the pump. The tube is now sealed off successfully. That is, it was a large power tube. It stands, as I said, in the notes up to 100 milliamperes and 10,000 volts without blue glow. It took two days of cathode bombardment up to 20,000 volts to free the anodes and the grid from gas. Then I go on to say that

"Yesterday and today Dushman and I have been trying to use this relay to produce high frequency oscillations.

"This afternoon we found the very fine result that the apparatus produced high frequency oscillations better by itself than when the grid was stimulated by the small oscillator."

That is, we tried first to so amplify high frequency amplifications from another source, but it produced its own oscillations, and it was those oscillations that we have later measured the wave length of, that is, this tube was being used then as a high frequency oscillator.

(Whereupon at 5 P. M. adjournment was taken until Tuesday, November 2, 1926, at 2 P. M.)

U. S. District Court, Wilmington, Del.,
Tuesday, November 2d, 1926,
2 o'clock P. M.

FOURTEENTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Davis: If your Honor please, I made a statement during the trial as to the priority of the Coolidge drawn wire filament. I want to be clear that there is no misunderstanding about that statement; that is, I have no hesitation in admitting, because I think it to be a fact, that the Coolidge drawn wire filament——

The Court: Will you wait just a moment, for Mr. Darby?

Mr. Darby: Pardon me.

Mr. Davis: I say I have no hesitation in admitting as I meant to admit, that the Coolidge drawn wire filament in its most perfect thoriated form was known to Dr. Langmuir before he made the invention of the last three patents in suit, which was, I suppose, at the time, the only thing in which the defendants were interested. Now, I do not want my statement to be construed to mean that it was on the market in that form at such a time, or at any particular time, because I think that investigation would show that the first drawn wire filaments that were put out, were made by the Battersea Crucible process, which is described in the Coolidge patent, and which was filed later, I do not know just when it was, that the thoriated filament began to be used. I say that lest there be misunderstanding as to any statement I make.

Mr. Darby: I understood from your statement that you admitted that the thoriated tungsten filament had been on the market prior to some time before the middle of 1912, which I understand to be unqestionably the fact.

Mr. Davis: If it is so, it is outside of my knowledge, and if it is important, I shall not oppose any objection to the fact being proved. I will co-operate to prove it.

Mr. Darby: That will be entirely satisfactory to me if I elicit that statement from you as a stipulation before the defendant closes its case.

The Court: If the stipulation was modified for any reason, why then, of course, you will be at liberty to establish what proof you desire. You can have such reasonable time as you desire for it.

Mr. Davis: We will get the facts, if your Honor please, and submit them to Mr. Darby, if necessary.

Irving Langmuir, resumes the stand:

Direct Examination (Continued).

By Mr. Davis:

Q. 176. Do you know Professor Wien?

A. I do.

Q. 177. In a few words, who is he?

Mr. Haight: Cannot we avoid that by putting the question directly to him of what you want to get?

Mr. Davis: It will involve the question of being somewhat leading.

Q. 178. Is it or is it not true that Professor Wien is a very distinguished physicist who has won the Nobel Prize and who has done a great deal of work and published a great deal on electrons and their properties; that you met Dr. Wien at dinner in the spring of 1913, and that you then and there disclosed to him that you and your associates at Schenectady had tubes which operated by pure electron discharge, substantially independent of positive ionization, and if your answer to that question is yes, then I will ask you whether or not Professor Wien on hearing that statement expressed astonishment or incredulity?

Mr. Haight: I would rather have had it the other way. I think the question should be what did Professor Wien then say.

Mr. Davis: I am perfectly willing to put it that way.

Mr. Haight: I object to the question on the ground that what Professor Wien may have said is irrelevant and objectionable under the hearsay rule.

Mr. Davis: Then I think I will go back to my first question of whether he did or did not express or show incredulity or astonishment and I prefer to leave it in that form.

Mr. Haight: That would call for a conclusion from the witness and we will get nowhere on that.

(Discussion.)

The Court: I am of the opinion, Mr. Davis, without an opportunity to investigate it, that it is not admissible, and that its admission would be as damaging to the field of evidence as would be the admission of hearsay evidence. I can understand if these were a party to a cause, there might be some distinction there which I do not appreciate, but if he was a party to a cause would be one thing, but to permit a person who was not a party to a cause, who believed or knew a certain thing, I think is extending the field of evidence more broadly than would be justified. Consequently, I sustain the objection, but I give you the permission, of course, to put it in under Rule 46, if you want to.

MR. DAVIS: I do not care to prolong the argument, your Honor. I will, if your Honor will permit me, take advantage of the rule and ask the witness to answer the question which is in substance yes or no to the long question.

[The witness was then permitted to give his answer under Rule 46, and it was ordered by the Court that the answer should appear in an appendix to the record.]

By MR. LUNT:

Q. 181. Will you now refer to your notebook No. 504, Plaintiff's Exhibit No. 132, and state whether this notebook as well as the other notebooks, Plaintiff's Exhibit No. 101, notebook 413, and Plaintiff's Exhibit No. 131, notebook 458, were books which you regularly kept in the course of your work and in which you kept notes of your work?

A. Yes.

Q. 182. Was it your duty to keep these books?

A. Yes.

Q. 183. And were all the statements which you made in all these notebooks true according to your belief at the time you made the respective notes?

A. Yes.

Q. 184. Will you now refer to page 186 of your notebook No. 458, Plaintiff's Exhibit No. 131, and give us your recollection of the note which you there made?

A. I find on page 186, and in the upper part of 187 of this notebook, reference to an experiment or a test which I remember very distinctly, that was made with the high voltage tube that Dushman had been operating while still connected to the pumping system. This test was essentially like that which I had made with White a few months before, where I used the audion to interrupt a plate current, which was passing through a high inductance coil, and in that way obtained sparks 0.3 millimeter long. The same experiment was now tried with the tube which Dushman had made, and negative voltages were applied to the grid, and then it was noted:

> "With about 2400 volts in the plate circuit (this taking the place of the primary D. C.) a ¾ inch spark about 15,000 volts was obtained across the terminals of the inductance in plate circuit."

That means that with this tube we were able to get grid control; that is, to be able to control the plate current with the grid, even when voltages of 15,000 volts were acting on the plate. In other words, it was acting as an audion normally operates, but with 15,000 volts——

Q. 185. I find I have omitted something as we went along——

A. I do not think that quite finishes that—yes, I think it does.

Q. 186. I find I have omitted something as I went along, and I would now like to take you back for the moment to your notebook No. 413, Exhibit No. 101, and ask you your recollection as to the matter contained on page 223 of that notebook, I think under date of February 7, 1913?

A. Yes, that is correct. On this page is the statement:

> "Alexanderson has been wanting a method of controlling high frequency discharge by means of the waves produced by a telephone. By an arrangement of tubes corresponding in principle to the audion he proposes to interrupt his oscillatory discharge by means of the 'grid' connected to telephone. This I think could be accomplished by a hot cathode tube."

And a sketch is shown of the arrangement of audions for this purpose.

Q. 187. Was it or was it not a fact that this was subsequently accomplished?

A. Yes, this was accomplished and it was the basis of our development of radio telephone transmission.

Q. 188. I would now like to call your attention again to your notebook No. 504, Plaintiff's Exhibit No. 132, and would ask you to tell us your recollection as to the matter on pages 48 to 50, giving the date of the entries?

A. May I ask that page again?

Q. 189. Pages 48 to 50?

A. Under the date of November 11, 1913, is the following entry:

> "Relay for wireless telephone. This morning Dushman and I tested out the hot cathode relay tube with 10,000 volt high frequency current from Alexanderson's machine."

This was a two-kilowatt 100,000 cycle generator.

"The results were most encouraging. By a variation of grid potential of only about 30-40 volts the load taken from the machine was made to vary from 80 watts to about 400. In other words, a load of about 300 watts was controlled by a D. C. potential of about 30 volts with a current of probably not over 0.1 milliampere. Thus an energy of about 300 W was controlled by about .003 watts or a power magnification of about 100,000 fold."

And then there is a diagram of the connections that were used.

I remember that test very distinctly, for it showed the operation of Dushman's first audion, or what we called at that time the hot cathode relay at voltages for 10,000 volts for actually controlling and modulating high frequency power of 400 watts energy, just such as would be needed in the antenna of a wireless station, which was to send out radio telephone signals of 400 watts energy. We subsequently used the tube with practically this kind of a circuit in actual wireless station, and sent messages from Pittsfield to Schenectady, between Pittsfield and Schenectady.

Q. 190. Will you refer to page 52 of this same notebook, Exhibit No. 132, and tell us your recollection as to the matter noted on that page?

A. Under the date of November 19, 1913, this refers to the matter of terminology. We needed a name for the high vacuum devices which we had made, in order to distinguish them from older devices which operated in the presence of gas, and it is noted here a large number of Greek terms are suggested, and finally it is decided:

On November 22, on page 54 of this notebook:

"Have decided to adopt the names *Kenotron* for electron discharge tube." "*Pliotron* for electron discharge relay."

Mr. Darby: Will you give me the date of that?

The Witness: November 22, 1913.

Mr. Darby: That is subsequent to the valid date? Does that make that book available?

Mr. Lunt: It is in evidence.

Mr. Darby: That particular book?

Mr. Lunt: Yes.

Q. 191. Before passing that, I would like to ask whether you ever received distant wireless signals making use of any of the apparatus which you may have already described in giving your testimony?

A. In January, 1914, we used audions of the type of—practically exactly like audion No. 2 that I have already described. I mean, the same type of construction. We used those audions to receive wireless signals, but particularly continuous wave stations. For this purpose, we used Alexanderson's system of tuning in geometrical progression, along early in 1914, probably February and March, with a relatively small antenna, and using two stages of radio frequency amplification, each stage being tuned, and a detector tube, and another tube to produce high frequency oscillations, so that we could detect the signals by the heterodyne method. We received radio signals from San Francisco and from Honolulu quite regularly. Those were sent from Honolulu at about six or seven thousand meter wave lengths. And we were frequently able to overhear the signals from Honolulu when the station at San Francisco asked to have them repeated, because they could not get them. That was a thing that impressed us very much at the time, and I think it would only have been possible by the good tubes we had at that time. We were using some 125 up to 250 volts on the plate.

Q. 192. Did you read a paper setting forth some results of your work on electron devices, and when was it?

A. Yes. I read a paper I think in October, 1913, which was subsequently published in the *Physical Review* in December of 1913.

Q. 193. Will you refer to that paper, which I think is Plaintiff's Exhibit No. 21, and call attention to the parts of the article or paper, especially those that may have to do with the preparation or building of tubes. You might read those parts if they are not too long.

Mr. Haight: I am wondering whether that is really going to help us any. The paper is in evidence. It speaks for itself.

The Court: It seems to me to be a duplication; does it seem otherwise to you?

Mr. Lunt: Well, except that it renders more intelligible the answer to subsequent questions; but of course it can be looked up and it is in the record.

The Court: All right.

Mr. Lunt: I will do just as your Honor says about that.

The Court: The record is going to be pretty long, and if there is no substantial point in duplication——

The Witness: May I refer to the page?

Q. 194. If you will indicate where those parts are, without reading them, or perhaps just read the first few words, to make it clear?

A. On pages 479 and 480 is a description of the methods of preparing electrodes and exhausting the tubes in such a way that a pure electron discharge may be obtained.

Q. 195. Is that the only place you wish to refer to or point out?

A. I think that is enough.

Q. 196. When and where was this paper, Plaintiff's Exhibit No. 21, read?

A. It was read in the Physics Lecture Room of the Physics Department of Columbia University.

Q. 197. And when?

A. October, 1913.

Q. 198. And what transpired at that meeting?

A. There was considerable discussion after the meeting, mostly by Dr. Arnold. He pointed out to me that the 3/2 power law had been previously published by Child in 1911, and that was for the case of parallel plane electrodes. In my paper I had also given the derivation for electrodes in the form of a wire as the center in the axis of a cylinder. Dr. Arnold also stated that he felt that it was very doubtful if I had really obtained currents at such voltages as I had spoken of (250 volts), that were free from blue glow and ionization effects. After the meeting I had a longer talk with Dr. Arnold and he told me that they had been working on electric discharges in evacuated tubes from hot cathodes and had used the Wehnelt cathode, and said that they were particularly interested in low voltages, much lower voltages than those I had been talking about. I think that he spoke of voltages of 20 to 30 volts as being the voltages that he intended to use in operation. The impression that I got at that time from the conversation with him was that they had not gone very far in making devices utilizing thermionic currents in vacuum.

Mr. Richmond: Your Honor, I object to the drawing of a conclusion in the statement of an impression.

The Court: The objection is sustained unless you desire to be heard, Mr. Lunt?

Mr. Lunt: Well, your Honor, so far as his answer concerns the drawing of conclusions, I have nothing to say.

The Court: Then the last sentence is stricken out.

Q. 199. What other papers have you written regarding this work, at least, so far as concerns the period up through 1915?

A. Two other papers were published on the same subject in Germany in I think January and February, 1914, which cover somewhat the same ground that was covered in this *Physical Review* paper that I have just spoken of, but they were entirely separately written papers, and I think in many ways the German paper went into a good deal more detail as to the method of obtaining high vacuum and getting a pure electron discharge. Those two papers were published in the *Phys. Zeit.* Then in April, 1915, I read a paper before the American Institute of Radio Engineers, and that paper was published in the *General Electric Review*, and also in the transactions of the Institute of Radio Engineers. That paper dealt with the applications of a pure electron discharge to radio telegraphy and telephony.

Mr. Lunt: I believe, your Honor, that these are already referred in the Interference record.

Q. 200. You have described your work on the improved audions in relays and on related matters. Will you now review the distinguishing characteristics of these devices, which, in your opinion, affect that practical operation?

A. The pure electron discharge devices that we were able to build in 1913, and beginning in the latter part of 1912; and the practical part of the devices that we built in 1913 distinguished themselves over the older devices, such as the DeForest audion and Fleming valve, in a great many different ways, and I want to discuss those in relation to their practical importance.

Of course it was true that the vacuum was higher. They showed no blue glow. There was no perceptible part of the current carried by positive ions and there were many factors of that sort, but after all, it does not make the slightest difference in a vacuum tube whether there is blue glow or not. It does not make any difference whether the pressure is high or not, that as a factor in itself is not of the slightest importance.

The practical question depends entirely on the electrical characteristics of the tubes. These devices were used entirely as electrical devices.

The three-electrode tubes were used to control electric power. The two-electrode tube devices were used to rectify alternating current and in some cases to regulate an electric current by means of the filament temperature. The Coolidge X-ray tube was used to convert electric energy into X-rays. In all those cases it was of the utmost importance from a practical point of view to have reproducible characteristics, to be able to get the same result whenever the tube was operated under similar conditions. If a given voltage is applied to the electrodes of a three-electrode tube to each of the two electrodes it is of the utmost importance that you should always get the same current.

Now, this reproducibility is important, not only in taking successive readings. For example, if you make measurements on a tube and you take a series of readings by raising the voltage and measuring the current at each voltage so as to get a characteristic curve of the device, if you raise the voltage in steps in that way up to the maximum and then lower it in steps and you get different readings coming down from what you got going up that device is certainly not reproducible. But reproducibility means more than that. It means that the characteristics shall not only stay constant during the short time that elapsed between the time of the taking of the curve going up and coming down, but it means that the device shall stay constant from hour to hour and from day to day during its life.

In all practical applications of the three-electrode tubes, that factor is very important, because the tube is only part of the outfit that is being used, that is, the tube is part of a circuit and the circuit has to be adjusted to the characteristics of the tube.

For example, if used as a telephone relay it is very important that the tube shall be properly balanced with the characteristics of the circuit. The same is true in all radio receiving sets, particularly the more complicated ones. The characteristics of the tube need to be very definite in order that the whole set may be built around the tube or built to fit the tube. If the tube has one characteristic today and another characteristic another day you cannot build the circuit to fit the tube under both conditions.

There is another important feature in regard to the characteristics of the tube and that is that the characteristics shall be a smooth curve. For example, as you vary the grid voltage suppose the current to the plate changes in such a way that it has a kink at a certain point, a sudden change of direction and slope, such as was common and usual in the old DeForest audion, that means that the voltage on the plate and the voltage on the grid must be carefully adjusted so as to work at that particular part of the curve or at a definite point on the curve because a slight change in voltage on the grid or plate from that value changes the slope of the curve over the working range. So that again the electrical characteristics, impedance of the tube and the other important constants of the tube would vary very rapidly with such factors as the B-battery voltage.

The whole modern development of radio receiving sets has progressed along the line that effects of that sort are to be eliminated. It is desired to have a set which will work the same one day as another, even if the B-battery voltage should decrease a little. We did not want to have tubes that are abnormally sensitive to filament temperature, to B-battery or to C-battery.

So I think I have emphasized sufficiently the fact that all of the useful characteristics of the tube depend upon the volt ampere characteristics in the working range, within the range over which the tube is to be used. If the tube is to be used as a three-electrode tube it must be used on the part of the curve where the current is limited by space charge because it is only under that range that you can change the current by changing the voltage. If you are on the saturation part of the curve the current is limited by the emission from the filament and is not dependent on the voltage on the electrodes, and therefore you have no control over it. Plate voltage or grid voltage will not change the current through the tube, and such a tube is not useful as an amplifier or detector.

So I emphasize also the fact that we are interested in the characteristics over the operating part of the curve. In a three-electrode tube that means on the space charge part of the curve. The saturation part of the curve is of no importance whatever in a three-electrode tube, provided the current that is emitted is sufficient to allow the current to be limited by space charge over the operating range.

We come, therefore, to the reproducibility and the smoothness of the characteristics as the essential qualities that a three-electrode tube must have. The same thing is true of the Coolidge X-ray tube, although there we are operating on the saturation part of the curve and not on the space charge part, but there again it is reproducibility and definiteness of characteristics and smooth curve and emission must vary with the temperature in a definite regular manner.

Having that in mind that those are the only important factors, really important factors in the operation of an electron tube, I think we can analyze better the different tests or the other characteristics of the tubes that distinguish them. For example, the vacuum in the tube, the pressure in the tube.

The pressure does not make any difference in a tube, if the tube has good characteristics, is reproducible and stays reproducible during its life. No one would object to the tube because it had ten microns of gas in it, that would be the last thing to think of. But if it has ten microns of gas in it and that gas changes and the change of that gas causes the characteristics to change in an irregular way, in a non-reproducible way, then the gas pressure becomes important.

The same way with blue glow. If we had tubes that have good characteristics, that are good amplifiers, that fit into a circuit well, and stay balanced in that circuit from day to day, nobody would object to there being blue glow in that tube. It is the last thing that we would think of. It would be taken as a characteristic of the tube. For example, in the Tungar rectifier no one objects to the fact that there is a glow in the gas.

The same is true of positive ion current. For instance, we have the three-electrode test or "the counting of ions" that has been used as a test for the purity of electron discharge. Take the two-electrode tube. It does not make any difference in that tube if there is positive ion current or not as determined by a third electrode, which might be introduced for the purpose of counting the ions. The important point is only, do the electrical characteristics of that device have certain qualities and do they retain those qualities during the life.

This test of the reproducibility and the smoothness of the characteristic curve has, I believe, been emphasized by all those who have testified in this case on the motion and on the priority record. I think it was emhasized by Van der Bijl more than any one else and has sometimes in the record been referred to as Van der Bijl's test and I believe every one else has recognized the importance of it.

MR. HAIGHT: I think, if your Honor please, we are getting off into a field that is not that of the witness to explore. He is now discussing the evidence in the case. I do not know where it will lead us to.

THE COURT: I think he did that to shorten the testimony rather than adding anything to its substance. I think he is not discussing the evidence at length. He is referring to two circumstances and I think probably he has covered all the field that he intends to cover.

MR. LUNT: I think, your Honor, it is simply to identify the situation.

THE COURT: You understand, of course, Dr. Langmuir, that your last reference was to tie things together.

A. (Continued.) All I want to do now is to give names to the different tests so that we can refer to them. The first test we may call the reproducibility test. The second test, and by test I mean a particular characteristic of the pure electron devices which may be used as a means of identifying them—the second test is that as the pressure is decreased the characteristics shall not change as a result of that decrease in pressure. You may call that the pumping test. A third test is the blue glow test.

Now, I would like to point out that these tests are secondary, that is, I mean the second and third ones are secondary tests. A change in the characteristics with pressure is only important in the operation of the tube in so far as it leads to non-reproducibility. I believe that the non-reproducibility is the most essential single characteristic, that is, the reproducibility and the smoothness of characteristics can be stated as the most essential characteristic of the modern high vacuum devices as distinguished from the old.

How are we going to characterize that further? What must be true in a tube in order to get this reproducibility?

If there is gas in a tube that pressure will change. If the gas comes off the electrodes as the electrodes are heated more gas will come off and as the tube is cooled some gas will tend to disappear. If the voltage is raised on the electrodes there will be somewhat of an electrical clean-up unless the electrode gets too hot and then it will go the other way.

In other words, in the devices of the old art, in the DeForest audion, the pressure was continually changing.. It sometimes increased and it sometimes decreased. Both things went on and there was an evolution of gas, water vapor would come off the bulb and be decomposed by the filament and it would generate gas. Gases would come out of the electrodes. Positive ions would bombard the walls and the electrodes and would drive gas off. Those were three cases in which the gases would come out into the space and cause an increase in pressure.

There was vaporization of the metal of the filament causing compounds to be formed which would cause the gas pressure to decrease. The ions formed by the discharge in striking the walls would be entangled in the walls and disappear and it would cause a decrease in the pressure.

These things were going on in the most erratic and ungovernable way in the old devices and that is true of all devices that are poorly exhausted.

If there is a pressure of gas such that the ionization produced by it modifies the space charge, partly eliminates the space charge, and therefore allows more current to flow than would otherwise flow, then any change in that gas pressure will cause a change in the ionization and space charge will be eliminated to a different degree and there will be a resulting change of current.

One way to get rid of that effect is to lower the pressure at such a point and maintain the pressure at such a point that there is not enough positive ionization to have any appreciable effect in neutralizing the electron space charge. Then the current becomes definite. A further lowering of the pressure beyond that point is entirely immaterial as far as the effect on the characteristics of the tube go. It would not make any difference if the pressure is lower than that.

If in a given device at a pressure of one micron, if that is the maximum pressure under operating conditions and if with one micron pressure and a given voltage on the tube the positive ions are not sufficient in number to have any appreciable effect on the space charge, the current will then be definite and will be the same as though the pressure were made zero. Further lowering of pressure will not have any further effect in changing the current.

So that the second test is equivalent to the first test, that is, if you find that a lowering of the pressure produces no effect on the characteristics, then you will get reproducible characteristics, because the change in the pressure is the factor which causes the lack of reproducibility in the old art devices.

And it is because we cannot make that test in ordinary devices that are sealed off that we need to come back to such test as the 3/2 power test. Let me explain that.

If we can pump out the tube and see if there is any further change in the characteristic on pumping out, we make a very good test, but that is not the practical thing to do in a sealed-off tube. We cannot have a tube that is sealed off and tell whether the characteristics stay constant as we are lowering the pressure.

Now, the effect of the pressure is primarily to change the space charge effect as the result of the ionization produced by the gas. We can avoid ionization in any device by going below ionizing voltage. If we lower the voltage to fifteen or twenty volts (at fifteen volts we get no ionization in any device), and if as we raise the voltage we know the law according to which the current would flow in the absence of ionization, and that is generally the 3/2 power law, and then we take the characteristics in a device which contains gas below ionization, it should be the same because the pressure of the gas does not affect the current in the space charge part of the curve as long as there is no ionization. As you raise the voltage above the ionizing voltage and you have some gas present, you will have some ionization and the current will rise above the value that you would get if you had no gas. Let us assume that we have no gas; you will then get the 3/2 power law from below ionization to above ionization. Then, if you have gas you will get the 3/2 power law up to the ionizing voltage and then gradually you will get an increase in current. That represents a departure from the normal curve characteristic of high vacuum. That will mean in general an increased slope. The current will rise more rapidly with voltage than it would if you had an extremely high vacuum in the device.

It is for that reason, so that we can make a comparison between the device when operating with pure electron discharge as compared with what it is when it is not operating with pure electron discharge in the presence of gas,—that we use the law of the tube for the high vacuum.

It is important to know then in a given type of device what the law of the tube is in a high vacuum because then, if we get a departure from that above the ionizing voltage and little or no departure below the ionizing voltage we use that as a means of telling what effect is produced by the ionization.

In other words, the use of the 3/2 power law in that case is practically equivalent to the pumping test where you lower the pressure. The object of lowering the pressure in a given device is to avoid the ionization and thus to see what happens in the absence of ionization.

Suppose you have a tube with 100 volts on the electrode. We get a certain current with a certain voltage. We pump out the gas and the current decreases say 30 per cent. That is due to ionization and not due to pressure of the gas. It is due to the ionization which results from the pressure of gas. If we can avoid that ionization in any other way we would know what effect would have resulted from pumping out the gas. If we can lower the voltage until the ionization stops then we have the same curve as though we did not have the pressure. We have the same effect although we did not pump it out. That is the importance of the 3/2 power law. It enables us to compare the characteristics in the absence of ionization with that in the presence of the ionization.

If there is no difference, that is, if the law is the same as if it was in a perfect vacuum then we can conclude that a further lowering of the pressure would not have any effect on that characteristic and we also conclude that the characteristics will remain reproducible during the whole life of the device; making a measurement going up and coming down tells you that the curve is reproducible during that period of time while you made the measurement.

If you can go further than that and prove that that device is not influenced in any way then you know that you have no effects of ionization.

THE COURT: The possibility of gas subsequently coming in?

A. Yes, being evolved. At any rate, a clean-up may take place in the tube which will cause no effect. You can see from that that a clean-up in the tube may be a very bad thing, in that it may cause a change in the characteristics.

Suppose you take a device and balance it in a telephone circuit while it has gas, and subsequently that gas disappears. The device is no longer balanced.

I might say a few words about the blue glow test. Blue glow results from the impact of electrons on gas molecules, causing them to give out light. It is not essential that there should be ionization, but ionization usually accompanies and greatly increases the blue glow. But in most cases blue glow is in general proportional to the strength of the current, that is, with 100 milliamperes, other things being the same, you will get 100 times as much blue glow as with one milliampere.

Blue glow increases as the voltage goes up. We have spoken about the ionizing voltage. Suppose we consider a gas which has an ionizing voltage of twenty volts. That means that unless an electron has moved through a difference of potential of twenty volts and has acquired a velocity corresponding to that, it cannot produce any ions at all, because there will be no ionization at all below the ionizing voltage.

But if you go slightly above the ionizing voltage, say twenty-one volts, only a very small fraction of the collisions result in ionization. At twenty-two volts a larger fraction; at thirty volts a still larger fraction. So that the ionization begins abruptly at a certain voltage but increases only slowly beyond that.

It is for that reason that in an old tube like the DeForest audion containing a certain amount of gas, you usually do not notice the effect of ionization right at the ionizing voltage. It comes in a little higher than that, five volts, ten volts. The effect begins at the ionizing voltage but it begins by being almost imperceptible. The result is that in most of these devices, ionization first becomes to be important at twenty or twenty-five volts or thirty volts. Then it increased steadily until you get up to about 200 volts or thereabouts, when it reaches a maximum, and under those conditions thirty or forty per cent. of the collisions result in ionization, not all of them even at those voltages.

Therefore, blue glow as a test for ionization does not measure the number of ions produced. It does not measure the effect of the ionization on the characteristics which is the thing we really care about, but it measures something which is related to the voltage in a complicated way and is proportional to the current.

As a result of this blue glow at 250 volts with large current is a very sensitive test you might say for vacuum. And it is so sensitive that with large currents, say 100 milliamperes, that we can be sure that any device that does not show blue glow under conditions of that sort in the ordinary structure—it might be conceivable that you will not get this effect with certain structures—then you know that the ionization is so small that it will not affect the space charge.

On the other hand, if you are working at lower voltages and small currents, there may be enough ionization to eliminate space charge and yet not show blue glow. Blue glow becomes a better and better test the higher the currents you are working with and the higher the voltages you are working with. At low voltages and currents it may be a very insensitive test and it is not necessarily related to the thing that we are interested in, the reproducibility of the characteristics. Only in so far as the ionization which accompanies the blue glow is in sufficient amount to neutralize the electron space charge do we care at all about it.

By MR. LUNT:

Q. 201. Is the 3/2 power test necessarily any proof of the degree of vacuum? It may be that that can be inferred from what you have said, but I do not know that it appears clearly.

A. The 3/2 power law I consider to be particularly useful as a test of the quality of the pure electron discharge devices for the reason that it is a characteristic that tells us just what we want to know. It tells us to what extent the characteristics are affected by gas in the operating range.

We operate in the three-electrode tube on the space charge. The 3/2 power law is a measure of the characteristic on the space charge part of the curve. So that they are both on the space charge part of the curve.

If the gas is present in sufficient quantity to cause a deviation from the 3/2 power law, it of course changes the characteristic of the device, because if there was no gas it would follow the 3/2 power law and a departure from the 3/2 power law due to gas shows that the characteristic has been modified by gas.

That is the value, I think the particular value of the 3/2 power law as compared with the other tests. It does not measure pressure. It measures the effect of the gas on the characteristic, that is, the departures from the 3/2 power law measure the departure of the characteristics from those characteristics of a perfect vacuum.

We do not want to measure pressure in a practical device. To know that the pressure is five microns or one-one-hundredth of a micron does not tell us whether the device is good or bad. We want to know what the characteristics are.

There are deviations from the 3/2 power law when the amount of positive ionization is a certain fraction of the number of electrons per unit volume. You will get certain deviation under given conditions. As you lower the current you lower the positive ionization, but the departure from the 3/2 power law may remain constant. You may get with a low current as great a departure from the 3/2 power law as you may with a larger current.

In the same way the pressure will be different in different devices when they show the same amounts of departure from the 3/2 power law. For example, if we take a device with long distances between the electrodes and we have, we will say, one micron of pressure, we will get a certain amount of ionization in that space and the electrons in passing across that space of say ten centimeters will produce a certain number of ions. If we had that same pressure of one micron and we had a distance only one-tenth as great you will get only one-tenth as many ions formed, but the electron space charge will be the same close to the surface of the cathode.

So that the important element in determining the effect of gas on ionization is not the pressure at all, but it is the amount of gas in the space between the electrodes. For example, if we take electrodes ten centimeters apart with a certain amount of gas, and we put those electrodes closer together, keeping the same total amount of gas between them, we would get the same amount of ionization but we would have ten times the pressure, because there would be the same amount of gas in one-tenth of the space or volume. Do I make that clear?

THE COURT: If that is what you mean, that is not clear. Where do you get the same amount of ionization?

THE WITNESS: If an electron travels a certain distance through gas at a certain pressure, there is a certain probability of collisions that result in ionization and let us say there is a 50 per cent chance that the electron will collide with a molecule in traveling say ten centimeters. If you take the same amount of gas in a smaller volume, you will have to have a larger pressure.

THE COURT: Yes.

THE WITNESS: You will have the same amount of gas——

THE COURT: I missed that. Then I understand now.

THE WITNESS: That is, if you take two electrodes and bring them closer. The important element is the total amount of gas in the volume inside of the electrodes inside space.

THE COURT: I did not know you kept that the same.

THE WITNESS: Not the pressure.

THE COURT: Shall we take our short recess?

(Here a short recess was taken.)

By MR. LUNT:

Q. 202. Had you finished your answer?

A. Not quite. I want to make it clear that if you have a tube with the electrodes close together you can have a much higher gas pressure and still get it to agree with the 3/2 power law, and still get characteristics that are not affected by ionization. For example, in this tube of Exhibit 56, the anode and cathode are very close together. You can tolerate a very much higher pressure, two or three times higher pressure than you could in a device like Exhibit No. 47, where the anode and cathode are two or three times as far apart.

THE COURT: May I ask this: Assume the pressure to be constant and you move your electrodes closer together, do you get less ionization?

THE WITNESS: Less ionization the closer they are together. The more as you put them further away.

THE COURT: The pressure remaining constant?

THE WITNESS: Yes. That goes back then to the days of the old-fashioned X-ray tubes. In the old-fashioned X-ray tubes if you put your electrodes closer together you had to use a higher voltage to get a discharge between them because there is less gas between them to ionize. There is less ionization, and therefore it is more difficult to get a discharge because that discharge depended upon ionization.

Q. 203. Those were Defendant's Exhibits numbers which you have just referred to, are they not?

A. Yes.

Q. 204. Do you wish at this time to talk briefly about some of the causes which mask the 3/2 power law or to say something about it?

MR. HAIGHT: That is a pretty large question.

THE COURT: Read it. (Question repeated.) I assume you won't press that in the presence of objection?

Q. 205. Will you explain briefly some of the causes which affect the 3/2 power law or its manifestation?

A. I have already said that in case there are three electrodes, a modified form of that law should be used, where you take the 2/3 power of the current and plot that against either the plate voltage or the grid voltage, that method of plotting the relationship using the 2/3 power of the current tends to eliminate some of the secondary factors that may influence the relation between the current and the voltage. First of all, the potential of the electrodes may not be what you think they are, because of a contact difference of potential which may amount in some cases to as much as three volts, so that where the voltmeter shows a difference of potential of 15 volts between two electrodes it may actually be twelve or eighteen, and that is a constant amount that would be added to the voltage. If you plot the current against the voltage on logarithmic paper, that constant amount displaces the curve by different amounts at different parts of the curve because of a non-uniform scale; but if you plot the 2/3 power of the current against the voltage a change in the voltage displaces the whole curve laterally, without changing its slope or its curvature. Thus by plotting the 2/3 power of the current, we eliminate effects or errors, which may come in because of the contact potential. On the other hand that factor alone cannot cause the displacement of the curve by more than two or three volts, the magnitude of the contact potential, unless as in some of these cases we are plotting the plate voltage, and the contact potential is not on the plate but on the grid. Then there is the amplifying action or amplification constant comes into between the relationship between the grid voltage and the plate voltage.

Now, another fact that may cause apparent deviations from the 3/2 power law is a voltage drop along the filament, the cathode. However, if we take the voltage from the mid-point of the filament that factor becomes relatively unimportant.

In tubes of special design, deviations from the 3/2 power law may be exaggerated, and particularly is this true in the case of three-electrode tubes. For example, if we had a grid and a three-electrode tube, and a linear filament, a straight line filament, and over one part of the length of the filament we had a coarse grid and the other part we had a fine grid, we really have two tubes in parallel, and if we then put a negative voltage on the grid, you might have a negative voltage enough to stop the electrons entirely in the passages through the grid in that part of the grid where the wires are close together, but they would pass easily through the part where it was coarse. So we begin by getting the current characteristic of one part of the device, and then of the other.

That is one kind of factor that causes variations, that is, a non-uniform structure of a grid causes deviations, particularly at the very lower end of the curve, with small currents. As soon as the grid becomes positive that effect disappears because then the electrons go through the whole of the grid, and it is the average characteristics of the grid that becomes more important.

If the cathode is almost entirely enclosed in a shield, as for example, it was in the Coolidge X-ray tube (indicating), thus if you take a cathode that is at the bottom of a cup-shaped depression, and we measure the volt-ampere characteristics of the anode, we do not get the 3/2 power law, because there the electrons which escape are determined largely by the initial velocities and only a few electrons have sufficient velocity to carry them out into the region where the field of the anti-cathode is effective. On the other hand, if you take exactly the same tube and remove that shield, you get an excellent agreement of the 3/2 power law, so that these are cases where the geometry of the tube may cause departures.

But I would like to say this, that with practically all of the tubes that are used today, the 3/2 power law expresses admirably the characteristics in the absence of gas, and if you put in gas, it causes deviations beginning a little above the ionization voltage and increasing rapidly as you go above that point. The same is true even where the anode and the cathode are of the most varied shapes, out in the middle of bulbs, for example. Take the early experiments that I have already described, where we had two hairpin filaments in a cylindrical bulb. In those cases, the 3/2 power law applies with very great accuracy. I mean within one or two per cent. of accuracy, or something of that sort. There are factors, such as the factors that have been included in the derivation of the equation, for example, the initial velocities of the electrons that cause appreciable deviations, but they do not produce deviations that can be mistaken for the effects of gas. The effects of gas are usually quite unmistakable, if present in important amounts; so that for that reason I believe that the 3/2 power law and the inverse law, the 2/3 power law, constitute by far the most useful test we have that can be applied to a sealed-off device, to tell whether or not the characteristics of that device are modified appreciably by ionization resulting from gas.

Now, that does not mean, however, that the 3/2 power law is a test that you would apply in a factory, or in a laboratory, day by day, as the means of testing the usefulness of a device that you are making. For example, in our own laboratory, when we make or exhaust a tube, we do not stop during that exhaust in order to see whether the device has characteristics that follow the 3/2 power law, because we have the device still on the pump. We could apply the pumping test much more conveniently, but as a matter of fact in the practical manufacture of tubes, the third electrode test, which Professor Millikan described, or the method of counting ions, is by far the most convenient, because if you are making any definite type of device, making that device over and over again, you calibrate that test. You find by experience, after making up several of these devices, or a large number of devices of the same geometry, how good your vacuum needs to be in order to get a tube that is satisfactory, that means a reproducible characteristic, long life and any other factors that you may wish; we find by experience how high the vacuum is and measure the vacuum by the three-electrode test. A certain current is found by experience to mean a certain number of microns of a gas, but it is then necessary to measure the upper limit of pressure with which you could afford to operate the tube. The advantage of this test is that it is made by one measurement. You simply put a definite voltage on each of the two electrodes, and you measure the current. It is a test that can be made while the tube is being pumped out, or at any time afterwards. But it means nothing unless it has been calibrated; that is, unless you know the relationship between the positive ion current that you obtain under these conditions, and the characteristics of the tube that you obtain from that device under operating conditions. As I said before, it would not make any difference if you had a microampere or several microamperes of positive currents obtained under test conditions, if the characteristics of the tube during operation were satisfactory. The usefulness of the tube depends upon the characteristics under operating conditions, and any test for the satisfactory operation of the tube must be interpreted in its relation to those operating characteristics.

Q. 206. I think that the first X-ray tube exhibit which you referred to was No. 22 in the Interference, and a second one was No. 25, which correspond respectively to Nos. 42 and 45 in this case; is that correct? At least as to the original numbers which you find?

A. Yes, Plaintiff's Exhibits 45 and 42.

Q. 207. We will now pass on to the next subject and I will ask you to describe the difference in principle between the operation of a three-electrode tube as a detector, and also as an amplifier, and to compare the behavior, when gas ionization is present, with that when gas ionization is absent.

THE COURT: Compare what?

Mr. Lunt: The behavior.

A. When a tube is used as a detector, a high frequency current is applied to the grid and a constant direct current potential is applied to the plate, and a telephone, for example, or other indicating device is placed in that plate circuit. Ordinarily, the high frequency alternating current that is applied to the grid varies with time, that is, it is modulated so as to increase and decrease in magnitude periodically of an audio frequency, and it is desired to cause variations in the current through the telephone which do not follow the radio frequency applied by the grid, but follow the audio frequency which modulates the high frequency of the grid circuit. Do you understand that effect of modulating?

The Court: Yes, I know what it does, but there are a lot of things I do not know about it.

A. If we have a radio frequency wave with, we will say, one million vibrations or cycles per second, and we cause that to vary in amplitude periodically, we speak of its being modulated; but the frequency remains the same with the amplitude increasing and decreasing again. The time intervals that elapse between a period of maximum amplitude and the next period of maximum amplitude, will be the audio-frequency period; that is, one-thousandth of a second, for example, if we modulated it at a thousand cycles. That is, the radio frequency wave will be at a maximum intensity at a certain time, and then will fall to low intensity, and after one-thousandth of a second, will increase to maximum intensity again.

Now, in order to get audio frequency variations in the telephone which is connected to the plate, we must have changes in the average value of the direct current component of that plate current.

Let me illustrate. Suppose, for example, we have a point A on the characteristic curve, which I now illustrate (indicating). We have a curve, for example giving the plate current as a function of grid volts, and we take the point A of that curve, that corresponds to a definite grid voltage, which we will say is V_1 and the plate current I_1. Now, when the radio frequency wave is applied to the grid, the grid potential fluctuates between the lower value V_2; and the upper value V_3, and in the corresponding way the plate current changes from the value I_2, when the voltage is V_2, to the value I_3, when the voltage is V_3. So we may say that we go at the rate of a million times a second back and forth between the two points on the curve which we may call A_2 and A_3.

Now, if that line between A_2 and A_3 is a straight line, it is seen that the current increases and decreases by the same amount. Therefore, whether you have the radio frequency signal applied or not, will make no difference in the average value of the plate current. That is, if no signal is applied at all, we have the current I_1. If the radio frequency signal is applied to the grid, we have currents that vary from I_2 up to I_3; but since the characteristic line at the point A is straight, the increases and the decreases just neutralize each other, so far as the average current goes, and thus the average current through the telephone remains the same as though no signal were applied. It is true that the current varies a million times a second up and down; but the telephone cannot respond to a million cycles per second, neither could the ear hear the sound even if it were produced with the frequency of a million cycles per second.

If we vary the amplitude of the signal as when we actually do apply a radio frequency signal on the grid, we are merely changing the current so that in one case it stays very close to the value I_1 and in the other case it oscillates back and forth between the value I_2 and I_3; but the average current through the telephone which is the only current that will affect the movement of the diaphragm is practically the same in both cases. Thus the diaphragm is not put into motion at the low frequency with which the modulation is made.

Suppose for example, a thousand times a second you change between having a steady voltage V_1, and the alternating voltage which varies between V_2 and V_3, the total current flowing through the telephone will be the same in both cases, so that it will not cause any motion of the diaphragm, since the position of the diaphragm at any time depends upon the average current flowing through it at that time. The rapid fluctuations of a million cycles do not cause motion of the diaphragm.

The point I want to bring out is that the detector action is zero if the curve is straight, if we are causing fluctuations of voltage, which cause the current to change only over that part of the curve where the characteristic is straight, the sensitiveness as a detector is practically nothing.

On the other hand, if we pass down to a point where we have a voltage V_4 applied to the grid in one case, and in the other case we let the voltage fluctuate between V_5 and V_6, then the plate current changes between I_5 and I_6, when the alternating current is applied to the grid, but it stays steady at I_4, if a steady voltage is applied to the grid.

Now, we see, however, because of the curvature of the characteristic of the curve near the point corresponding to V_4, the increases in current in going from I_4 to I_6 are much greater than the decreases that occur in going from I_4 to I_5, so that the average value of the current while the grid is fluctuating, is considerably larger than the average value of the current when the grid stays at the fixed potential V_4. Therefore, as the radio frequency current increases and decreases in value, there will be fluctuations in the average value of the current through the telephone, and since these fluctuations occur a thousandth of a second apart, and the telephone diaphragm can respond to variations of current that extend over that speed, the diaphragm will be set in motion at a frequency of a thousand cycles a second.

The point I want to emphasize, therefore, is that the detecting action of the audion depends upon the curvature of the characteristic curve, and the curvature may be either an upward curvature or a downward curvature. Exactly the same method of analysis that I have applied to this point V_4 could be applied to point A_7 where the curvature is a downward curvature.

In general, therefore, with a vacuum tube of the audion type there are two portions of the curve where there is good detecting action, a place where the upward curvature is the maximum, and the place where the downward curvature is the maximum, and there is a point in between where the curvature is the minimum or zero, where the detecting action is small or entirely absent.

On the other hand, we have just opposite considerations to take into account if we are dealing with the amplifying power. First of all, let me say that when we use a tube as an amplifier we do not apply a radio frequency to the grid, but we apply the audio frequency, or we apply to the grid the same frequencies as the frequencies which we wish to observe.

In the case of the detector, we apply one million cycles to the grid when we wish to observe, say, about one thousand cycles. A detector converts waves of one frequency into waves of a lower frequency which represent a modulating frequency that is applied to the high frequency signal; whereas, in the case of amplification we have a certain signal at a certain frequency and we wish to convert it into another identical frequency, the same kind of wave, except more energy. To do that we wish to apply certain voltages to the grid and get as large a change in current as we can.

Therefore, we pick out a place where the slope of the curve is the greatest, and, in general, the point where the slope of the curve is the greatest is the point in the curve where it is straightest. At the lower end of the curve it is flat and increases in slope to a certain point and then decreases in slope again. The steepest place is where it does not curve one way or the other and therefore, it is very nearly straight.

Thus the amplifying power of a tube is measured by the slope of the curve, the steepness of the curve. The detecting power is measured by the curvature and not by the steepness. The greatest amplifying power for small signals, of very low intensity at least, occurs at a portion of the curve where the detecting power is the least.

Mr. Lunt: To avoid confusion, I would like at this point to offer this explanatory diagram in evidence as Plaintiff's Exhibit 167.

(Received in evidence and marked "Plaintiff's Exhibit No. 167." *See Volume IV, Plaintiff's Exhibits, page 49.*)

A. (Continued.) If we put gas into a tube of this sort the curve slopes upward much more markedly above the ionizing voltage, and I might indicate here, for example, by a dotted line, the curve that might be observed in the case of gas ionization. I will mark that by the curve S. T. U.

There is another portion of the curve where in the neighborhood of S. there is a high curvature, that is, when ionization begins or shortly after ionization has begun, where the curve curves upward rapidly. That, therefore, will be the region where the tube becomes a good detector.

Then at the upper range, just before the curve becomes saturated at the point T, will be a place where the curvature is very high and there will be another region where such a tube may be used as a good detector.

In between the curve has a much greater slope than it would have if there was no gas present and since the amplifying power depends primarily on the slope, the amplifying power of the tube will in general be much increased by the presence of gas. That has not only made the detecting action greatly increased but the amplifying action of the tube will be greatly increased but the range over which it becomes a good amplifier is very much decreased and it will require a critical adjustment to get the best amplifying power, just as it will require a critical adjustment to get the best detecting action.

To illustrate some of these points I would like to show you some curves that I had made with standard tubes that have been manufactured by the General Electric Company. These first two curves are taken on a UV-201 tube.

Q. 208. May I ask you, doctor, to indicate these different curves by letters or numbers so that we can distinguish them.

A. I will take first A. I will mark them A, B,—I see they are already marked. I will mark them A, B, A^1, B^1, and D. Now curve B or the family of curves on sheet B were taken with a UV-201 tube, which is a high vacuum tube. In these curves the 2/3 power of the current is plotted as ordinate and the plate voltage from zero up to one hundred volts is plotted as abscissæ, and the five curves correspond to different fixed grid voltages, —2, —1, 0, plus 1 and plus 2 volts.

Curve A is a similar set of curves obtained on the same tube but with a lower filament temperature, so that the total emission is about one milliampere.

It will be noticed that these curves, particularly those with the positive grid voltages, are straight lines, and they are over the larger part of their range parallel straight lines; only at low currents, which are small fractions of a milliampere, do the curves with the negative grid voltages tend to flatten out slightly, and that is due, I believe, to the fact that the grid is not quite uniform in mesh, so that some electrons are able to get past the grid, a very few electrons are able to get past one part of the grid when it is at such a negative voltage that electrons cannot get through the other parts of the grid.

The same is generally true of the curves with the lower filament temperature. They are essentially parallel straight lines until they approach saturation and then the current flattens out to approach saturation value.

We will now take a tube of practically identical structure—they were made in the factory about the same time, and are as far as we can tell almost identical structurally, but this is called the UV—200 tube shown on curve sheets A^1 and B^1. This tube contains sixty microns of argon which was deliberately put into these commercial tubes for the purpose of making them better detectors for radio signals. A large number of these tubes have been sold because of the better detector action of these tubes for radio signals.

If we look at the family of curves obtained from these we find that up to fifteen volts we again get practically a series of parallel straight lines, but beginning at fifteen volts they curve suddenly upwards, characteristic of ionization.

That is, these curves without ionization would follow out along the lines which I have indicated in dotted lines, and the sudden upward departure beginning at fifteen volts and becoming very large, indeed, at a little over twenty volts, is the normal and characteristic effect of gas ionization, showing that the limitation of the space charge is rapidly being removed and these currents would rise within a few volts up to saturation value no matter how high that might be. That is, no matter how high the electron emission from the filament may be, the curves would rapidly rise up to that saturation value. Of course, practically the tube might very rapidly become overloaded and injured.

Thus these tubes in their ordinary operation were limited to a very definite and narrow range of voltage running from about eighteen up to twenty-three or twenty-four volts, but in that region they are excellent detectors because of the high curvature, and excellent amplifiers, very much better amplifiers than the high vacuum tube at the same voltage.

Now, on curve A^1, curves that were taken with this gas tube when the emission was lowered to about one milliampere——

Q. 209. What is the number of that tube?

A. UV-200. No. 2 was the number given to this tube for the test. They were taken right out of stock and the pressures sixty microns are determined by the third electrode test, measuring the positive ions, these tubes this type of tube having previously been calibrated for use in that way.

Another tube was taken of the type of UV-200, which contained an unusually low pressure of gas for these tubes, nine microns, and during the course of the measurement of these tubes which ran up to fifty volts, the gas pressure cleaned up until there was only four microns of gas at the end of the test. For that reason, and as I do not know how the pressure changed in between, these curves are not strictly comparable on the part of the curve where there is ionization. But again we see the sharp upward bend of these curves beginning very definitely at about fifteen volts and running up as the voltage increases to thirty volts where the maximum slope is obtained.

But the currents become many times greater than they should be if the current followed the 3/2 power law over the whole range. I would like to point out that where on this curve the current appears to be twice its normal value, it really means about three times its normal value, because we have only plotted the 2/3 power of the current and I would have to put on these curves, on one margin, the currents of milliamperes so that it can be seen just how large the currents are and how large the deviations are due to the effect of gas.

I think everybody recognizes that in detector tubes gas greatly increases the sensitiveness as a detector in those parts of the curve where the curvature is made abnormally large by the presence of gas. There is a critical adjustment of any one of several factors. The plate voltage or the grid voltage or the filament temperature can usually be adjusted and all three can be adjusted to give the point of maximum sensitiveness as a detector.

But the amplifying power of the tube is also increased in a similar way by the presence of gas.

I have here taken some data on the amplifying power taken with the UV-200 tube and the 201 on this curve which I will mark E. We have plotted there as ordinate the millivolt amperes output plotted against the millivolt plate input when there is—1 volt on the grid. It will be seen that the tube which contained gas, which is the UV-200, shows a very great increase in sensitiveness as an amplifier at a plate voltage of about 27 volts, and that with voltages above 30 volts, it is a poor amplifier, poorer than if it had good vacuum. This amplifying power becomes higher beginning at about 15 volts.

The amplifier power of the high vacuum tube starts in gradually and increases very steadily without any critical points. By the time voltages of 65 volts are reached, the amplifying power becomes as great as that which was observed with the gas tube at 27 volts, and that illustrates what we do today with these tubes.

Although it is possible by means of gas to get high amplifying power, you can get high amplifying power with a high vacuum tube by going to higher voltages and since the high vacuum tube will stand the higher voltages, you can then get a curve which is uniform and has a uniform slope and this is a very much more desirable thing to do.

Besides that you can use your tube over much wider range of voltage and power input without getting appreciable distortion.

By The Court:

Q. 210. I miss why you get the same amplifying power at 65 in the vacuum tube as you do at 27 in the gas tube?

A. Amplifying power is represented by the ordinates in this case, the vertical distance above the axis. When the plate voltage is 65 volts the ordinate in this case is 3.4, which is a little greater than the ordinate of 3.16 for the gas tube at a voltage of 27 volts. You have more amplifying power with the high vacuum tube at 65 volts than you have with that at a lower voltage, say, for example, 27 volts. The amplifying power of the gas tube is 3.18 as compared with less than 0.5 for the other one.

That is, it is nearly six or seven times—the gas tube is nearly six or seven times better as an amplifier at 27 volts, but you can make up for that by going to a higher voltage on the plate.

Still another curve was made for a comparison of the amplifying power of these two tubes. In fact, a third tube was also tested, a gas tube, using a Western Electric Company amplifying test set that we got a good many years ago. We have not used it within recent years, but we resurrected it for the purpose of making these tests and the only object in using it is that it gives the "gain in miles," which has frequently been spoken of in this case.

It shows practically the same thing, that at voltages of 24 or 25 volts, one of the gas tubes shows a maximum amplifying power which falls to practically nothing at 30 volts; another gas tube increases very greatly in amplifying power and goes off the scale of the instrument, that is more than thirty miles at 28 volts; whereas, the high vacuum tube showed a steady increase in amplifying power as the voltage was raised.

Both the gas tubes within a certain range of voltage showed greater amplification than the high vacuum tube. The curve is not very smooth, because with this instrument it is a step-by-step instrument, so that you can only get certain definite miles gain and you cannot measure fractional miles.

By Mr. Lunt:

Q. 211. Did you give the designation of this sheet? A. It is marked F.

Mr. Lunt: I would like to offer in evidence these various sheets and have them marked collectively. They are explanatory diagrams.

The Court: Do you want to reserve for the record that Dr. Langmuir will make some additions?

Mr. Lunt: Yes. I would like to reserve the right to have the figures for currents supplied to the diagrams. I think it would be of help to all of us if we will also reserve the right to ink in these curves.

(The said sheets were received in evidence and marked as follows):

(Diagram A marked "Plaintiff's Exhibit No. 168." *See Volume IV, Plaintiff's Exhibits, page 50.)*

(Diagram A^1 marked "Plaintiff's Exhibit No. 168-A." *See Volume IV, Plaintiff's Exhibits, page 51.)*

(Diagram B marked "Plaintiff's Exhibit No. 168-B." *See Volume IV, Plaintiff's Exhibits, page 52.)*

(Diagram B^1 marked "Plaintiff's Exhibit No. 168-C." *See Volume IV, Plaintiff's Exhibits, page 53.)*

(Diagram D marked "Plaintiff's Exhibit No. 168-D." *See Volume IV, Plaintiff's Exhibits, page 54.)*

(Diagram E marked "Plaintiff's Exhibit No. 168-E." *See Volume IV, Plaintiff's Exhibits, page 55.)*

(Diagram F marked "Plaintiff's Exhibit No. 168-F." *See Volume IV, Plaintiff's Exhibits, page 56.)*

By Mr. Lunt:

Q. 212. In a tube of the character of the Fleming valve does the rectifying property of the tube, which enables it to detect wireless waves, depend necessarily on high vacuum?

A. The Fleming valve depends simply upon its rectifying ability to detect radio signals. It depends on the fact that the characteristic can rise above the axis but not below the axis and therefore it necessarily has a high curvature at some point between.

Below a certain voltage there can be no current flowing through the device. Above a certain voltage the current increases rapidly. In between there must be a point where the curvature is high.

Radio signals received are of very low voltage, giving voltages far below the ionizing voltage on the device, so that there will be no ionization within the device even if there is a large amount of gas present.

The rectifying action does not in any way depend upon the presence of gas or upon the absence of gas. It depends entirely upon the fact that the cathode cannot emit electrons except when there is a positive field to draw them away. No current of electrons can pass across from one electrode to the other if the anode is of negative potential.

Only if such high pressures of gas are present that they actually collide with the electrons to such an extent that they seriously impede the motion of the electrons would the presence of gas decrease the effectiveness of the device as a detector. At pressures of 100 microns or more the electrons will make several collisions with gas molecules in passing across the device. So that pressures of 100 microns or more would be somewhat deleterious, but there is no advantage in the device of the character of the Fleming valve to go to pressures of less than 50 microns.

Q. 213. Will you discuss briefly the matter of anode bombardment in thermionic vacuum tubes and point out whether or not heat production is in all cases necessary to disengage gas?

The Court: This is in the operation of the tube?

Mr. Lunt: In the preparation of the tube.

The Court: I see.

Mr. Lunt: That was the point that I had more particular reference to, but the phenomenon might appear, I suppose, in the operation.

The Court: That is the reason I asked. Dr. Langmuir explained it to me, or Mr. Davis, rather, at recess yesterday, and I was wondering whether bombardment at any time plays any part in the operation of the tube. I do not know that it does, but I have not been told. If this has not anything to do with the case, you may omit it.

Q. 214. Will you please clear up this point which his Honor has mentioned?

A. When electrons flow through a metal they meet extremely little resistance. They are already moving in the metal at room temperature and the difference of voltage applied between the ends of a piece of wire causes them merely to drift. They are already moving in all kinds of directions. A little voltage applied tends to make more drift one way than the other, and results in the transfer. That is not accompanied by any large evolution of heat.

For example, suppose an electric current flows through a tube at say 100 milliamperes. The passage of that current through the electrodes and through the wires leading to them will not appreciably heat them.

The electrons in the hot cathode evaporate out, tend to evaporate out, but if there is no electric field which tends to draw them away they will go back again, the same as if you had a kettle of hot water on the stove. Steam will be coming off, but it will be condensing back and unless you have an opening for it to get out there will be no cooling effect and no net evaporation.

If you draw off the electrons from the hot cathode they do not return back to the hot filament and you get a cooling effect due to the evaporation. It actually cools the cathode but not very much. It is an effect which can be measured.

When those electrons get out into the space and pass across the space they may be accelerated and set into very rapid motion by the pull of the positive charge on the anode if the anode is positively charged.

For example, suppose the anode is charged to a positive potential of 100 volts. Then the electrons moving through that potential are continually set into more and more rapid motion just as a body falling under the earth's gravitation starts in moving slowly and continually accelerates and the energy is stored up in the form of kinetic energy.

The electron acquires kinetic energy. When it is finally brought to rest on the surface of the anode all that kinetic energy is converted into heat. Electrically we know just how much heat can be produced because it is the product of the current times the voltage. Watts is equal to volts times amperes. If we have 100 milliamperes of current, that is one-tenth of an ampere, and 100 volts, the product of those two is ten watts.

There will be liberated at the anode ten watts of energy just as though that anode were in the form of a fine filament which could be heated with ten watts of energy. But in order to heat it in the form of a filament it would have to be made of small cross-section, so that its resistance would be high. If it is in the form of a plate the passage of one-tenth of an ampere through it would not appreciably heat it.

We speak of that as bombardment by electrons, because the electrons give up their energy just as a projectile gives up its energy when it strikes a wall. In the exhausting of tubes and in the operation of vacuum tubes the anodes or any positively charged electrode which takes up electrons becomes heated as a result of this electron bombardment and it becomes important to inquire how strongly it is heated. That depends on the energy.

Suppose we take for example an old-fashioned audion, an old DeForest audion. Suppose the filament takes five volts and it takes four-tenths of an ampere of current. That is two watts of energy put into the filament. That energy is radiated from the filament into the space around and a certain amount of it is intercepted by the two plates, we will say one-third of it may be intercepted by the two plates or one-sixth by each one. That will be one-third of a watt that will be intercepted by each of the two plates, and that will tend to heat those plates, and in vacuum it heats them quite a good deal, that is, probably to two or three hundred degrees Centigrade—just the radiation from the filament.

Now, besides that fact, during the operation of the tube there is a certain amount of energy generated by the electron current that flows. Suppose we have one-half of a milliampere of current, and suppose we had fifty volts, that is, 0.025 watts, which is less than one-tenth of the energy which is radiated by the filaments and intercepted by each of the plates. So that the total energy of that discharge of half a milliampere and fifty volts is negligible compared to the heating due to the radiation from the filament.

So that bombardment, although it is of the same kind as bombardment that could be used for heating the electrodes, is negligible in quantity and without appreciable effect on freeing the electrodes from gas.

On the other hand, if you have, for example, as mentioned yesterday, in this audion No. 2, during its operation or during the measurement of the characteristic of the audion, 15 milliamperes at 250 volts, the product of that is 3.7 watts. 3.7 watts as against 1/40 of a watt is 150 times more energy liberated on the plate.

That would heat those anodes only moderately, 3.7 watts, because the energy used in an ordinary filament would be of the order of thirty or forty watts to raise it to incandescence, for example, or fifty watts would be used—I do not know the exact figures and I think they are in Mr. White's notebook—the actual energies used in raising the anodes to incandescence, while they are run during the baking out of the tube.

I want to point out that it takes a great many watts on a small electrode to heat it even to a moderate heat. Energies of a few hundredths of a watt are not of any importance in that regard.

Now, there also occurs in tubes such as the De-Forest audion positive ion bombardment. If there are positive ions in the gas, that is, if there is ionization of the gas there will be a certain number of positive ions produced. And those positive ions will usually go to the cathode and if the glass walls are exposed they will also go to the glass walls and they strike the glass walls, having fallen through a considerable difference of potential, so that they have relatively high velocity by the time they strike the glass walls, since the glass walls as well as the cathode will be negatively charged, because the electrons flow so easily to them that they give a negative charge to the walls just as there is on the cathode. The positive ions strike the cathode and strike the walls. They cause a slight heating of the walls that is not very important, except in some devices like the mercury arc rectifier, when it is important.

But they bombard the walls, and I believe even with no heating of the walls (thus, the temperature of the walls may be very low, they may be cooled with ice, for example); bombardment by the positive ions causes the liberation of gas. For example, in the mercury rectifier tube or mercury lamp, if it is cooled with ice, the bombardment is much more severe than if it is allowed to be at room temperature, and it causes an actual disintegration of the glass itself, and it will wear the glass down. I have seen positive ion bombardment so severe in some cases that it has actually worn the glass through, until the air leaked in or where it had worn it so thin that it could no longer hold the atmospheric pressure.

The positive ion bombardment will liberate gas from the surface, and it may do that even when there is little positive ion bombardment, if the gas has not been properly baked out. In the same way the electrodes that have not been properly baked out, may have gas liberated by a very moderate amount of positive bombardment in the tube.

With very high voltages such as exist in X-ray tubes and even at several hundred volts, positive ions may be driven into the glass with such velocity that they actually penetrate the glass and therefore are removed from the space.

Now, just one other point, and that is, that the positive ion currents that can be obtained, are always in these devices very, very small compared with the electron currents, even if there are enough positive ions to neutralize space charge completely and allow the current to run up to saturation, for if you neutralize space charge entirely nothing else limits the current. Under these conditions the currents carried by the positive ions will in general be of the order of 1 per cent. or less of currents carried by the electrons. The reason for that is that the positive ions, even with the same force, move 100 times slower than the electrons, so that although you have as many positive ions as electrons in the space (where the space charge has been eliminated as when you have no space charge), since the positive ions are moving 100 times slower than the electrons, they carry much less current, because the current measures the density multiplied by the velocity with which they are moving. So that even in a mercury arc rectifier, as for example, under the conditions that Dr. Arnold spoke about, where he had his auxiliary electrodes bombarded by positive ions, he having put negative voltage on these electrodes (in that case he used 300 or 400 volts), he got only a few milliamperes of current, whereas when he baked out his anodes by electronic bombardment, probably fifteen or twenty volts was effective in causing amperes of electrons to move, so that in such cases we will have a high current at low voltage. We may get the same amount of energy in other cases by the reverse.

Q. 215. I think you have overlooked, or may have overlooked one portion of my question: Is heat in all cases necessary, or is some peculiar effect of bombardment which makes it unnecessary in some cases to operate to secure a diminution of gas?

A. From the experiments that I described yesterday, which were carried on by Mr. Sweetser, before Mr. White built audion No. 2, I became convinced at one time that the impact of electrons on a metal electrode, caused the evolution of gas, and therefore concluded that if a pump were operating at that time, the ~~gas~~ could be removed. That is, the impact of electrons even without heating the electrode, appreciably could be used to remove gas from the electrodes.

I now think that I was entirely wrong in that conclusion, and that I was led astray by the fact that I did not recognize that the gas was liberated not by the impact of the electrons on the surface of the electrode, but by the small number of positive ions formed by the discharge in the liberated gas—by the positive ion bombardment that accompanied the discharge. That is, you may have an electron current which is accompanied by a small amount of ion current. The positive ion current although small in amount, may be enormously more effective in causing the evolution of gas from the walls and the electrodes, than the electron current is.

I think that the electron current in itself does not cause any evolution of gas from the electrodes and therefore can not be used as a means of freeing electrodes from gas unless that electron bombardment heats the electrode and I think that heating in any manner to the same temperature and for same time, would be just as effective as the electron bombardment.

Q. 216. Now, referring to the matter of getting rid of gas from the anode of a tube, will you explain the degree of effectiveness to be expected from the use of heat applied externally to the bulb without internal generating heat in any manner?

A. Baking out a tube containing metal electrodes to the highest temperature that the glass will stand, is entirely ineffective as a means of freeing the electrodes from gas, to a degree sufficient to be useful in making a pure electron discharge device. That tube I spoke of yesterday, with the metal electrodes, that first audion that we built with the plates as the anodes, was the first thing that convinced me of that fact. That tube was baked out at 425 degrees for an hour and then allowed to cool, and the filament was baked out, but as soon as we applied voltage to the electrodes, voltages below 250 volts, and drew the appreciable electron currents, we had clear evidence of ionization. In other words, heating to 425 degrees for an hour, which is really a very severe heating treatment of the bulb, did not make it possible to operate that device as a pure electron device, because gas is immediately evolved as soon as the device is used.

Now, I have had many other occasions to notice that same phenomenon. In this case on the motion to dissolve, I believe I constructed a tube of that character and made a tube with a nickel anode, a nickel cylinder, and put into it a tungsten filament, and we baked out that tube at high temperature for, I believe, about an hour, using liquid air, with a liquid air trap below the lamp, and using, I think, a condensation pump, that is, a mercury vapor pump, a very rapidly operating pump. In other words, we used all the knowledge of the year 1920 or thereabouts, 1919 it may have been, to get a good *vacuum* in the tube, and we also flashed a filament to get the gas out of a filament, and the device was sealed off; but immediately before we could measure the first characteristics of the tube, just as soon as we raised the voltage above the ionization voltage, there were very marked evidences of gas ionization. The resulting curves are given in the record on that motion to dissolve.

Q. 217. I would like now to call your attention to the Lilienfeld & Rosenthal paper which I think is Defendant's Exhibit No. 31. If you have a copy of that paper available, will you look at that portion of the paper referring to the auxiliary discharge, making use of the hot cathode and explain how the same operates, and what are the surrounding conditions in your opinion?

A. In this paper as in the first paper by Lilienfeld & Rosenthal, there is given a diagram showing the four electrodes of this tube. That is, the X-ray cathode and the anti-cathode, or target; and then the auxiliary anode and cathode. It is, I think, recognized by every one that the X-ray part of this tube, that is, the discharge between the cold cathode and the anti-cathode or target, depends absolutely upon positive ionization. That is, no electrons can get out of the cold cathode, except as the bombardment of that cathode by positive ions, and the positive ions can come only from the ionization of gas in the tube.

Now, when in this tube it is desired to get soft rays, as is stated in the paper that just follows by Rosenthal, the current of 180 milliamperes is passed between the auxiliary cathode and the auxiliary anode, and the voltage is said to have come from the city supply line; and in Germany, that means 220 volts, as that is the usual voltage, and the current is regulated by a resistance control in that line.

The voltage available, that is applied between the auxiliary anode and cathode, is less than 220 volts, depending upon the magnitude of the resistance, that is, in series. Assuming that voltage is 200 volts, we can estimate from the geometry of this tube how much current could flow over to the anode, if the current is limited by space charge. I can also tell from my own experience with high vacuum tubes, the order of magnitude of currents that can be obtained from hot cathodes to cold anodes, with distances such as those that are described here; and I find that it is utterly impossible to account for any such currents as 180 milliamperes, except by assuming that the space charge was eliminated by positive ions, or partly eliminated by positive ions; that is; a current of 180 milliamperes is many many times larger than a pure electron discharge current that could flow across a tube of that character.

Now, just to show the kind of difficulty that you get into if you try to account for these currents as a pure electron space charge current, let us make what my experience has taught me to be an equivalent construction. Assuming the bulb to be five or six inches in diameter (the ordinary size of an ordinary X-ray tube, which is about seven or eight inches in diameter), the cathode appears to be about two centimeters long, and the distance between the cathode and the nearest end of the anode is well over a centimeter, or a centimeter and a half or so, and certainly the average distance between the cathode and the near end of the anode, can be taken as two centimeters. The larger part of the anode is at a much greater distance than that.

Now, just assume that that distance is about two centimeters, and assume that the effective area of the cathode and anode are three square centimeters, and that we can apply the space charge equation that applies to the parallel planes. Then substituting into that equation the voltage of 200 volts, you can calculate that the current will be five milliamperes.

Now, of course the geometry is not exactly that. These are not parallel planes, but that would not affect the order of magnitude. There were many factors which would tend to make the current much less than that, if the current were limited by space charge. For example, the whole surface of the bulb, the very large surface of the bulb, is going to be negatively charged even with respect to the cathode, and that is going to add to the effect of the space charge and tend to decrease the current.

For example, suppose, however, you say that the area of three square centimeters is less than the effective area of the anode (I really think that would be the best value to take for the effective area), the question arises as to how big you would have to take the area, in order to get 180 milliamperes. Well, you find you would have to have about 100 square centimeters, that is, the anode and cathode would each have to be 100 square centimeters in order to give you the current at that voltage. But that is utterly impossible, because neither the anode or cathode have anything like that area.

I may also say that my own experience, with a large variety of different kinds of tubes with different kinds of geometries, and currents of only 200 volts, tells me that we get voltages of a few milliamperes under conditions of this sort, two or three milliamperes, up to five or six, or something of that sort, and that you can not possibly get currents of 180 milliamperes limited by pure electron space charge at any such voltage as 200 volts.

That is one factor that indicates to my mind positively that the Lilienfeld X-ray tube could not have had the currents even in the auxiliary circuit limited by electron space charge independently of positive ionization. The positive ionization was needed as much in the auxiliary circuit as in the other X-ray circuit to make that tube work.

There is another factor that makes me feel absolutely sure that that tube had to have positive ionization for its operation even for the auxiliary circuit, and that is this fact: There is in this tube a cathode, a cold cathode of the X-ray discharge, and that cathode is negatively charged to some thirty to fifty thousand volts. This voltage is used to speed up the electrons, so that they will strike the anti-cathode. This must be negative to say 50,000 volts. Now, we know, and I know from my own experience, that putting my hand on the outside of those tubes in November, 1912, and connecting them to 250 volts shop line, completely stopped the current. I could stop it with the finger held near the bulb.

Q. 218. What do you mean by those two?

A. I mean the three lamps that I exhausted on November 19th. Here we have a much worse case. We have an electrode inside the bulb at a potential of minus 30,000 volts that would have absolutely stopped any pure electron discharge between the other electrons in the bulb. It is essentially like a grid with minus 30,000 volts, which would have stopped any current that might have flowed from the hot cathode to the auxiliary anode.

If, however, there is gas in the tube, and of course, we know there is gas, we know there would have to be positive ions, to have the tube work at all;—if there is sufficient gas to partly neutralize the space charge in the auxiliary discharge with the currents that flow from the hot cathode to the cold anode, then you will have a *screening action.* My work in Schenectady for the last three years has been very largely a study of this phenomenon in connection with mercury vapor discharges, the screening action of gas ionization as effecting the charge on a given electrode.

For example, I can illustrate by this: Let us suppose for example, that we have in this bulb ionized gas so that the space charge is largely eliminated. For the sake of illustration, let us assume that positive and negative ions are present in equal numbers.

Now, we put 10,000 volts negative on the cold cathode. The effect of that is to draw the positive ions towards the cathode and to push back the electrons so that the electrons that are moving around in this space that have come from the hot cathode, are pushed away from that electrode, and there is therefore a certain volume near the cathode from which the electrons are excluded, but the positive ions are not. The positive ions are moving into that region.

Now, as that electron atmosphere is pushed away from the cathode, by gradually increasing the voltage on the cathode, the amount of positive charge within that volume from which the electrons are excluded, gradually increases, as its volume increases, until finally the total positive charge in that space becomes equal to the negative charge on the electrode. Well, then, they neutralize one another so that at the edge of this region which I have called by the name of sheath (the positive ion sheath is the region where there are positive ions only) at the outer edge of that sheath where the electrons are no longer repelled, there is *no field* due to the cathode and it is for the reason that there is no field that the electrons are not repelled. If the field extended beyond that, electrons would be pushed still further out.

So we find always in ionized gases, and I have studied them at various pressures, with a very small fraction of a micron, and with high and low current densities, that if you have an ionized gas and put a negatively charged electrode into it, it becomes surrounded by a sheath beyond which the field of that electrode does not extend at all; so that the field is screened off from the other electrodes in the tube by the positively ionized atmosphere that accumulates.

We know in this device that we have positive ions streaming towards the cathode, because that is the way the tube works, and what I wish now to point out is that these positive ions not only cause the cathode to work as an X-ray cathode, but it screens the auxiliary cathode from the negative charge on the cathode, and make it possible for *that* to work. It is only because of that screening action that it would ever be possible to get any electrons at all out of the hot cathode in the neighborhood of another electrode charged by 20,000 volts.

There are thus two phenomena that I understand perfectly well and have worked on for years, that prove to me conclusively, and it is my opinion, that the auxiliary cathode in that device depends upon positive ionization for its action, just as much as the X-ray cathode or cold cathode did.

Q. 219. I have one very short question I would like to ask you before we leave this subject. Will you compare the magnitudes, and do so very briefly, of the degree of vacuum in the old style X-ray tube, and the modern X-ray tube, operating with a pure electron discharge?

Mr. Haight: This invention does not relate to X-ray tubes, I understand. That is immaterial.

Mr. Lunt: It does not relate, your Honor, to specific styles of X-ray tubes, but the X-ray tube which I referred to as the modern tube, is a tube which operates with a pure electron discharge, and to that extent is an exemplification.

THE COURT: I think the X-ray tube is possibly not so far removed from the subject matter of the invention as to make it wholly irrelevant, so I overrule the objection.

A. In the old-fashioned X-ray tube, the positive ion bombardment was essentially to cause the electrons to pass from the cathode, and that, of course, required gas. Now, in the old X-ray tubes, there was gas in the electrodes. They usually used an aluminium cathode which had never been baked out, and which was just loaded with gas. It was heated when the tube was heated, during bake out, and it became heated somewhat by the passage of current through the tube, while the device was on the pump, but it never became baked at all in the sense in which we bake out electrodes today, so that during the discharge bombardment of the cathode by positive ions caused the liberation, practically instantaneous liberation of large quantities of gas right from the surface of the cathode during the operation of the tube. At the same time, the passage of the discharge with these high voltages produced positive ions, which also were at high velocities, and were driven into the glass, and to some extent driven back into the electrodes, so there was a balance between the gas evolution and the gas consumption, or the gas removal by driving into the glass.

Now, at those high voltages the gas driven into the glass did not all come back: very little of it came back during the operation of the tube. The residual gas in the tube at the time of pumping was a negligible factor compared with the gas that came off from the electrodes during the operation of the tube. The tube could be pumped down to a good vacuum. I mean below a micron, if you wished, and the first time you put on high voltage, the gas would be evolved from the electrodes, more or less, as it was needed, and the moment the discharge started, the pressure would come up to several microns.

Now, if those electrodes were baked out, as they gradually became during the operation of the device itself, the X-rays became more penetrating, and both the cathode and the anode became more and more heated, and they gave off larger and larger quantities of gas. But the gas was absorbed gradually, or became consumed by being driven into the glass. There finally came a time when the gas evolution was no longer sufficient to keep the discharge going.

Now, then, they had devices for introducing gas, and these would help out for a certain length of time, but finally the tube would stop even then. Even putting in considerable quantities of gas, you could not get the tube to operate for more than one exposure, lasting perhaps a couple of seconds. Thus the tube would start out in the beginning by being a soft X-ray tube, and at the end, during one exposure, of maybe one second, it would become very hard, and you could then not get a discharge through it lasting long enough for the X-rays that had been generated to take a photograph. That was said to be a cranky tube. The pressures in that tube that were necessary to keep a discharge going after the electrodes became at all deficient in gas were of the order of 5 to 10 microns.

In the beginning the tube would operate with somewhat lower pressure gas, for then the gas was evolved from the electrodes as the discharge passed and the vacuum during matters of seconds would change manyfold. As there were enormous changes in the vacuum that would take place almost instantaneously.

In the Coolidge X-ray tube, on the other hand, its is very important to get rid of the bombardment of the cathode by positive ions, because such bombardment disintegrates and destroys the cathode very rapidly. The ordinary vacuum in the Coolidge X-ray tube is of the order of 0.01 micron, that is, several hundred times better vacuum than in the old-fashioned X-ray tube.

(Whereupon, at 6 P. M., adjournment was taken until Wednesday, November 3, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del.,
Wednesday, November 3d, 1926,
10 o'clock A. M.

FIFTEENTH DAY.

HON. HUGH M. MORRIS,
U. S. District Judge.

Appearances: As before.

IRVING LANGMUIR, resumes the stand.

DIRECT EXAMINATION (Continued).

By MR. LUNT:

Q. 220. I will ask you if you have read the deposition of Lamont and of Mrs. Beck offered on behalf of the defendant in this case, and I believe referred to as part of the San Francisco depositions; and do you understand the state of facts and procedure under which the DeForest tubes therein referred to were exhausted?

A. Yes. I have read the deposition and I understand the facts concerning the exhaustion of these tubes.

Q. 220a. If this state of facts and procedure correctly represents what actually occurred and what was the apparatus used as set forth in the deposition, what is your opinion as to the degree of vacuum which was obtained in the DeForest tubes by following the procedure outlined and would the tubes operate as pure electron discharge tubes? In giving your answer, will you please state the facts upon which it is based?

A. The method of exhaust that is described in Mrs. Beck's deposition and is referred to again in Mr. Lamont's deposition was a very crude exhaust using a rather poorly made Springel pump. There was no attempt described in the deposition to remove mercury vapor, in fact it would have been impossible from the construction of that device to have removed mercury vapor from the lamp. Several ground glass joints were used which was made tight with a mixture of vaseline and bee's wax. A ground glass joint of this kind with this material on it gives off hydrocarbon vapors which are decomposed by the filament when it is lighted and generates considerable quantities of gas and prevents the obtaining of a good vacuum.

There was no treatment of the electrodes, no bombardment of the electrodes, no voltage was applied on the electrodes during the exhaust treatment. I know from my own experience that unless metal plates are heated to a very high temperature by bombardment during the exhaust, the apparatus will not function as a pure electron device in operation.

I discussed yesterday the experiment of the nickel anode tube in which the object was to give the tube as good an exhaust as we knew how or give all the exhaust treatment that we give the tubes that are exhausted most carefully, leaving out only one factor, and that is leaving out the bombardment of the anode during the exhaust for the purpose of heating it and denuding it of gas and I stated that the results showed that the treatment was entirely inadequate. Merely heating the bulb with the electrodes in it does not suffice to free the electrodes sufficiently from gas to allow the proper operation of the tube.

Q. 221. No matter how hot you heat it?

A. Up to any temperature that the glass will stand. If you could heat to a bright white heat by external heating you might be able to——

By The Court:

Q. 222. What temperature would that be?

A. Red heat in an ordinary room begins about 700 degrees Centigrade. In a very dark room you can see at night, with the eyes well rested, you can see it at five or six hundred degrees, but ordinarily you first begin to notice red heat on small bodies in the vacuum at about 700 degrees, and eight or nine hundred degrees would be a fairly bright red heat.

I did not finish what I was going to say. If you could heat to a bright white heat probably you would get the gas out sufficiently well, but the glass will not ordinarily stand over 360 to 400 degrees. Four hundred degrees is approximately the maximum temperature in heating glass bulbs made of ordinary glass. Only with the very hard glass that we use nowadays, like pyrex glass, can you go about 100 degrees higher. Even with pyrex glass we do not heat over 450 degrees.

By Mr. Lunt:

Q. 223. What is your opinion as to the adequacy of the heating means if there was any that was used by these witnesses?

A. There was no way of telling what kind of heat treatment these bulbs received. There was no measure of temperature, or if any attempt was made to measure the temperature it would not have meant anything, because the bulb was not in an oven which would have reached a definite temperature. The bulb was placed above a ring burner, a Bunsen burner in the form of a circle which was placed below the tube and above the tube was a rather flat cone made out of asbestos. Probably the lower part of the bulb was quite hot and the upper part or the sides may have been very much lower temperature. If a thermometer had been placed by the side of the bulb there is no way of knowing whether the thermometer and the bulb were at the same temperature.

Q. 224. Excuse my interruption. Now, will you go on with your answer?

A. I think I had finished my answer.

Q. 225. I do not think you gave me your opinion as to what kind of a vacuum would have been secured, and whether the tube operated with a pure electron discharge?

A. I think an audion made in the way that is described in these depositions would not operate with a pure electron discharge but would operate about the way most audions did operate at that time.

Q. 226. Is there anything else that you found in these depositions or any of them which would alter the opinion you have expressed?

A. No.

Q. 227. Would the method of obtaining the vacuum as set forth in the Lamont and Mrs. Beck's depositions, if used in a device containing a thoriated tungsten filament as set forth in the second, third and fourth of the patents in suit, would it have been sufficient to obtain the degree of vacuum and freedom from deleterious gases characteristic of the devices of those patents, as set forth in those patents?

A. No. The quality and degree of vacuum would not have been nearly sufficient to enable the beneficial results of the use of the thoriated filament to have been obtained.

Q. 228. What are the reasons which you had in mind in giving the last answer?

A. The fact that the electrodes are not sufficiently freed from gas to enable the device to operate in such a manner as to retain during operation the film of thorium on the surface of the thoriated filament. Furthermore, I believe that the bulbs would not have been sufficiently freed from water vapor to have permitted the operation as thoriated filament.

Q. 229. Would the mercury vapor which I understood you to say would inevitably have been present in that bulb, would that have had any effect?

A. That would have prevented the operation of the filaments giving the characteristic emission of the thoriated filament after properly activated at voltages materially above the ionizing voltage, because the mercury ions and the ions of other gases would bombard the surface of the cathode and would knock off the thorium. That is, a thoriated filament which has the high electron emission because of the monatomic film of thorium on the surface is extremely sensitive to positive ion bombardment. It is only a layer of one atom thick which is about one one-hundred millionth of an inch thick. A very minute amount of positive ion bombardment at voltages of say fifty volts will rip off or disintegrate this film and destroy it.

So that the degree of vacuum must be so high that that can not happen and the degree of vacuum in these tubes could not have been sufficiently high for that purpose.

Q. 230. Is it or is it not your opinion that ionization must have been inevitably present at voltages above the ionization voltage in these DeForest tubes?

A. There would have been some ionization just above the ionization voltage, and it would increase rapidly, as the voltage was raised above that.

Q. 231. What difference in operation do you understand there would have been in these DeForest bulbs exhausted by Lamont and Mrs. Beck, as compared with the DeForest bulbs about which you have testified, I mean the DeForest bulbs of 1912?

A. I think they would be like most of the DeForest bulbs of that time. They may possibly have been heated a little hotter than some of the DeForest bulbs were by the Bunsen burner flame, but I do not think there is any real reason to believe so. I forgot to mention among other factors that would have prevented the obtaining of a good vacuum in those devices, the fact that sulphuric acid was used as a drying agent. Sulphuric acid, so far as I know, has never been used in any kind of apparatus for getting good vacuum in modern days. In fact, I have never heard of a case before where sulphuric acid was used as a drying agent. Sulphuric acid is a liquid which boils at a moderate temperature and has a very high relatively high vapor pressure, giving off, sulphur trioxide vapors, which would be a very high hydroscopic, and would probably condense to some extent over the inside surface of the bulb. It is stated in Mr. Lamont's deposition that phosphorus pentoxide was used and sulphuric acid, so that there is no way of telling when one was used and when the other was used. The photograph shows a liquid in the bulb below the lamp, and Mrs. Beck refers to this as the acid bulb, indicating that when she used it, at any rate it contained sulphuric acid. An oxygen-containing substance like sulphuric acid is very bad naturally to use with a thoriated filament. That is, if it is desired to get the high emission which can be obtained from a thoriated filament, a gas such as sulphur trioxide would spoil the surface of the filament. Even phosphorus pentoxide I found destroys the activity, that is, the vapors of the phosphorus pentoxide at room temperature destroys the activity of the thoriated filament.

Q. 232. Now, I would like to direct your attention to the pump used by Lamont and Mrs. Beck, or either of them, and will ask you to explain later, briefly, very briefly, the operation of the pump and whether you find any significance in the fact, which I believe you have not mentioned, although I think it is referred to in the depositions, and I wish you would correct me if it is not the fact that a charge of thirty cents was made for the evacuation of each DeForest bulb?

A. I do not remember that Mrs. Beck states definitely the length of time in which the bulbs were exhausted. Mr. Lamont says in one place that the exhaust was continued for from one hour to two and a half hours. Mr. Lamont speaks of using the automatic lift for the mercury; as the mercury was returned after flowing through the pump, it was returned from the bottom of the pump back to the reservoir (which is referred to as the percolator), by an automatic pump. But Mrs. Beck stated that that pump was not used, I think, until 1913 or 1914, and that before that the mercury was returned by hand in containers that weighed sixteen pounds. That is, periodically, the mercury would have to be lifted from the reservoir at the bottom and poured back into the reservoir at the top. It seems to me very obvious that nobody could afford in a commercial laboratory to spend two and a half hours exhausting a single lamp by a process that required continual attention; lifting the mercury at frequent intervals from one reservoir to another, and watching the operation for two and a half hours, for thirty cents. The thirty cents to me suggests that the exhaust treatment given was of the very simplest sort, and that it could be done without giving very serious attention or attention for any long time.

Q. 233. If Mrs. Beck has testified in effect that the vacuum secured in these DeForest tubes was as good as an X-ray tube vacuum, what inference would you draw from that?

A. Of course that——

Mr. Darby: Pardon me. Are you construing the testimony, Mr. Lunt, or will you refer to the portion of the testimony where Mrs. Beck says that?

Q. 234. I will ask the witness if he can refer to the place in the testimony.

A. I do not know that I can lay my hand right on it. I remember Mr. Lamont refers to the pump, that I think he said he knew the pump gave a good vacuum, because they used it for a very satisfactory exhaustion of X-ray tubes. I think it is in Mr. Lamont's examination where there is reference to the X-ray tube.

Q. 235. Never mind looking up that reference, please. If it be a fact that the vacuum was as good as that in an ordinary X-ray tube, what would be your opinion then as to the degree of vacuum?

Mr. Darby: May I have that read?

(Question repeated as recorded.)

A. The X-ray tube being a gas device requires for its operation a pressure far above that which will be sufficient to prevent the operation of an audion as a pure electron device; so that the fact that the exhausting system was sufficiently good for an X-ray tube, does not prove that it was good enough for the exhaustion of a thermionic device operating as a pure electron discharge.

Q. 236. I now wish to draw your attention to the second, third and fourth patents in suit. In these patents, as I understand, there are set forth certain materials which act to secure and maintain the vacuum. I will now ask you if in the following list of materials which I referred to in various places in the prior art, you find any material, which, according to your experience, would be capable of performing, to a sufficient extent, the functions of the materials referred to in the last three patents in suit. This list is as follows: Phosphorus; arsenic; sulphur; iodine; spongy platinum; mercury vapor; iodine vapor; ammonium; cuprous chloride; mercury amalgam; tungsten; hexachloride. For your convenience, I hand you a paper in which these substances are listed.

A. No one of these substances would produce or would help to produce the conditions that are needed for the proper operation of a thoriated tungsten filament as a thoriated emitter.

Q. 237. Will you very briefly give your reasons, as to each substance?

A. Most of these substances have far too high a vapor pressure. Iodine, for example, mercury vapor; iodine vapor, have relatively high vapor pressures. Sulphur has a very material vapor pressure.

Yellow phosphorus has a relatively very high vapor pressure, but red phosphorus has no appreciable vapor pressure. Phosphorus and arsenic, and in fact sulphur, iodine and of course iodine vapor and tungsten hexachloride vapors would react chemically with the filament and injure it, and tend to destroy the monatomic filament of thorium on its surface.

Mercury vapor obtained either from mercury itself or from mercury amalgams would produce no beneficial action and in so far as the vapor is present it results in positive ionization, it would cause a destruction of the film as a result of positive ion bombardment.

The same is true of each of the other substances which give off vapor in sufficient quantity to give ionization at the higher voltages. Ammonium cuprous chloride would probably be decomposed and give ammonia and nitrogen and hydrogen which would produce no beneficial result but would be distinctively harmful by causing positive ion bombardment. The whole character of these substances is very different from those that are used in the three patents that you have mentioned.

Q. 238. I think you referred to a film in the answer you have just given. What film did you mean?

A. The film of thorium atoms on the surface of the thoriated filament when operating with a high electron emission that is described in the last three patents.

Q. 239. What can you say as to the degree of effectiveness of vaporized tungsten in this same connection, that is, as a vacuum obtaining and maintaining material in connection with the devices of the last three patents in suit?

A. The act of vaporizing tungsten in a bulb, especially when the bulb is cool, greatly improves the vacuum, in that it removes certain gases. That is, the tungsten vapor combines with many different gases. At room temperature it does not combine with hydrogen but it does combine with nitrogen, oxygen, carbon-monoxide, carbon dioxide, and those are gases that are likely to be present in lamp bulbs. However, the fact that it does not remove hydrogen is a disadvantage even of the process in which tungsten is vaporized. If the bulb is cooled in liquid air while the tungsten is vaporized, hydrogen is to a very large extent removed and probably becomes covered up by the deposit of tungsten on the bulb, so that if a heavy deposit of tungsten is formed on the bulb, especially if the bulb is cooled in liquid air during the process, then the bulb can be removed from the liquid air and the vacuum will stay good provided no more gas is evolved from the electrodes, but after the deposit of tungsten is once formed on the surface of the bulb, if any more gas is evolved, as for example from the electrodes, or from a surface of glass that has not been thoroughly covered up by tungsten, the tungsten film is ineffective, almost completely ineffective in removing or combining with such gases.

That is, a deposit of tungsten does not give any keeping action; it is not a surface which will take up gases that may be evolved from electrodes or water vapor that is evolved from the surface of the glass.

That is quite different from the alkali metal which is used in the third patent, and the magnesium or calcium films used in the fourth patent. Those reagents are extremely effective in giving a keeper action, that is, maintaining good vacuum conditions even if gases are evolved from the electrodes or escape from the glass during the operation of the device.

Q. 240. In the testimony you have given I think you have referred to the DeForest audion as being sluggish. What were the facts as to that as they may have developed?

A. In January and February, 1913, when I was told that the DeForest audion was sluggish, I attributed it to the fact that positive ionization so obviously played an important role in the operation of the device. Later, I think it was in April and it may have been in May, when I visited the laboratory of John Hayes Hammond, Jr., at Gloucester, Massachusetts, and talked with Mr. Hammond and also with Professor Pierce of Harvard University who was there at the time, I realized that the sluggishness that had been referred to could have been amply accounted for by the fact that a grid had apparently always been used by these men.

Q. 241. Do you mean a grid?

A. I mean a condenser had apparently always been used by these men in series with the grid and there was no grid leak. I say that would be a sufficient cause for the alleged sluggishness because the condenser would become charged and the charge of condenser would leak off slowly. That is, the condenser would retain a certain charge although there was positive ionization to gradually neutralize the charge and this would not take place instantaneously, so that a certain time was required to discharge the grid after a signal had been received.

I did not investigate the question as to whether there was any other source of sluggishness. As far as I know the audion may also have been sluggish even if the grid condenser had been eliminated but I have no proof of that.

Q. 242. We will come now to another matter. You have spoken, I believe, of some disclosure that you made to Dr. Coolidge in December, 1912, and I think in that connection you referred to or read from your notebook. Will you refer to that notebook and particularly to that page, and I think it is page 157 of notebook 413, and if you find there a sketch of a plan for an X-ray tube, will you state whether you were able to make this function as an X-ray tube or a device like it?

A. I never attempted to make the device function as an X-ray tube and I know very well now from the ideas that I had at that time I would not have succeeded in making an X-ray tube even if I had built a device as illustrated in the picture.

When Coolidge did use the hot cathode to construct an X-ray tube, following my suggestion to him on December 10th, he did a great many things and things that were essential, which I had no idea of on that date.

My experience up to this time with electrodes free from gas had been entirely by the passage of current through the anodes themselves, for I realized that plate-shaped or massive metal electrodes gave off large quantities of gas and that it would be a very difficult matter, if not impossible, to remove the gases sufficiently well from such electrodes.

I did not attempt to solve that problem myself. I by-passed it and went around it by using anodes through which I could pass current, anodes in the form of filaments, because I felt that the other problem was one that was very difficult and I knew that Coolidge had been working along such lines and as to whether or not it would be possible to get massive electrodes sufficiently free from gas was a proposition that he was very much better prepared to work on than I was.

Q. 243. I would now like to direct your attention to the sixth paragraph of your answer to Q. 65, in which you make some reference to the fact that the current was limited by space charge. What was the state of the vacuum in the tube about which you were testifying?

A. At that time the vacuum was extremely high and the discharge was a pure electron discharge in which the current was limited by electron space charge independently of ionization. The ionization was not sufficient to appreciably affect the electron space charge. That same tube in the beginning had shown a relatively poor vacuum, but the vacuum had improved by the treatment that it was subjected to.

Q. 244. Will you now refer to your answer to Q. 216? You there stated that you used all of the knowledge of the year 1920 or thereabouts to get a good vacuum in the tube. Did you endeavor to deprive or denude the anode of gas? I think you have referred to this matter already in one of your previous answers, but I do not know whether it has been made quite clear.

A. I exhausted this tube, using the best methods of exhaust with the exception of the treatment of the anode by bombardment. The anode was only heated by the fact that the bulb was in an oven and the fact that the filament was lighted for a short time. There was no voltage applied to the anode and therefore the anode was not bombarded. That was deliberately and purposely done in order to see what would be the result of omitting this one factor in the preparation of the tube, that is, omitting the bombardment of the electrode by electrons and the resulting heating of the electrode.

Q. 245. I will draw your attention to the answer which you gave to Q. 116, page 1187 of the record, which you gave yesterday, and ask you in what sense you referred to Exhibit 105, tungsten wire audion No. 2, as "the first tube that was made which involved the use of an anode which could be heated to very high temperature to free it from gas"?

A. I meant to say that this was the first audion and not tube. I meant a tube of that character, a three-electrode tube of the audion type which had provision for heating the anode by passing the current through it. You will remember that a few weeks before that I had made an audion type of tube in which the electrons were in the form of plates and could not be heated by passing current through it.

Mr. Lunt: If your Honor please, I now have here the White notebook and the test record about which I interrogated this witness the other day and I would like to have them marked for identification. It was not done at that time.

The Court: Let them be marked. You do not want to put them in evidence. You will prove them by Mr. White.

Mr. Lunt: Yes.

The Court: Very well.

(Received and marked "Plaintiff's Exhibits F and G for Identification," respectively.)

Mr. Lunt: I am through with the direct examination.

Mr. Haight: May we ask your Honor's indulgence, in view of the fact that the labor in this case has been divided in the way I indicated, that Mr. Richmond and Mr. Darby, both be permitted to cross-examine in the respective fields with which they are familiar.

The Court: Yes.

By The Court:

Q. 246. May I find out from this witness the difference between a tube and an audion? You said that this Exhibit 105 or audion No. 2 was an audion and not a tube.

A. A tube is used as a general term to describe any kind of a device other than a lamp with high vacuum. We came——

Q. 247. And an audion is what?

A. An audion is a kind of tube, a vacuum tube. A Fleming valve and an audion and an X-ray tube are all spoken of as vacuum tubes. An audion is a particular kind of vacuum tube.

Mr. Davis: Three-electrode tube. The witness was distinguishing, I think, between a three-electrode tube and two-electrode tube.

The Court: I thought he denied it being a tube and said it was an audion.

The Witness: I said when I referred to it as a tube, I did not have in mind that this, for example, was the first tube in which I had heated the anode, because I had previously made in August, and November and December, I had made many tubes in which the anode had been heated but they were not audions.

The Court: Very well.

Mr. Davis: They were two-electrode tubes.

THE COURT: I get it, but this was the first——

THE WITNESS: Audion that I made.

THE COURT: The first three-electrode tube?

THE WITNESS: Yes.

THE COURT: I just missed that.

CROSS-EXAMINATION.

By MR. RICHMOND:

XQ. 248. I understood you to say that for tubes with hairpin filaments, you expected conformity to the 3/2 power law within something like one or two per cent.; is that correct?

A. I was discussing, I think, the effect of the initial velocities of electrons, and I think I had reference to the accuracy with which that factor would cause deviations in the 3/2 power law, and I may say I had in mind relatively high voltages, because at very low voltages the deviation became progressively greater.

XQ. 249. Would you consider that such a tube was "substantially affected by positive ionization," if the departure was more than one or two per cent., as compared with what it would be for a perfect vacuum?

A. I would not attach much importance to a few per cent. deviations.

XQ. 250. I want to get an idea of "substantially unaffected by positive ionization," as that expression has been used so much. In such a tube, what percentage of departure would be permissible from absolutely unaffected by positive ionization, and still come within the range of "substantially unaffected by positive ionization"?

MR. LUNT: If your Honor please, I think I must object to that. That calls for really an interpretation of the patent and the claims, which I take is for the Court.

THE COURT: Is not that in cross-examination?

My recollection is that the witness said that his first calculation was 1.7. Now, then, whether he is comparing any calculations or variations from infraction of the rule, I do not recall. Is this directed to that?

MR. RICHMOND: It was not directed to that particular example, but more than once he has used that particular expression, referring to his own work "substantially unaffected by positive ionization." For example——

THE COURT: I think that question is permissible, and I overrule the objection.

A. I do not think I can in general define what I mean by "substantially free from ionization" in terms of actual percentages. I think it is just the ordinary common sense meaning of the word "substantially." There is no definite demarcation between a thing that is substantial and a thing that is not substantial. You have got to decide that question for each tube, and take into account all the different factors. I mean nothing more by the word "substantially" than I would mean in ordinary usage. It is not a thing that I can express in percentages.

XQ. 251. Cannot you express it in percentages for a particular case, as, for example, for a tube with hairpin filaments?

A. I do not think so. In fact, if you use a particular curve, it would be a question to decide whether the deviations from the 3/2 power law are probably due to ionization or not due to ionization; and in order to decide that, you would have to take into account the fact, for instance, that the deviation would begin above the ionization voltage, and deviation below that would be ionization and would increase in the way that is characteristic of ionization. Now if the effect were too small, there would come a point where it would be so small that you could not be sure that it was due to ionization or whether it was due to something else.

XQ. 252. Then I understand you that any effect that is appreciably due to positive ionization violates the criterion of "being substantially unaffected by positive ionization," does it not?

A. Will you read that? (XQ.252 repeated as recorded.) To my mind "appreciably" is not at all the same as substantially. You may be able to measure an effect, and yet it may not be substantial, because it may not be important. "Substantially" implies the idea of something more than merely measurable or appreciable; but it means that it has substance, that is, that it is material; that it affects the things that we are considering, whereas appreciable means merely measurable.

XQ. 253. I want very much to get a definite idea of its meaning, and I was hoping that you could answer in somewhat the same way that you did in this place that I mentioned, where you suggested one or two per cent. Suppose you consider a modern General Electric type UV-201-A tube, that is a high vacuum tube, is it not, Dr. Langmuir?

A. Yes.

XQ. 254. Now, if that tube had a perfect vacuum it would have a certain characteristic; we understand that no tube has a perfect vacuum, but what percentage of departure in the operating part of its characteristic would be permissible, keeping within that criterion of being "substantially unaffected by positive ionization"?

A. At for example, at 100 volts?

XQ. 255. At the normal working voltage for that tube. I do not know what it is?

A. Well, that brings us back to the consideration of what the tube is used for, and so on, as to whether it is substantial or not; but practically speaking, it seems to me that if the current at say 100 volts is 10 per cent. or so above what it would be if it had a perfect vacuum, there begins to be substantial ionization. However, if the tube were used for purposes in which reproducibility much greater than 10 per cent. were very important, then, I think that you would have to say that a smaller value than 10 per cent. would become substantial, and on the other hand, if you are using the tube for some other purposes, or the tube is designed for other purposes, it might be that a value of more than 10 per cent. would not be a substantial amount. In other words, I think that "substantially" is to be used in the ordinary common sense way, the way that the man in the street uses it practically, and it is not a thing that has a precise, scientific meaning that can be expressed in percentages.

XQ. 256. And unless you have the use for the device very particularly in view, it is quite a meaningless phrase, is it not?

A. Not meaningless, no. I think, as the ordinary use of the word expresses quite a definite idea, but not necessarily a quantitative idea. I mean, not one that can be expressed in definite percentages. It is a relative expression, like most words in the English language. Their meanings are relative, rather than absolute.

XQ. 257. The current values of which you relied in your August, 1912, work, as plotted in the Interference record at page 2091, were limited by space charge, and were "substantially unaffected by positive ionization," were they not?

A. May I see the reference that you refer to? May I have the question read? (Question repeated as recorded.) Within the accuracy of the measurements, I see no evidence from these currents that positive ionization had any measurable effect on the electron space charge.

XQ. 258. But Dr. Langmuir, it seems to me you are now taking a kind of negative position, that you discovered no evidence that positive ionization was present. I thought your position was that you discovered evidence that positive ionization was not substantially present in this case?

A. I did. That is, it was not present in any amount that produced any observable effect. Of course, there was some ionization, but it was not substantial in this case.

XQ. 259. This means then, that these current values were substantially the same as if there had been no gas in the tube?

A. I think so, within the accuracy with which the measures could have been made, or were made, they are the same as if there had been no gas present.

XQ. 260. And the accuracy of measurement was to what percentage?

A. I should say the voltages were not measured, you see. They were determined from the shop line, and the shop line was on the average of about 250 volts. It may have been possibly ten volts less than that, five or more, or ten volts less. But the difference in those voltages was measured directly, let me point that out. If there is an error of ten volts in the upper reading there would have been an error of ten volts in the same direction in the lower reading. The voltage of 200 for instance, was obtained by subtracting the fifty volts, which was measured accurately from the assumed value of 250 volts. If it had been 240 volts for the upper reading, then the lower reading would have been 190, so that the slope would not have been very much affected.

XQ. 261. But aside from this possible inaccuracy in the voltage readings, you do think there could have been any inaccuracy of such order due to the presence of gas?

A. Of what order?

XQ. 262. The same order that you have mentioned for the voltage readings?

A. I do not know whether you refer to the percentage accuracy or the absolute accuracy, or what?

XQ. 263. You suggested ten volts at something like 200 or 250, that would be?

A. That is 4 per cent., say.

XQ. 264. Yes. Could there have been any such departure from the——

A. Yes. The currents were read on a voltmeter and I think the full scale reflection was 150 volts, and the currents were read to a tenth of a volt. I suppose there may have been something like 10 per cent., 5 per cent., to 10 per cent. possibility of error on the lowest current readings; that is, two-tenths of a volt, possibly.

XQ. 265. But I think that departure that you have in view is a possible instrumental one, is it not?

A. In reading the instrument; not an error in the calibration of the instrument, but the currents were very small.

XQ. 266. But now there was some gas in there, and how much——

A. I beg your pardon. One of these readings, I do not remember now, one of these readings was taken on a milliammeter; the other was taken by the voltmeter.

XQ. 267. There was some gas in the tube, we have all agreed that you can never get all of the gas out of the tube?

A. There was about 0.4 of a micron of gas.

XQ. 268. And in so far as these readings were different from what they would have been in a perfect vacuum, what percentage was that?

A. I do not know definitely, except I can form an estimate of it from subsequent experiments that were made.

XQ. 269. Well, we want your estimate.

A. Oh, I think they may have been 10 per cent. higher than they would have been in a perfect vacuum.

XQ. 270. Now, I want to ask you the same question for your three tubes of November, 1912, the ones that went under the names of lamps 3, 6 and 2; what percentage departure could there have been in the readings there from the perfect high vacuum condition, due to the fact that there was a little gas residue?

A. Well, of course, in these measurements there were a good many different readings. In some cases the vacuum was purposely made bad. Now, excluding those, if I may,——

XQ. 271. That is right.

A. Taking those in which the vacuum was made as good as I obtained in these readings, I believe that the effect of positive ionization in those was entirely negligible, probably less than 1 per cent. That is, the currents in a perfect vacuum would not have been more than 1 per cent., probably not as much as a very small fraction of 1 per cent. different from what they were observed to be. I base that on the fact that the method of exhaust treatment used, for example, in those lamps, is a very excellent one, as when I cool the bulb in liquid air, I know from subsequent experience that I would have obtained an extremely high vacuum, so high that ionization would not have had 1 per cent. effect on the count.

XQ. 272. I understood you to say that when you experimented in December, your bulbs were very much the same as in August, referring to the year 1912 for both months, except that you made them very much smaller for convenience in immersing them in liquid air in December; that is correct, is it not?

Mr. Davis: Is it not November? I simply

do not remember any testimony about December.

A. Mr. Davis, it is in the record, the old record.

XQ. 273. My understanding is that the very latter part of November, 1912, you started another experiment?

A. November 21 I started the experiment.

XQ. 274. That was when Sweetser started, was it?

A. Yes.

XQ. 275. And it ran over into December?

A. Yes.

XQ. 276. And you have relied on data taken in December?

A. I have spoken of them.

XQ. 277. It is that experiment that I am referring to?

A. Yes.

XQ. 278. It is in Exhibit 80 on the motions?

A. The experiment 317, Sweetser's experiment 317.

XQ. 279. Then, this reduction in size of the bulb ~~in~~ that experiment of the latter part of November and the month of December, 1912, as compared with August, 1912—I say this reduction in the size of the bulb was not a material change in the conditions of the experiment, was it, except as it facilitated using liquid air?

A. I do not think it had any appreciable effect. The electrodes were about the same distance apart, if you remember.

XQ. 280. What was that distance?

A. I do not know that I remember now. I think it is given in the notes somewhere, but my recollection is that it was about half an inch.

XQ. 281. I looked rather carefully in the notes and did not find it and that is the reason I asked you.

A. That was our practice at that time in making them up. They were all run on one press.

XQ. 282. Was the exact spacing of the electrodes material?

A. No, it would not have made much difference except in the actual values of the current.

XQ. 283. The further apart they were the less currents——

A. Yes, sir, smaller currents.

XQ. 284. What were the sizes of the bulbs in August and December of 1912?

A. Do you want me to look up the original notes or just from recollection? I remember them approximately.

XQ. 285. Go ahead and give us your memory.

A. I think the August experiments were in a bulb about something like four inches in diameter and the December experiments were in bulbs about an inch and a half or an inch and three-quarters in diameter, a little cylindrical tube.

XQ. 286. In both cases the bulbs were cylindrical?

A. I think so. I know they were in December and I am not quite sure whether they were in August or not.

XQ. 287. If you had repeated the August experiment with the December tube, would the current have dropped to the same space charge value when the pressure reached four-tenths of a micron?

A. The same order of magnitude. Certainly not exactly the same value.

XQ. 288. And if you had your filament temperature at 2225 degrees K., would the current have changed from 16 milliamperes to 5 milliamperes as the pressure was reduced?

A. I do not remember whether the diameters of the filaments were the same or not. If the filament had been a little larger in diameter or different in diameter in the two experiments the saturation current would have been different and the space charge current would not have been appreciably different.

XQ. 289. This August, 1912, bulb has not been saved, has it?

A. No.

XQ. 290. What is the last record you have of it?

A. At the end of the experiment 291.

XQ. 291. That ended in what month?

A. May I see the notes? I have the notes on experiment 317.

XQ. 292. Let me just defer that question. There was nothing important——

A. I think roughly that the experiment lasted until the first week in September, thereabouts.

XQ. 293. That is quite sufficient for my purpose. And that is the last record of the bulb that was used in that experiment so far as you know?

A. As far as I know the bulb may exist. Mr. Sweetser has kept most of the bulbs that he used in different experiments. Of course, a good many have been broken. They have not been very carefully kept.

XQ. 294. Have you made any search for it?

A. No.

XQ. 295. Quite indifferent as to whether it exists or not?

A. Yes.

XQ. 296. There was no particular reason for saving it, was there?

A. No. We obtained the information we wished with it.

XQ. 297. And the particular dimensions and appearance of the bulb which might have been learned by inspecting it or measuring it would be quite immaterial you think?

A. Practically so. We can find the exact shape of the bulb from the record that is made of the lampmaker's number, that is, the mould number was recorded by Mr. Sweetser and that bulb can be duplicated at any time.

XQ. 298. You did save audion No. 2 that was made in 1913, did you not?

A. Not deliberately. I do not think we did deliberately. I certainly had nothing to do with it. If it was kept it was simply because it happened to be kept. We keep some of our tubes and others we do not.

XQ. 299. Aside from the distance between the hairpin filaments in these bulbs of August, 1912, and December, 1912, what was the spacing between the two legs of each filament?

A. Roughly about half an inch or five-eights of an inch at the point of maximum separation.

XQ. 300. And a little variation in this dimension one way or the other would not have materially affected the results which you have testified to, would it?

A. No.

XQ. 301. What was the relative area of the filament and the lead-in wire for the bulb of August, 1912?

A. From the notes I would be able to tell exactly what the area of the filament was because we know the length and the diameter and I can estimate approximately the area of the lead-in wire. But I cannot tell you what the relation was unless I remember the diameter and length of the filament. I think it was probably about a five mil. filament and I think the total length is about 3½ inches.

XQ. 302. For the filament?

A. Yes.

XQ. 303. And what were the dimensions for the lead-in wires?

A. I think in all that work we used platinum lead-in wires, probably about a twenty mil. wire and the part inside of the bulb would be about ¾ of an inch for each lead, maybe ⅝ of an inch. In regard to the diameter of the filament I know that can be found in the notes of Experiment 291. So that although—

XQ. 304. I find I have it noted here. According to my notes it is 4.99 mil. tungsten wire. That seems reasonable?

A. Yes.

XQ. 305. I am sure then that it is in the notes. What was the diameter and length of the filament for the tubes of November, 1912, that is, that go by the name of lamps 3, 6 and 2?

A. The filaments were in length and diameter practically the same as those of 120 volts, 40 watt lamps. There were six loops, I do not remember the exact diameter, although I can calculate it. Roughly, the diameter was about 1½ mils. and the length about twenty or twenty-two inches for each filament before the middle section was burned out.

XQ. 306. And there were four lead-in wires each of what length and diameter?

A. I do not know definitely. Probably normal length of leads at that time. They were not factory made lamps. They were laboratory made lamps.

XQ. 307. But that length was what, the length of those leads was how much?

A. Probably about half an inch, each of those four leads inside of the bulb, perhaps 10 mils. in diameter.

XQ. 308. Suppose the distance between the filaments had been changed in the August, 1912, tube, suppose it had been doubled, for instance, would this have changed the gas pressure at which the current would suddenly have gone down in value?

A. A little, but not very much, though.

XQ. 309. In which way would the change have been?

A. The greater the distance in general the more ionization there would have been, so that I should think the lower the pressure at which the effect would take place, but it would not vary anywhere near as much if the anode were in the form of a plate. The distance would not be so important, because the electrons do not move in a straight line, between the cathode and anode, but they form very curved paths and circulate around the anode for relatively long distances before they are finally able to strike it.

XQ. 310. And would this same change have changed the value of the current at its lower value?

A. Which change, the change in gas pressure?

XQ. 311. Spacing the filaments further apart?

A. It would have decreased the space charge current slightly. Again, not as much as you would have expected from the space charge equations which applied to parallel plates in series.

XQ. 312. Referring to a time before August, 1912, you have said with some emphasis that you introduced a method of hunting for the cause of a certain effect by exaggerating various possible causes and noting whether any one of them gave the effect in an exaggerated degree. Do you mean that this general method was original with you?

A. No, I think I stated very definitely that it was not original with me but it was one that I used perhaps a larger percentage of the time than most people around the laboratory and probably elsewhere.

XQ. 313. Was it by this method that you arrived at the crucial results of August and November, 1912?

A. The experiments in August were made in carrying out that idea, that is, I was deliberately putting gases into lamps to much higher pressures than they ordinarily existed in lamps for the purpose of studying these fundamental factors in the way as I have described, and it was in the course of those experiments that I obtained the results that I testified about. In November, on November 19th, the object of starting the experiment was not an application of that method of working, but in the course of the experiment I did that very thing, that is, as soon as I had produced a good vacuum I proceeded to get a better understanding of the phenomenon that I had just observed by deliberately spoiling the vacuum in two ways, by heating the bulb and by applying high voltages.

XQ. 314. Was the idea of a vacuum oven original with you?

A. Yes, I think so. I have a patent on it. A vacuum oven for the purpose of exhausting bulbs. People may have heated some objects in an oven but I do not know about that. I mean long prior to my work we had a vacuum furnace, an Arsem furnace. That was not for the purpose of heating bulbs, but the purpose of a vacuum in such a vacuum furnace is an entirely different one from the vacuum oven that I made. The vacuum in the oven that I made was not for the purpose of evacuating the outside of the bulb, for example, or getting gases out from the outside of the bulb which is the purpose more or less analogous used in the Arsem furnace, but it was to take away the atmospheric pressure from the bulb so that the bulb could be heated to a higher temperature without collapsing.

XQ. 315. Did you use this vacuum oven on the bulb that you experimented with in August, 1912?

A. We used the oven, but I do not know that we used the vacuum on the outside. I think not. We only baked out that bulb to about 350 degrees, so that it would not have been necessary to use vacuum outside of the bulb at that temperature.

XQ. 316. Nor did you use it for the lamps, 3, 6 and 2 in November, 1912?

A. No, we did not use it then.

XQ. 317. You explained about the use of the radiometer as a vacuum measuring device before August, 1912. Did you use this to measure the vacua in the tubes of August and November, 1912?

A. No.

XQ. 318. You told us about the hot wave manometer that was developed in your laboratory before 1912. Did you use this to measure the vacuum in the tubes of August and November, 1912?

A. No.

XQ. 319. How about the elastic quartz fiber gauge that was developed by you or in your laboratory before the middle of 1912; was that used on these tubes?

A. No.

XQ. 320. And the molecular gauge that had the aluminum disc, was that used on any of these bulbs?

A. No.

XQ. 321. Tungsten lamps were satisfactorily made before you entered upon your study of offsetting, were they not?

A. Squirted filament tungsten lamps were on the market. They were not as good as they were later by any means.

XQ. 322. I understand that the criterion for the presence of the invention on which you relied in August, 1912, is the one that has sometimes been called earmark No. 3. Is this a correct statement of it? Assuming a constant fixed voltage across the tube somewhat greater than the ionization voltage and below the saturation voltage, the current decreases as the vacuum increases, but this decrease slows down and finally stops altogether giving a final definite useful current through the tube, which current is not decreased by further increase of vacuum. Is that a correct statement of earmark No. 3 and is that the criterion upon which you relied to determine the presence of the invention in August, 1912?

A. I do not remember this criterion as whether it is No. 3 or No. 2 or what number it may be, but the statement I think is correct, that is, the current at voltages sufficiently far above the ionizing voltage and below saturation decreases as the vacuum improves and finally reaches or tends to reach a limiting value which does not change as the vacuum gets still better.

XQ. 323. And that is the criterion that you relied on to show that you had a pure electron discharge substantially unaffected by ionization in August, 1912?

A. Oh, not entirely, no. The way that I know that I had a substantially pure electron discharge in August, 1912, is first, that there was a discontinuous break from the value corresponding to saturation, which at the higher filament temperature was about 17 milliamperes, there was a break from 17 milliamperes down to 5 or 4½. That break was not due to the change in the electron emission of the filament. It was due to the fact that a new factor came in which limited the current and I know now that that fact is space charge, electron space charge, which limited that current.

The fact that the pressure continued to decrease over quite a perceptible range without any material further change in current is earmark No. 3, if you wish to call it that. That is another fact that indicates that the discharge was practically a pure electron discharge.

A third fact is that the two measurements at different temperatures a similar break or decrease in current occurs at about the same pressure in both cases but in one case it comes down to 4½ milliamperes at 250 volts and the next time it comes down to about 3 milliamperes at 200 volts, and those two values of 3 and 4½ are close to what you would expect from the 3/2 power law, as close as measurements are accurate to.

Then there is another fact, and that is, at the higher current of 17 milliamperes there was a pronounced purple glow and that that disappeared when the current decreased abruptly to the value of 5 milliamperes or 5½, so that the absence of the glow is another factor which helps to indicate that the character of the discharge had been entirely changed and that the currents were now limited by space charge, electron space charge.

Now, the reason that I attached quite a good deal of importance in this case to the blue glow or the purple glow was that the currents were large; that is, 5 milliamperes at 250 volts represents a good deal of energy and the absence of blue glow under these conditions is a pretty good indication that there is not very much ionization.

By itself that is of no importance, but that taken in conjunction with our later observations that under those conditions when blue glow does not occur with 5 milliamperes at 250 volts, there is not enough ionization to modify space charge to any great extent, is just another indication that we are dealing with——

XQ. 324. You mean that there was blue glow——

A. Purple glow in this case.

XQ. 325. Yes, when the current was at 17 milliamperes?

A. Yes.

XQ. 326. But that that disappeared when the current dropped to 5 or 4½ milliamperes?

A. Yes.

XQ. 327. Have you ever mentioned that blue glow before in your testimony?

A. No, I think not.

XQ. 328. Is it mentioned in Sweetser's notes?

A. Yes.

XQ. 329. I wish you would show me where?

A. I called attention to that fact——

XQ. 330. I understood you to say that in 1912 Dr. Coolidge had the remarkable result that in the old-style X-ray tube with the discharge going, and his electrodes white hot, the discharge stopped suddenly and abruptly; did I understand that correctly?

A. That was what we thought we saw.

XQ. 331. Please tell me what you did see in the light of your present knowledge?

A. In the old-fashioned X-ray tube the electrons are emitted from the cathode as the result of positive ion bombardment. That positive ion bombardment not only knocks electrons out of the cathode, but it also causes the heating of the cathode. At the higher gas pressures or with cathodes which are not very thoroughly freed from gas, there is not a great deal of heating at the cathode; but when Coolidge used a tungsten plate as a cathode (I think he had it a little distance back in the side arm so as to get a focusing action on the target), for some reason, I do not know just why, the positive ion bombardment became very much more intense in proportion to the electron current, so that the heating of the cathode became more and more marked until finally the cathode became about as hot as the anode, and both electrodes were a bright white heat. Now, during that process the clean-up of gases was going on all the time. That is, with the high voltage discharge, gases are disappearing continually, and finally the pressure became so low that the supply of positive ions on the cathode was no longer sufficient to supply the requisite number of electrons to maintain the discharge.

Now, at that time, just before this device stopped, the cathode was a bright white heat, and both Coolidge and I thought that if it was ever going to emit electrons it surely must be emitting electrons at that time as a thermionic cathode. Verv likely it was emitting electrons, but suppose it was emitting electrons, it is very obvious that it could not continue to emit electrons after the vacuum got too good, because there was then no source of energy at the cathode: if the supply of positive ions disappears there is no longer any mechanism for getting the cathode hot. The emission of electrons does not keep it hot. Only positive ionization keeps it hot, and the thing that we did not realize at that time was that, of course, as soon as the gas pressure falls below a certain point, no matter how many electrons a cathode might emit at the temperature that it had just been at, it will be found to cool off as soon as the supply of positive ions disappears. Since it was only the middle part of that cathode which was heated, and the heat was being conducted out of that part very rapidly, the very instant the supply of positive ions disappeared, or became too small, the hot spot in the center of the cathode would cool off, and as soon as it cooled off below the point where it would stop emitting enough electrons, it would still be at a white heat, 2000 degrees or thereabouts. The supply of electrons would stop and then the entire discharge would stop, and of course the whole thing would cool off; and the rapidity with which it would cool off and the discharge was stopped, was so great that it could not be followed by the eye. So that we could not see by the eye what the exact sequence of events was actually, before the tube stopped. The cathode must already have cooled off, probably cooled off considerably before the discharge actually stopped; but the difference in time was so small (probably a very small fraction of a second it was actually) that the tube gave the appearance of ceasing to function while the electrode was white hot.

What really happened was that the supply of positive ions disappeared. The cathode was no longer maintained at the high temperature. It fell to a temperature at which it could no longer emit electrons, and the whole device ceased to function.

But at that time neither Coolidge nor I, nor did Professor Richardson, on October 12, 1913, have any suggestion as to how that experiment could indicate anything other than the conclusion that the electron emission in a very high vacuum from tungsten must disappear. It looked to us all as though when the vacuum became too good the electron emission action stopped. We can see that what really stopped was that the positive ionization stopped, and the source of heat at the cathode disappeared, and therefore the tube cooled off and ceased to function.

XQ. 332. I understood on your direct testimony that you said that while the electrodes were a dazzling white heat, the current suddenly stopped?

A. That is the way it appeared; actually the cooling effect probably took place within a fraction of a second before the discharge stopped.

XQ. 333. And if it had stopped actually while they were at a dazzling white heat, that would have been a nut for Richardson to crack, would it not? I mean that——

A. We do not know whether it had stopped simultaneously with it, or a fraction of a second before. I simply told Richardson what I had seen. I mean Richardson and Coolidge and I were all in the same dilemma, all three of us.

XQ. 334. Richardson did not see it himself, did he?

A. I think he saw it when he came to the laboratory in November.

XQ. 335. But he had not seen it when you told him about it in October, 1912?

A. No.

XQ. 336. And you did not tell him then that the current stopped after the cathode cooled off, as you now tell us?

A. Of course not, because I did not know it myself. I do not think he would have known it if he had seen the tube working either.

Mr. Richmond: I think I must object to the answer, your Honor.

The Court: That last part may be stricken out.

XQ. 337. So that the explanation that Richardson failed to make when you told him about it, was that the appearances were deceptive, was it not?

A. No. No, he never said any such thing. I misunderstood the question. Will you read the question? (Question repeated as recorded.) I suppose he failed to make lots of explanations, but all that I remember that he said was that he did not understand how those facts could be explained.

The Court: If I understand the tube at that time, there was no heating of the cathode by the current?

The Witness: No. The cathode was a flat plate about an inch and a quarter in diameter mounted on a stem, and there was no provision for heating it.

XQ. 338. What you told Richardson was that the current stopped while the cathode was at a dazzling white heat, was it not?

A. I think I told him what we had seen. That is the whole setup of the apparatus, and I think I told him quite a good deal about it; I mean, all there was to tell as a matter of fact.

XQ. 339. And this statement was comprehended within what you told him—that the current stopped while the cathode was at a dazzling white heat, just as you have told it to us?

A. As I remember, I told him what I saw. That is, we had the tube operating with both electrodes at a dazzling white heat, and while we were looking at it, it suddenly stopped functioning, and no current could pass through the tube, the electrodes being at a dazzling white heat at the time. Of course they were a dazzling white heat; even after the electrode cooled off, it was still white heat because tungsten will not admit a sufficient number of electrons at say 1900 degrees or say 2000 degrees absolute, there would not be a sufficient temperature to allow the cathode tube to emit electrons and still it would be at a white heat, perhaps not dazzling, but a very bright white heat.

XQ. 340. Referring to Exhibit No. 163 which you produced on your direct examination, this shows the current gradually declining from eighteen milliamperes to sixteen. That was where the blue glow appeared, was it, at that stage (indicating)?

A. I think there was blue glow all during that time. The notes that Mr. Sweetser made on the blue glow were mostly just before and just after the break occurred, that is, he contrasted the condition of the tube before and after the sudden decrease in current.

XQ. 341. And called attention to the blue glow before and the absence of it after, yes?

A. The purple glow, yes.

XQ. 342. Now, can you point that out in the notes (indicating)?

A. It was not in this particular experiment that I refer to. It was on a repetition of that experiment, about a few days later where the same voltages and practically all of the same conditions existed in the tube. The points that I refer to are on pages 1186 and 1187.

XQ. 343. Just point that out for the record.

Mr. Howson: Of the Sweetser notes.

A. About three-fourths of the way down on page

1186, at the time, twenty-three minutes past three, or twenty-five minutes past three, rather, it is stated: "Pronounced purple glow" for a current of seventeen milliamperes.

And then at 3.36, the current was five milliamperes, and it said: "There was no glow," and then at the very top, the first two lines on the next page, 1186: "At 17 milliamperes again there was a 'strong glow,' and at 5 milliamperes, there was 'no glow.'"

I can give you the pressures there, if you wish to know.

XQ. 344. No. That is sufficient for the present. Now, I want to confine attention to the work that is recorded on Exhibit 163, was or was not there blue glow before the sudden drop in current occurred?

A. There was no reference to the notes on that point of blue glow, but I believe there was a blue glow before the break occurred, because the conditions were identical, so far as I can tell. I believe they were identical with those that were recorded at this later date.

XQ. 345. Are you sure that that happened?

A. I do not remember.

XQ. 346. Then, of course, you have no independent recollection as to whether there was blue glow or not?

A. But I know—I remember distinctly seeing the blue glow in the tube.

XQ. 347. But not on this occasion. I mean the occasion——

A. The occasion of the experiment.

XQ. 348. Not on the occasion for which the records are plotted on Exhibit No. 163?

A. No. I do not remember whether there was blue glow or not from my observation at that time.

XQ. 349. A little while ago you enumerated several indications on which you based your conclusion that you had a pure electron discharge "substantially unaffected by positive ionization," in August of 1912. The second of these indications was that the current remained constant after it had dropped to its lower value. Can you show me a single place in Sweetser's notes where constancy of current is recorded?

A. When the current dropped from sixteen down to five, or jumped from seventeen down to five, and back to sixteen, and down to five again, that fact was recorded very carefully by Mr. Sweetser. The pressure there then was about 0.5 micron, and the reading of five was recorded twice at the lower pressure.

XQ. 350. Five milliamperes?

A. Five milliamperes of current, and then the pressure decreased to 0.37 microns, which was about a 25 per cent. decrease in pressure, and the pressure is still recorded as five. In other words, 25 per cent. decrease in pressure caused no appreciable or no measurable change in the current. Practically the same thing happened in Run 2, the pressure changed from 0.54 down to 0.44 and the change in current was from 3.2 milliamperes down to 3.0, which was practically a negligible change, compared with the change that had taken place at a higher pressure. Now, the reading taken at the lowest pressure on Run No. 1 was recorded at 4½ milliamperes, which is less than the value five milliamperes given just before. So it is probably that the current had not quite reached its ultimate limiting value.

The significant thing, I think, however, is that although there was a change of about over 30 per cent., 33 per cent. or so decrease in the pressure, the changes in the current were practically within the limits of reading by the instruments, and were very small relatively to the enormous change that had taken place before that when the current decreased from sixteen milliamperes. Those results in themselves would not, of course, establish the fact that the current was going to stay constant down to zero pressure, and it did not occur to me at that time that this experiment indicated any such thing. As I said, it did not convince me that I could have gotten the discharge in an absolutely perfect vacuum. I did not know at that time that this current would reach the limiting value, but I believe that now, from what I have learned later about the discharge, I believe that it had reached practically its limiting value, certainly within 10 per cent. probably a little less than that.

XQ. 351. But there is no record in Sweetser's notes of two successive readings at these lower values, showing the current to be the same——

A. Yes. I just stated that there was reading of five milliamperes so recorded at two pressures which were 25 per cent. different, three times; in fact, it was recorded three times in succession, five milliamperes. At the time 2.31 is given five milliamperes twice, and then at 3.34, at a 25 per cent. lower pressure again the current is given at five milliamperes, so that three times in succession the current was given at five milliamperes.

XQ. 352. Oh, yes, the first time was when it jumped down to that and then it jumped back up, and the next time was when it jumped down to that again?

A. Yes, and the next one, the pressure is 25 per cent. lower, and it is still five milliamperes.

XQ. 353. And after that the current dropped down to 4½ milliamperes?

A. Yes. I do not believe we were reading those currents any closer than to the nearest half of a milliampere; that is, there may have been an error of a quarter of a milliampere in those currents.

XQ. 354. I understood you to refer to this jump, this sudden decrease of current as a very remarkable phenomenon. That is, as your diagram, Plaintiff's Exhibit 163, shows, with almost no change in pressure the current suddenly jumps from sixteen milliamperes down to five milliamperes, then without any time interval long enough to record, it jumps back again to fifteen milliamperes and then as quickly jumps down again to five milliamperes. When it jumped back to sixteen milliamperes it showed blue glow presumably, did it not?

A. I do not know. Very likely.

XQ. 355. It seems to me it would be likely if it showed at seventeen milliamperes. Is not this kind of thing, flickering blue glow and then no blue glow, just what was familiar in the DeForest audions of the prior art, blinking as they called it?

A. At low voltages around thirty or thirty-five or forty volts such phenomena were common in the DeForest audion due to the changes in gas pressure that had taken place.

XQ. 356. And the DeForest audion had a very different geometry from this August, 1912, tube, did it not?

A. Some of it did. The filament in many of the tubes was pretty much exposed on one side. In some cases the filament and grid was on one side and in that case the geometry was not so very different as it would be in the case where the filament was entirely surrounded by the anodes.

XQ. 357. And you never get this jumping of current from a high value to a low one and back with tubes in which the anode rather completely surrounds the cathode, do you?

A. I do not know whether you would get it under those conditions or not.

XQ. 358. Then you do not know of any experience of getting it with the anode surrounding the cathode, do you?

A. Do you mean now having it periodically changed from one value to another? Yes, I think I have seen it.

XQ. 359. I mean intermittently.

A. Yes, I am pretty sure I saw it in some tubes in which we used mercury vapor.

XQ. 360. Just please describe them a little more in detail.

A. My recollection is not very clear, but I think some of the work that led up to the making of that kenotron containing mercury vapor in the Interference motion——

XQ. 361. I guess that tube was sometimes referred to as the regulator kenotron experiment?

A. Yes, but some of the preliminary experiments made before that, I think we saw intermittent glow.

XQ. 362. And those had cylindrical anodes?

A. Partly. It was a cup-shaped anode.

XQ. 363. A cup-shaped anode?

A. The sides were cylindrical but one end was closed and the filament extended up into this cup-shaped anode.

XQ. 364. So that the enclosure was far from complete in that case?

A. I think it is about as complete as it is in most tubes today. It is not quite.

XQ. 365. I do not mean to set up most tubes of today as my standard of comparison, but I understood that you had worked with cylindrical anodes and axial cathodes in which the anodes were rather long and I had this in mind when I put my question. You would not get such flickering effect in such a tube as that?

A. I do not remember having obtained it with those tubes.

XQ. 366. Do I understand correctly that you have occasionally remarked that charges on the glass walls of a tube have a gridlike action in controlling the current flow. Is that a correct statement of your testimony?

A. Yes, the effects are quite analogous to the action on the grid in many ways.

XQ. 366a. And a variation of the charge on the glass walls may stop the current flow and a variation the other way may permit the current flow to start again, is that right?

A. Under some conditions, yes.

XQ. 367. Referring again to your Plaintiff's Exhibit 163, when the current was at and near the value of seventeen milliamperes it was limited by the number of electrons emitted from the filament, was it?

A. Yes, I think so.

XQ. 368. And at that time there was abundant positive ionization in the tube, was there?

A. Yes.

XQ. 369. And what was the charge on the glass walls at that time, positive or negative?

A. Probably negative. Surely negative.

XQ. 370. Will you please give us your reason?

A. Do you mean the charge or the potential? There is a difference.

XQ. 371. I confess I will have to ask you to explain the difference. I wish you would.

A. I think there was a negative charge on the glass but the potential of the glass was probably above that of the cathode. If you say the potential of the cathode is to be taken as zero then the potential of the glass was positive but the charge on it was negative.

XQ. 372. Do I understand that when you say you think that the charge on the glass was negative even though the potential was positive you mean that the algebraic sum of the positive ions and the electrons on the glass wall was negative?

A. Yes. Potential is not the same as electric charge, but potential results from the distribution of electric charges.

XQ. 373. Yes, I think you made that clear, and you think that at that time the potential was positive relative to the cathode?

A. Slightly so.

XQ. 374. But when the current fell a little later down to 5 milliamperes from the value of 17 milliamperes, the tube was then operating, according to your view, as substantially unaffected by positive ionization and the current was limited by the space charge effect; is that correct?

A. Yes.

XQ. 375. Now, please tell us what modification the device was subjected to, what was done to convert it from one class to the other just in that brief instant of time?

A. Do you mean what took place of its own accord or what we did to it?

XQ. 376. What you did to it first.

A. There were both positive and negative things we did to it. We were applying voltage which was causing ionization of the gas and producing positive ion bombardment of the filament which was disintegrating the surface of the cathode and causing the tungsten vapor to leave the filament which combined with the nitrogen and thereby lowering the pressure. That was one factor that caused the pressure to lower.

The other thing that is very important is that we had previously baked out this bulb and the cathode and the anode to such an extent that this same positive ion bombardment did not cause the evolution of the gas from the glass and the electrodes and the bombardment of the anodes did not cause any evolution of the gas. Unless we had done those things I do not think the pressures would have gone down in the tube the way they did. Other gases would have been evolved.

XQ. 377. Now, I will ask you what you did intentionally to convert the tube from a tube operating with abundant positive ionization to one manifesting a pure electron discharge substantially unaffected by positive ionization?

A: I did not plan to make a tube that would operate substantially free from ionization. That was not my intention. We were studying the clean-up of nitrogen at different pressures and with different electron currents; filament temperatures and so on, and I wanted to work at very much lower pressures than we had before so as to see what the laws of the phenomena would follow at low pressures of nitrogen.

We started in with five microns of nitrogen and let the gas clean up, knowing perfectly well that it would clean up because all our work before that had shown that the nitrogen pressures did go down as the discharge passed through the lamp.

So that we knew perfectly well we would lower the pressure from what we started with and the pressure was allowed to go down and we took the readings of the pressure and the current and the filament temperature and we watched what happened, not knowing what was going to happen beforehand. That is what happened.

XQ. 378. What happened was that the current flickered and then took decidedly lower values than it had before?

A. Yes.

XQ. 379. And thereupon you ceased taking further current readings, did you not?

A. We did not take any below those that are noted in that diagram.

XQ. 380. You did not know at the time or you did not suppose at the time that you had a pure electron discharge substantially unaffected by positive ionization, did you?

A. No, I did not draw that conclusion at that time. I know now, but I did not know it then.

XQ. 381. And the reasons you think you know now are the four reasons you mentioned a little while ago, the fact of the drop in current, the fact as you say, that the current remained constant after the drop, the fact that at two different voltages you can get an approximation to the 3/2 power relation, and the fact that you had purple glow before and did not have it after?

A. And also the fact that since that time I have repeated experiments very much like that one and know what kind of things happen in a device of that character and also I know how good the exhaust treatment was that we had given that lamp in August, and that it was ample, apart from the nitrogen that was there, it was ample to give a pure electron discharge just as soon as the nitrogen pressure was reduced to a certain value.

XQ. 382. You say apart from the nitrogen that was there?

A. I mean up to that time. We put in nitrogen.

XQ. 383. And that nitrogen had not gotten to the outside of the tube at any stage of this experiment, had it?

A. I do not understand that.

XQ. 384. It had not gotten outside of the tube at any stage of the run indicated on this Exhibit 163?

A. No, it was converted into a very stable compound of nitrogen which deposited on the bulb in the form of a nitrite of tungsten.

XQ. 385. If it was so stable why was it that the current flickered back and forth here from 17 milliamperes to 5 and then up to 16 again and down to 5 again. What was the reason for that flickering like that? Was it that more gas came out?

A. There were probably two balancing factors, that nitrogen was being cleaned up at a certain rate resulting from positive ion bombardment, and also nitrogen was being evolved by the decomposition of this deposit on the walls and also resulting from positive ion bombardment of the walls.

XQ. 386. Then if nitrogen was being evolved, it seems to me that you did not have an ideal vacuum at all. I should not use the word "ideal," you did not have a practically good vacuum?

A. After the clean-up went beyond a certain point the bombardment of the walls would be very much less, that is, with those lower currents. I do not maintain for a moment that the vacuum there, in view of the fact that we had 3/10 of a micron of nitrogen was as good as we have in the present-day devices, or as good as we had in either of the experiments in November, but it was sufficient to have the currents limited by space charge without being very materially affected by positive ionization.

XQ. 387. You have just said that an additional reason why you were satisfied that you had a pure electron discharge here substantially unaffected by positive ionization is that in later months or years you have done experiments to throw light back on this. What were the additional indications in those later experiments that you did not have in this one?

A. In the later experiments we did not stop at 3/10 of a micron of nitrogen but we kept right on going to much lower pressures. We found that when we did go to these lower pressures, that the conditions did not change appreciably from what they were in the experiments described here.

XQ. 388. And in other respects were the conditions of your later experiments the same as for this one?

A. Substantially the same.

XQ. 389. You never testified about those later experiments?

A. I made the experiments for years on the effects of gases and filaments of different shapes and sizes. I have not testified about them. I have testified about the experiments in December and in the December experiments we did just that thing, we went down to lower pressures than 4/10 of a micron and the currents stayed substantially constant, as we went down below that point. They did not change very much.

XQ. 390. Tell us what those later experiments were that you mention?

A. I have had Mr. Sweetser at different times, particularly about 1920 or thereabouts, work for months with tubes containing two filaments and also tubes containing a filament and a cylinder in which we could put in at different pressures different gases and study the effect of the gases in neutralizing the effects of space charge, so that they have given me a general familiarity with this whole field so that I know from that general experience what would have happened if we had pumped this down much more, that is, the current of 5 milliamperes might be changed to 4½ and possibly might have gone down a few tenths of a milliampere below that but nothing more would have happened even if we had a vacuum one thousand times as good. Most of the effect had taken place in those August experiments.

That is much more nearly true with the bulb as we had it designed at that time, that is, with the two filaments, than it would have been with a cylindrical anode, for the reason that I mentioned before, that with the cylindrical anode the positive ions that were formed had to get back to the cathode, whereas, in this case, the positive ions that are formed, a large percentage of them, perhaps 90 or 95 per cent. go to the walls rather than go to the cathode.

Therefore, they are removed from the region of the discharge much more quickly and are therefore made much less effective, and it is also for that reason that the discontinuity takes place so abruptly. That the break in the curve occurs so definitely at a given pressure is largely the result of the fact that the walls of the tube played a part in removing positive ions and in changing the potential at that moment. That is, at the moment that the current became limited by space charge, the walls became more strongly negatively charged and then remained practically constant in potential from that point on as the pressure was still further lowered.

XQ. 391. And when they became more negatively charged they exerted more of a grid-like action to restrict the flow of current in the tube?

A. Not appreciably when the current once fell to its lower value.

XQ. 392. How do you know?

A. From the experiments that were made. The potential of the glass does not change very much as you go into lower and lower pressures in these cases when the current is limited by space charge.

XQ. 393. You did not know that in August, 1912, did you?

A. No.

XQ. 394. How do you know it now?

A. From the fact that the current follows the 3/2 power law as well as it does in the presence of low pressures of gases in bulbs.

XQ. 395. Just before that break occurred there was almost the same quantity of gas in the tube as just after it occurred, was there not?

A. I think so, substantially.

THE COURT: You are referring to what exhibit?

Mr. Richmond: Thank you, your Honor. I refer to Plaintiff's Exhibit No. 163.

XQ. 396. Then it was not any notable decrease in the quantity of gas in the tube that caused the drop in current, was it?

A. That was the occasion that made it take place at that time. The pressure fell to such a value that the positive ionization was no longer sufficient to break down the electron space charge or neutralize it.

XQ. 397. And just before that occurred the walls were charged to a positive potential relatively to the cathode, you have said, and after it occurred the walls were charged to a negative potential relative to the cathode?

A. To a small positive potential in one case and a small negative potential in the other case.

XQ. 398. And just to the degree that there was that difference you got a grid-like action——

A. There was no grid-like action before that break took place. As I have said before, when there is approximate neutralization of space charge, the potential of the wall has no effect on the current from the cathode because it is shielded by a positive ion layer near the surface of the glass wall. There is a shielding action. Only after you get this break, only after the break at the lower value had taken place did the potential of the wall have any effect on the discharge. Before that it was quite immaterial what the potential was.

XQ. 399. And before that the current was at nearly, if not quite the full emission value of the cathode?

A. Yes.

XQ. 400. And after that it was to a degree at least restricted by the negative wall charge, was it not?

A. The negative wall charge fixed the potential of the walls at practically zero volts.

XQ. 401. I thought you said a moment ago—

A. It may have been half a volt negative with respect to the filament. Very negligible compared with the 250 volts that we had on the tube.

XQ. 402. Would that very slight negative potential suffice to draw the positive ions out of the path of the discharge current as you have indicated?

A. It does not draw them out, they go out of their own accord. They follow in straight lines in the discharge and they will strike the bulb unless the bulb actually repels them. You do not need a large negative potential on the bulb to pull them out. They will go out all right.

XQ. 403. How do you know that the change in the wall charge which you say occurs at the drop in the current as shown on Plaintiff's Exhibit 163, how do you know that that change of wall charge did not cause the drop?

A. I have been working for the last three or four years on discharges in gases from filaments under conditions that have enabled me to study those wall charges with a great deal of detail and I know that when you have currents at those larger pressures, that you have practically complete neutralization of space charge, you have as many positive ions per unit volume as you have electrons.

The potential distribution of the tube at that time is an entirely different one from what you get after that break has taken place. You have what is called a cathode drop. Nearly all of the drop in potential takes place near the surface of the cathode. The electrons are speeded up to high velocity right close to the surface of the cathode and they travel out in a nearly straight line away from that cathode filament and they strike the bulb or the walls which are slightly negatively charged with respect to the gas as a whole, although they may be positively charged with respect to the cathode.

Under those conditions where you have that neutralization of space charge I know that the potential on the walls has no appreciable effect on the distribution of current within the device. I have tried that under the most varied conditions and I have put on the inside of the bulb an electrode which fits the surface of the glass and I placed potentials on those electrodes for the purpose of studying that very thing, and I know that as soon as you have this neutralization of space charge that the potential on the walls or on the electrodes near the walls are quite without effect on the discharge.

But the moment you get down to this other condition where the current is limited by electron space charge then the potential of the walls if it varies, has an enormous effect on current between the cathode and anode.

The whole action of the audion and a lot of the control devices that we are making at present in the presence of gas depends essentially on these effects, which I have studied in great detail, and a few of which I have published.

XQ. 404. And although you are so sure that it could not have been a change in the wall charge, that cut the current down in this case, it is a fact that in such tubes a change in the wall charge frequently does cut the current down to nothing, or almost nothing, just as you have testified?

A. If the pressure is at the point where the break occurs, the wall charge is one of the factors that helps to determine the exact place that that takes place; but I say that when you are on that upper part of the curve, where the current is limited by saturation, the potential on the walls is without effect. Now, the critical region would be affected, to some extent, and is affected in this case, by any balance in the relations between the positive ions going to the walls, and the electrons going to the walls; but that does not affect the point that I emphasize, and that is, that just before the break occurred, the potential on the walls had no effect.

XQ. 405. I think that I can accept that statement readily enough; but I want to know about the effect of the potential on the walls after the break occurs.

A. The potential after the break occurs, the potential on the walls is practically fixed by the initial velocity of the electrons, and the potential from that point on is very close to the same potential as the negative end of the cathode, within a volt or so of the potential of the negative end of the cathode, so that these variations are negligible then, compared with the voltage on the anode.

XQ. 406. And that statement does not apply though, for your November, 1912, work where the current stopped entirely, did it?

A. But that was when I applied voltages of 200 and 250 volts to the glass walls, not due to the changes of one volt or so, and that would occur in cases like that correspondingly. Of course, after the current is limited by space charge, if you then could charge the walls negatively to 200 volts, it would stop the current entirely; but here the potentials are not due to any such external cause as that. They are due to the initial velocities of the electrons, and those potentials due to that cause are very, very much smaller than those that can be applied externally.

XQ. 407. How did you apply those high voltages in connection with the November, 1912, tubes?

A. By surrounding of the bulb with my hand, and taking hold with my other hand of electrodes, the terminals of the shop line, for example, one end of which was say zero volts, the middle at plus 125 volts, and the next one was plus 250 volts. That is, there was 250 volts difference of potential between those terminals, and by touching them in succession with one hand, while I held on the bulb with the other, my body acting as the conductor, I would carry those potentials on to the outside surface of the bulb, and that would induce charges on the inside surface of the bulb, and thereby change the current flowing through the tube.

XQ. 408. And it is only by some such external application of a high voltage, that you can cause the current to stop by wall charges in such tubes, is it?

A. No. If you take the entire bulb and immerse it in liquid air, it may charge up to much higher negative potentials, due to the fact that the charges can not leak off, and under these conditions the discharge is likely to stop. However, when you raise the voltage to a point where it does start again, you get exactly the same current as though you did not have the bulb in liquid air. There is no half way about it. It is either all on or off. There is no controlling action in the sense that you can cause continuous variations of that current.

XQ. 409. There is a change in potential on the walls for a tube such as that of August, 1912, when this jump occurs that is shown in Exhibit No. 163, is there?

A. Oh, yes, the glass becomes slightly more negatively charged, and it goes to a potential slightly negative with respect to cathode. Perhaps one volt or a volt and a half negative, with respect to the negative end of the cathode.

XQ. 410. And was it slightly or substantially positive before that?

A. Well, I have no way of telling just how much. Several volts positive, probably.

XQ. 411. And the total change is those several volts one way, plus the fraction of a volt, I think you mentioned, the other way.

A. Yes.

XQ. 412. Now, how about the change in pressure that occurs at that time; how much is that?

A. Well, the change in current occurs practically instantaneously, and I do not suppose there is any appreciable change in pressure just at that moment while the current is changing.

XQ. 413. Have you ever measured the wall potentials in such a tube as that of August, 1912, when the pressure was at about four microns pressure?

A. Only indirectly. I have not made specific measurements of the potential, but I can draw conclusions as to the potential from the characteristics of the tube.

XQ. 414. How nearly directly? Please indicate how remote you mean by the word "indirectly."

A. Well, I mean that if the current is limited by space charge, and not by saturation, the walls act like a grid, and if the walls are at practically zero potential, they will act like a distant grid at zero potential, not a grid which is right close to the filament, but one that is a long distance from it; whereas, if the walls were at a large negative potential, they would act like a negatively charged grid and stop the current.

Now, the whole behavior of the tubes of this character even with pressures up to four-tenths of a micron, is such as to indicate that the equivalent grid or the action of the glass as a grid, is that of a grid having very close to zero potential, not a grid that has a large negative potential, or a large positive potential.

Furthermore, the theory of the factors which causes the charge on glass, is well understood. That is, I have investigated them in considerable detail, and in gaseous discharges, I have measured the potential of the glass walls by very direct methods, several methods, and from an understanding of those factors that I get, I believe that the charge on the glass under these conditions where we had five milliamperes at 0.4 of a micron would not be materially different from what it would be at lower pressures. That is, a few volts or so, with respect to the negative end of the filament.

XQ. 415. I understood you to say that you thought there was no accident with the tube of August and September, 1912, that required re-pumping. Please look at page marked S-5, for August 30th, and see if there was not such an accident.

A. I do not remember having said—please read the question? (Question repeated as recorded.) I do not remember having said that the bulb was not re-exhausted. As a matter of fact, I do remember having pointed out——

XQ. 416. I may not have indicated that page in Sweetser's notes correctly. The date is right, and it has a 5 on it.

A. I might say that this experiment 291 was started with one lamp, and that lamp was found to leak, so a new lamp was substituted. That was on S-1148, and I have already called attention to that fact, and the exhaust schedule that I describe was of the second of those lamps. Now, all the references that I have made to the experiments described in this experiment 291, have, I believe, been prior to August 29th, and I have not meant to refer to anything that was done after that time. I notice under date August 30th, these are my notes taken and recorded in my own handwriting, I think at the time that Mr. Sweetser was away for a few days for sickness or for some other cause, and I was applying the high voltages from the spark coil to the bulb, and near the top of page 5 of these notes of my own is the record:

> "Punctured glass, repaired with balsam and exhausted."

That exhaust, however, does not mean anything more than the fact that we used the pump to lower the pressure, which is a thing that we did practically every day, as we were doing with all these experiments. That is, we put in nitrogen and allowed the gas to clean up, and before putting in more nitrogen, we would exhaust the residual gas left over from the preceding run, so as not to allow impurities to accumulate.

The Court: Recess until 2.15.

After Recess.

Mr. Davis: If your Honor please, among the exhibits offered by the defendant in the Interference and reoffered in the present case is an exhibit consisting of certain extracts of the testimony of Major Armstrong which was 125 in the Interference and 237 in the present suit. Major Armstrong is here prepared to testify and if this exhibit should go in we would desire to take his testimony. My friend Mr. Darby has decided that he wishes as we all do to shorten the case as much as possible and is willing to withdraw this exhibit if that will avoid taking Major Armstrong's testimony.

The Court: Is that consented to?

Mr. Darby: Yes, sir. We withdraw Exhibit 237 in this case and 125 in the Interference record.

The Court: Let it be withdrawn.

IRVING LANGMUIR, resumes the stand.

CROSS-EXAMINATION (Continued).

By MR. RICHMOND:

XQ. 417. After the puncture of the tube of August, 1912, which was mentioned before lunch, and after its repair with balsam as you have stated, or I should say before the repair with balsam, the pressure in the tube came up to atmospheric pressure, I suppose, is that correct?

A. No, it did not. A perceptible increase in pressure had been observed on the McLeod gauge.

XQ. 418. No perceptible increase in pressure had been observed?

A. No, I say a perceptible increase in pressure was observed when measured with the McLeod gauge.

XQ. 419. The notes show that there was such a measurement made, do they?

A. I do not think they do. It is probable that it was first noticed that the bulb had punctured by the localization of the brush discharge over the surface of the glass at a particular point a little bright spot of light would mark the place that had been punctured. The hole through the glass, however, would be so small that the leakage of air through the hole would be extremely slow and a drop of balsam was then probably placed on that spot and then the Toepler pump was operated until the pressure was satisfactorily low.

XQ. 420. Is your answer just preceding given from independent recollection?

A. Not on this particular occasion, but it had happened I suppose in all a good many times in the course of work that extended over a year or two that bulbs had been punctured by the high frequency discharge.

XQ. 421. You did not bake the bulb out when you re-exhausted it after it was punctured?

A. Not in this case, no. I was only interested in working at that time, I think, at fairly high pressures of gas.

XQ. 422. About how far apart are the filament strands in a forty-watt incandescent lamp where they are attached to the lead-in wires?

A. In the lamps that I used on November 19th, they were probably about a half an inch apart, between half an inch and five-eighths of an inch.

XQ. 423. And the spacing is about the same for commercial lamps at that rating, is it not?

A. I think in commercial lamps they are rather closer together than that.

XQ. 424. How was it before the middle of 1912?

A. I do not remember exactly what was the practice in this regard in commercial lamps. The lamps that I speak of were lamps made in the laboratory for me, special lamps that had been made for me about a year before, that is about 1911. I know it was our practice at that time to have the leads rather further apart than they usually are now and I think than they usually were in commercial lamps at that time.

XQ. 425. And although the wires diverge as they leave the lead-in wires, the average separation of the most positive and most negative strands is about five-eighths of an inch or possibly three-quarters of an inch; is that right?

A. Do you mean the filament wires?

XQ. 426. Yes, the filament wires. You understand that I am speaking of the 40-watt incandescent lamp and not of your lamps, 3, 6 and 2, of November?

A. Yes, I understand that. I should say that the average distance would be a little over an inch, about an inch.

XQ. 427. And in those 40-watt incandescent lamps the length of the strands is about three inches, is that right?

A. I do not know exactly what you mean by strand. There were six loops, each consisting of two legs and each leg I should say would have been a little over two inches in length, roughly two inches.

XQ. 428. It is that length that I want to get. So that as to length of filament and as to separation, these two positive and negative legs in an incandescent lamp simulate at least in a rough way the filament length and separation in your August, 1912, tube; is that correct?

A. The average distance between the two sections of a filament used as anode and cathode in these experiments on November 19th was about one inch and there was a glass stem of about one-eighth of an inch in diameter in the axis of the bulb which separated these filaments. In the experiments in August, in the experiment 317, the filaments were single loop filaments about half an inch apart and were without any glass stem in the bulb, showing in some respects the conditions were considerably different. The diameter of the filament was also quite different.

XQ. 429. You remember that I am speaking of the 40-watt incandescent lamp in general?

A. The 40 what?

XQ. 430. The 40-watt incandescent lamp?

A. The 40-watt incandescent lamp?

XQ. 431. Yes.

A. Are you not referring particularly to those lamps I use of November?

XQ. 432. No.

A. Then I misunderstood your meaning.

XQ. 433. For the 40-watt incandescent lamp is not there at least a rough similarity between the spacing of the most positive leg and the most negative leg, as compared with the spacing of the filaments in your August, 1912, tube, and a rough similarity as to their length?

A. Well, that is only true of the portion close to the leads, the difference, of course, is that in the August experiments, the two loop filaments were in parallel planes, so that the distance between the filaments was practically constant; whereas, in the ordinary 40-watt lamp, the six loops were arranged, you might say, on the sides, as though on the sides of a hexagon, so that the two loops that formed the ends of the filaments were not in the same plane or in parallel planes, but in planes that diverged from each other, so that the ends of the filament that were attached to the lead-in wires were perhaps half an inch apart, whereas the other ends of that same loop were probably an inch apart, and that was not true in the August experiment. There the distance was probably a half inch at both ends of the loops.

XQ. 434. Now, if I remember right, you have testified in regard to the appearance of blue haze in these incandescent lamps before the middle of 1912; that is, when they were commonly pumped and operated at 220 volts, have you not?

A. They were not ordinarily operated at 220, 120 volts was the usual voltage, but the voltage was raised somewhat above that during certain tests. They were usually run for a short time at higher voltage than normal, after being sealed off from the pump, perhaps at 140 volts, or something of that order of magnitude.

XQ. 435. And you testified that you often had blue haze with them in your experimental work?

A. Yes. I have frequently seen blue haze in the lamps.

XQ. 436. And this blue haze flickered on and off, did it not?

A. Sometimes, not always. It would usually start in by being intense, and gradually become less intense, and stop abruptly; in some cases it would re-appear though.

XQ. 437. And the space current that existed after the blue haze went off in those lamps was of roughly the same order of magnitude as in your August, 1912, tubes, was it not, after the current had dropped to the lower value that we have been speaking of?

A. Well, of course, I never measured the space current in the way that I did in August, in the middle of August. That is, in all of those lamps, there is a single filament, so that there was no way of measuring the space current. The only cases where space currents have been measured at all, so far as I know, were in those special experiments when a little auxiliary wire was placed in. It was usually made very small, a small piece of platinum wire, perhaps half an inch long, sticking into the bulb through the glass, and the currents to that would be measured.

XQ. 438-439. But even without measuring, the currents must have been of the same order of magnitude because the voltage difference between the ends of the filament was of the same order, you have pointed out that it was somewhat less, and the spacing was of the same order of magnitude, or a little greater, I think you have indicated?

A. You mean from my present knowledge of the conditions of those lamps?

XQ. 440. Yes, Dr. Langmuir.

A. We can now conclude that the currents must have been of the same order of magnitude. I think that is true.

XQ. 441. I hand you a diagram, on which I have plotted all the points recorded in Sweetser's notes for August and September, 1912, in which the current had low values, which I understand you to say were due to the limitation by space charge, and at least some of those points you have said were substantially unaffected by positive ionization. The table in the diagram gives the pages of Sweetser's notes on which the records are found, and gives the corresponding pressures. With that diagram before you, I will ask you to refer again to page 2091 of the Interference record. First, let me ask you, the line on that page of the Interference record that is drawn with the 3/2 slope does not pass accurately through the two points that are plotted, does it?

A. No, it is drawn the way experimental curves usually are, that is, to fit as nearly as possible the two points, the slope being fixed by the 3/2 power law relation.

XQ. 442. If the line were drawn accurately between the two points it would have a slope of 1.83?

A. If I attempted to draw a 3/2 power slope, the slope would be in accordance with the 3/2 power line.

XQ. 443. But if you attempted to draw a line between the two points and see what slope it would have had, you would find a slope of 1.83?

A. I think I said so in the discussion of that curve. On page 2092, I pointed out that the curve drawn through those two points would be 1.83.

XQ. 444. That is right. That is the figure that I name. And that is the middle line on the diagram that I have just now handed you. But there were other current readings indicated by the other circles on the diagram and these would give slopes ranging all the way from .953 to 2.58, and why did you select that one which gave a slope nearest to 3/2?

A. I did not select one that gave a slope nearest to 3/2. I simply picked out the two runs that were made at the same time, as nearly as possible at the same time. On pages 1177 (Plaintiff's Exhibit 99) and then the run that immediately follows that on page 1178 and I took in both cases the lowest currents recorded in those two runs. That was my reason for taking those points.

Mr. Richmond: The diagram just handed to the witness is offered in evidence as diagram for ten points of Sweetser's notes—I will ask to have it marked for identification as diagram of ten points of Sweetser's notes of August, 1912.

(Received and marked "Defendant's Exhibit J for identification.")

XQ. 445. Then, if these other points that appear on the diagram are to be distinguished as representing the readings that were taken at another time it shows that the behavior of this tube was far from reproducible, does it not?

A. It shows the variations as great as those that are indicated there did occur with the range of pressures that were occurring in that tube.

XQ. 446. And these different values were somewhat dependent then, you think, on the difference of pressure at those different occasions; is that correct?

A. I think so. The variations are small compared with the differences between these readings and the sixteen and seventeen milliamperes that was observed just before the pressures went down to that value.

XQ. 447. But large as compared with one another?

A. Large to the extent as shown on the diagram. I do not think that all of these points were independent of the positive ionization to the same extent. I think the ones I picked out for plotting were much more nearly free from the effects of positive ionization than the other ones.

XQ. 448. Why do you think so?

A. Because they gave lower values and I naturally picked out the lowest values in any given series of readings. I had the two series that I was considering and I gave the lowest current values because those were the most free from positive ionization.

XQ. 449. But it seems to me that in view of this great variety among these readings you must have been in considerable doubt as to whether those were indeed the lowest possible values?

A. I picked out, I said, the lowest values in those two series of readings on pages 1177 and 1178 and I was not considering any others.

XQ. 450. And if the vacuum had been further improved there may have been lower values still?

A. Not appreciably. I said before that there might have been some perhaps 10 per cent. lower. Ten per cent. is about the accuracy of the readings. Of course, the two voltages, 200 volts and 250 volts are not very far apart. So that it does not have much significance to try to calculate the exponent from those two values.

The point is that the measurements of current are consistent with the 3/2 power law within the experimental error, and that the data as far as they go constitute evidence that the tube was following the 3/2 power law not with a very high degree of accuracy but with as good a degree of accuracy as the measurements permit, considering the errors that might take place in the readings.

XQ. 451. I want to come back to the matter on which I was questioning you a minute ago. The current between the most positive and most negative legs of the incandescent lamp, after the blue glow cleared up, you considered to be limited by space charge, did you not?

A. Do you refer now to the 40-watt tungsten lamp?

XQ. 452. Yes, and particularly about your experience prior to the middle of 1912.

A. In a well-exhausted lamp after it had been run a long time and the blue glow had disappeared, what current there was, from one end of the filament to the other, was limited by space charge.

XQ. 453. Referring to this diagram for the August, 1912, work, which is Plaintiff's Exhibit 163, you did not make any such diagram as that in 1912, did you?

A. No.

XQ. 454. When did you first have occasion to make such a diagram plotting the pressure against the Edison current?

A. Three or four years ago I made such a diagram from those data.

XQ. 455. After the current got down to the low value in this August, 1912, tube as you have testified and as shown on this Plaintiff's Exhibit 163, what did you do with the tube or what did Sweetser do with it?

A. We continued to study the clean-up of nitrogen with different currents and voltages and filament temperatures.

XQ. 456. That is, at once you admitted more nitrogen?

A. Yes.

XQ. 457. And that completely neutralized the space charge effect for the current immediately thereafter?

A. It brought it back in the condition in which it was in before.

XQ. 458. Do you consider that absence of blue glow is a false earmark of a pure electron discharge substantially unaffected by positive ionization?

A. Not necessarily false. It is not a question of falseness but of the usefulness of the test. It may be sometimes a useful test and at other times it may mean almost nothing. In itself blue glow is of no importance. It only has significance in connection with what it may indicate as to how the characteristics of the tube would be affected by the ionization that is indicated by the blue glow.

XQ. 459. When blue glow is manifest you are tolerably sure that you do not have a pure electron discharge, are you not?

A. Not necessarily. The blue glow indicates something quite different from the things that determine whether or not you have a pure electron discharge. Of course, the word pure is always a relative term which denotes a comparison between one thing and another. When I talk of pure electron discharge I have usually meant a discharge in which the effects of ionization do not materially influence the usefulness or characteristics of the device as it is to be used. That is what I think we always mean by purity.

XQ. 460. I need to get my thought cleared up on that because I had supposed that under some circumstances very gassy tubes were useful so that it does not seem to me that you can say that this whole question is settled by whether the tubes are useful or not, can you?

A. As I understand it, you are referring now to the term pure electron discharge?

XQ. 461. Yes.

A. As I understand the word pure it means free from harmful ingredients or harmful effects and of course that necessarily implies that the very word harmful means harmful for some purpose.

Ionization always occurs in all tubes at voltages materially above the ionizing voltage. So to some extent no electron discharge can be absolutely pure. There will always be some ionization. So that by the word pure we necessarily mean free from ionization to an extent that is such that the ionization bring about no harmful or deleterious action.

XQ. 462. Does the ionization in the General Electric Tungar rectifier lead to a harmful result?

A. No, but there it produces a definitely useful result, so that of course we would not talk about a pure electron discharge because an electron discharge free from ionization could not be used in a Tungar rectifier at all. The discharge in the Tungar rectifier requires absolutely the presence of positive ions.

XQ. 463. It seems to me that if the definition of "purity" is just to be that the ionization is not harmful, then your Tungar rectifier would be regarded as pure?

A. Perhaps I have not made that quite clear. By the term "pure" in general, I think we mean "free from impurities in amounts that are important." That is, it implies the idea that a further removal of impurities would not change the usefulness of the device or the object. We talk about a chemically pure substance, for example. Nobody means for a moment that it has no impurities. They mean that it is at least so pure that it would be immaterial to make it purer, and the same is true, I think, of an electron discharge. An electron discharge can be said to be pure if a further reduction in the amount of ionization would be practically immaterial. Now, of course, that is not true of a Tungar rectifier. It is not at all immaterial; it is absolutely necessary in the device.

XQ. 464. I do not remember, your Honor, whether a Tungar rectifier has been explained. It has been mentioned in this record, and I will ask Dr. Langmuir briefly to explain what it is.

THE COURT: What is the word?

XQ. 465. It is a coined word, a contraction of tungsten and argon, I think; is not that right, Dr. Langmuir?

A. That is right. After we built high vacuum devices and became familiar with the space charge effect, as the space charge of electrons, which limited the current to rather low values, we realized that the usefulness of the rectifier, for alternating currents, utilizing the pure electron discharge, was practically limited to high voltage work because the currents were small, and to get large energy, you would have to use high voltages, and as a result, we developed a high voltage device, which we called a kenotron, which we used up to 100,000 volts. The reason that such devices were not useful on low voltage circuits such as 110 voltage circuits, with large currents, such as 5 or 6 amperes, was that the electron space charge prevented more than a few milliamperes from flowing at those low voltages. To make a practical rectifier that would be suitable for low voltage, it was therefore necessary to eliminate space charge, and we therefore started experiments to see whether we could eliminate space charge, in a rectifier, without sacrificing life and other factors. So we put in different gases, and among the different gases that we studied, we found argon was the most suitable, and we found finally that the best pressure to use was about 5 centimeters pressure, 50 millimeters pressure of argon. This pressure would eliminate space charge practically entirely, and allow us to get a current of about 5 amperes with a voltage of about 8 volts. We thus made a perfectly good rectifier; and these were developed commercially and have been put on the market as rectifiers for charging storage batteries, for example, from alternating currents. Now, these devices absolutely depend on the presence of ionization for the elimination of space charge.

XQ. 466. I understood you to say just a few minutes ago that you can have a pure electron discharge in the presence of visible blue haze; did you say so? Did you mean that?

A. I meant to say that you might have such a discharge. I do not see any reason why you should not have such a discharge.

XQ. 467. Will you please tell us under what circumstances?

A. Well, I have seen such a discharge myself in the case of a hot filament, in the presence of alkali metal vapors in which the blue glow could be distinguished in a very dark room, but where the characteristics were in all other respects characterized by the pure electron discharge. The blue glow, which was very faint, occurred in a device in which the current was certainly limited by space charge independently of ionization, as the ionization had no appreciable effect on the volt ampere characteristics.

XQ. 468. Well, then, you will agree that it is very exceptional to have a blue glow except when it indicates substantial ionization, will you?

A. I think that is true.

XQ. 469. On the other hand, I think I have heard you say that the absence of blue glow does not prove substantial freedom from ionization effects; is that correct?

A. Yes.

XQ. 470. Now, with those two statements in view, do you consider that blue glow is a false or a true earmark of a pure electron discharge substantially unaffected by positive ionization?

A. I do not think you can talk about it being false or true, any more than you can talk of a foot being false or a true measure of length. It is a question of its sensitiveness and its accuracy. It may sometimes be a good test and at other times not be, depending on the conditions. In itself, it is of no importance. It is only what implications you can draw from it, and sometimes you can draw such implications, and sometimes not, depending on the magnitude of the current, for example, particularly the magnitude of the current and the voltage. The higher the current becomes the higher the voltage becomes, the better the blue glow becomes as a test of how much ionization, that is ionization which is sufficient in amount I mean, to partly neutralize space charge.

XQ. 471. When you make a plot of current ordinates against temperature abscissæ for a two-electrode tube showing how the current increases faster and faster with increasing temperature, then if the curve of that plot eventually bends over and becomes approximately horizontal, as on pages 134 and 135 [illegible] your notebook. Exhibit No. 81 on the motions——

A. Is it not 133 and 134?

XQ. 472. May be.

A. The curves are on pages 133 and 134.

XQ. 473. Those are the curves which I mean.

A. Here is the notebook (indicating).

XQ. 474. I say, if those curves eventually bend over and become horizontal, that proves that the current is then limited by space charge substantially unaffected by positive ionization, according to your view, does it?

A. Well, it proves it is limited by electron space charge, but there may be a certain amount of positive ionization, not very great.

XQ. 475. Well, is it great enough to be substantial?

A. I think it might be in some cases. I do not think it was in this case.

XQ. 476. Can you give us any idea of how to distinguish cases? I thought I had heard this referred to as a true earmark of the invention, and I should like to know whether it is that?

A. I think it is. But I do not think it is quite as good an earmark as some others.

XQ. 477. Do you think that sometimes it would break down?

A. Not break down, no. But not be very sensitive. That is, there may be enough ionization to cause a moderate, a small increase in current over what it would be without ionization, and still get a flat top temperature curve.

XQ. 478. How moderate or how small?

A. Oh, I do not know how great it might be made in certain cases, but I think not very many per cent., 20 per cent. possibly in some cases.

XQ. 479. Possibly 20 per cent.?

A. I do not know of any cases where it has been bigger than that.

XQ. 480. Now, if you use different voltages—you see, I have been speaking of one voltage up to this point?

A. Yes.

XQ. 481. But if you use different voltages, then, at each voltage, the flat portion will be at a different level, the level being higher the greater the voltage, is that correct?

A. Yes.

XQ. 482. The only factors determining the constant current value in the tube at each of these levels, are the space charge effect and the applied voltage, are they?

A. Well, in some cases, of course, if there is more than one electrode, the voltage is on all the electrodes and may have to be considered. In some cases the charge is on the walls.

XQ. 483. We will confine ourselves to two electrodes then. Referring to these curves that I pointed out in your notebook on pages 133 and 134, I understand you believe that the current values corresponding to the horizontal parts of the curves, represent pure electron discharges substantially unaffected by positive ionization; that is correct, is it not?

A. Yes.

XQ. 484. Why do you think so?

A. In the first place, because they are flat-topped. In the second place, because they vary with the voltage in the way that I know they would vary if they were pure electron discharges. Third, I know that the method of producing the vacuum that I used was ample. It was good enough to get a pure electron discharge.

XQ. 485-6. Now, please refer to your *Physical Review* paper of December, 1913, on page 453. This shows a series of such flat-topped current temperature curves, does it?

A. Yes.

XQ. 487. And does that prove to your mind that in that connection you had a pure electron discharge substantially unaffected by positive ionization?

A. Yes.

XQ. 488. Now please refer to page 463 of the same paper. There again you see a flat-topped current temperature curve marked IV with the pressure noted as .006 millimeter of hydrogen and a voltage of [illegible] volts. Does that prove you then had a pure electron discharge substantially unaffected by positive ionization?

A. It would take me some time to see just under what conditions these curves were obtained. I do not remember them at the present time. I really cannot tell because I do not know just in what order those experiments were made. I think the curves were obtained in experiment 317 and they were made apparently at different times.

Curve No. 1 and curve 3 are described at the bottom of page 46 and curves 2 and 4 are described at the top of page 464.

Now, I do not know whether the geometry of the tube was the same in both those cases or not. The filaments may have been at different distances apart because in that experiment we used magnetic fields and by using magnetic fields, while the current was passing through the filament, we bent the filaments out of shape and changed the distances apart.

The flatness of the temperature curve is an indication that the current is limited by space charge. There is no doubt about that. To what extent positive ionization may have influenced these results I am not able to say definitely without making an examination of the original records and finding out under what conditions the data was obtained.

XQ. 489. Where does the paper tell about these magnetic fields?

A. I do not think they are mentioned. I do not believe they are mentioned in the *Physical Review* paper; they may be, however. I do not know.

XQ. 490. You do not know that there was any change at that then, do you?

A. There may have been and there may not have been. I can find out by referring to the experiment 317.

XQ. 491. Then please refer to that and find out.

A. It will take quite a while. I mean I will have to identify those curves from the data that were taken there with particular sets of data and I think it should take two or three hours to do it. I may have to look through a great may curves to find out just what things these curves came from. I think I can answer what you probably want to know without going back to that actual experimental curve.

I think I have already stated that the flat-top temperature curve is of course conclusive proof that the current is limited by electron space charge. There may however, have been a certain number of positive ions co-operating with the electrons and modifying the space charge. Just how far that effect may go I do not know.

It is certainly a small effect compared—that is the extent to which positive ionization would modify those currents is I believe small compared to the extent to which ionization affected any prior art devices of the same character.

To that extent the type of discharge described here is new, I believe. This is one of the characteristics of the work that I had done which distinguishes it from all prior work.

It is however not a sensitive test. It is not as sensitive a test for the purity of the electron discharge as for example, the 3/2 power law. It is a test sufficient to distinguish a device of this character from prior art devices such as the audion.

XQ. 492. Would you say that it was a very insensitive test then?

A. Sometimes I think it is quite sensitive and at other times it is not. I have not made a very careful study of that particular point.

XQ. 493. Perhaps this is one of the cases where it is very insensitive; is that correct?

A. I do not know. I think that by referring to the original notes I might be able to form some idea as to whether or not there was enough positive ionization to have any appreciable effect on the current in the curve that you have shown me, but without finding out more about the device or the conditions under which those experiments were made, I do not feel able to tell you just how much effect positive ionization may have had.

XQ. 494. Is that a common practice for you to vary the conditions of an experiment as you suggest in this instance of changing the spacing of the filament by means of a magnetic field and not report on it in the paper that you present?

A. This paper is a short summary of a very large number of experiments that were made and the curves, as far as I know, 1 and 3 and 2 and 4 are simply for convenience placed together in one curve. They are referred to and described in different places in the text. For example, one comes under the heading of the general effect of residual gases on the constants of Richardson's equation and the other one is described under the heading of hydrogen. As far as I know, at present there is no direct connection between those two sets of curves. They may have been taken under very different conditions.

The experimental work I might say that was done in our laboratory was not done for the purpose of writing this paper in the way most papers are written which result from college laboratories where scientific work is usually done for the purpose of writing a paper about it. This work was done in order to get information on the subject and an amount of material had been gathered together which was perhaps ten times as much as would have been accepted for publication by the *Physical Review* and so I simply had to select here and there experiments to illustrate different points that I wished to discuss.

For that reason these different things may appear to be rather disconnected. It is nowhere in the paper stated that they are to be connected as far as I know. The order in which the experiments were made may be very different from the order in which they are described.

XQ. 495. That flat-topped curve on page 463 of your paper to which we have been referring marked IV, was at what pressure in microns?

A. The pressure there is given of six microns of hydrogen.

XQ. 496. Do you doubt that it is given correctly?

A. It probably is correct. The pressure may have varied in the course of the run somewhat, and if so that would have been the average pressure during the run.

XQ. 497. And this was a tube with two hairpin filaments, was it?

A. Yes.

XQ. 498. And have you been accustomed to get pure electron discharges substantially unaffected by positive ionization with pressures as high as six microns in such tubes?

A. Not as a rule, no.

XQ. 499. As an exception, then.

A. Of course six microns of hydrogen is only equivalent to about one micron of other gases because hydrogen has very much less effect on ionization than other gases have. I think it is improbable that the current was substantially pure electron discharge under these conditions.

XQ. 500. Why is it that hydrogen has this reduced effect that you have mentioned?

A. There are two or three reasons. In the first place the hydrogen molecules are relatively small compared to the molecules of other gases, so that the chance that an electron will hit one of them is less than if the molecules were larger. The electrons travel much bigger distances through hydrogen before they collide with them.

Then hydrogen does not ionize quite as readily as some other gases even when the collision does occur. The first factor I think is the most important one. Hydrogen, being the element of lowest atomic weight, has molecules much smaller in size than other molecules.

XQ. 501. Now, on that same figure on page 463, the curve marked III has another nice flat-top, which in your view, I understand, indicates that there was then a pure electron discharge substantially unaffected by positive ionization; is that correct?

A. I think so.

XQ. 502. And in this case the heights of those two curves, their levels go just the opposite way from the rule that you stated a little while ago; that is, the higher the voltage the lower down the curve?

A. Yes.

XQ. 503. This forms a very notable exception then to the rule that you endorsed a few minutes ago?

A. It does unless the electrodes were a different distance apart. The difference of the magnitude of those curves may be due perhaps to the fact that the electrodes were different distances apart.

XQ. 504. Can you think of any other reason?

A. The only other reason I think of is that there may have been ionization enough at the higher pressure one to cause a decrease of current.

XQ. 505. That is, since there was more pressure on the higher one even though the voltage was less, you think that may account for its being higher?

A. I think it may perhaps be possible.

XQ. 506. Then it is not a very dependable earmark for the presence of a pure electron discharge substantially unaffected by positive ionization if a change of pressure can work oppositely to a change of voltage like that, is it?

A. It is not as good as some other tests. That is what I said in the beginning. I rather doubt if that whole effect is due to ionization. I also doubt if that effect would occur to anything like the same extent in devices in which there are plate-shaped anodes.

XQ. 507. What effect?

A. I refer to the fact that a certain amount of ionization may occur in the presence of gas which may increase the current on the flat-top saturation part of the curve by a certain amount.

XQ. 508. Your November, 1912, tubes did not have plate anodes, did they?

A. No.

XQ. 509. They had hairpin anodes just like this one in the *Physical Review* paper, didn't they?

A. Yes.

XQ. 510. Now, please turn to page 470 of the same paper of December, 1913. I direct attention to the curve marked III. In this case the currents are plotted not against temperature as in the cases we have just been considering but against volts. And here I read from the paragraph just below the diagram:

> "The lower part of curve III, if obtained in a perfect vacuum, should therefore follow equation 11" (which is your space charge law equation). "In other words, the current should increase with $V^{3/2}$. By plotting the first six points of this curve on logarithmic paper, a straight line was obtained, but the slope, instead of giving 3/2 as the exponent of V, gave 1.71. This difference is certainly due to residual gas."

If that is the case, how is it you can point to an exponent of 1.83 for your August, 1912, work with just the same kind of a tube and say that that is a satisfactory indication that you had a pure electron discharge substantially unaffected by positive ionization?

Mr. Davis: I dislike to interrupt the cross-examination, but I think my brother should show the witness where he made the statement before he challenges it.

(Discussion)

Mr. Davis: It seems to me it is quite different from what Mr. Richmond suggested he said, that is all.

Mr. Richmond: All right. I will drop that question.

XQ. 511. What does that page that I have just referred to in the Interference record mean, or what does it prove, Dr. Langmuir?

A. What page?

XQ. 512. Page 2091?

A. Page 2091 is a plot on logarithmic paper of the two points that were obtained at two different voltages, 200 and 250 volts.

XQ. 513. Does it mean anything or prove anything in this case?

A. It proves that the points agreed with the 3/2 power law, within the experimental error.

XQ. 514. Then which are you testing there, the tube or the 3/2 power law when you made that plot?

A. We were testing the tube.

XQ. 515. Testing the tube?

A. Yes.

XQ. 516. And you say it is a high vacuum tube, because it conforms to the 3/2 power law; is that right?

A. The accuracy with which those points agree with the 3/2 power law is such that no sharp distinction can be drawn between 1.5 or 1.8. Both are within the experimental error of the measurements.

XQ. 517. But the experimental error might be the other way, might it not, and it might be as far off as 2.0?

A. Possibly, yes.

XQ. 518. Are you not taking advantage of the experimental errors to prove your case instead of to disprove it?

Mr. Davis: If your Honor please, I object to that question.

(Discussion)

The Court: Assuming that he had stopped there, I am not ready to say that was the whole substance of it, and I think the cross-examination then is material.

Mr. Davis: If your Honor so decides it.

The Court: Read the question, Mr. Smart.

(Question repeated as recorded.)

A. No.

XQ. 519. If the experimental error necessary to get from 1.83 back to 1.5 is 0.33, that same experimental error the other way would get you to 2.16, would it not?

A. Very likely, but either one lies within the experimental error in this particular case.

XQ. 510a. Do you think it proves such of anything in regard to the character of the tube in August, 1912?

A. Yes, I think it proves quite a good deal. Not as much as though I had taken ten points over a curve, as for example, it certainly would not prove as much as though I had taken a whole set of points running from less than 10 volts up to 100 volts as I did in the curve of the *Physical Review* paper on 470. Of course, the more points you have, the more definite conclusions you can draw and the more accurate the results agree with the theory the more definite conclusions you can draw.

XQ. 511a. Then is this the situation: That when you get 1.71 pretty definitely, it means that the difference is certainly due to residual gas, but when you get 1.83 indefinitely, it means that there was no effect due to residual gas?

A. It means with a certain probability, as in all experimental results. No experiment, or set of experiments, indicates anything with absolute certainty. It is a question of probability, and here there is a very considerable probability, that we did have the 3/2 power law followed just because those readings came out the way they did. It is not absolute proof, a mere strong probability.

XQ. 512a. I wish you could show it to us.

A. Well, I think the testimony I have given is ample too. I think I have stated very frankly just what the results should be taken to mean. They do not mean anywhere near as much as though I had taken complete data, complete curves; but to my own mind, there is not the slightest doubt but what I did have, and the results taken together, prove that I had a practically pure electron discharge in that device at 250 volts.

XQ. 513a. But I want to know what this particular result proved?

A. It is part of the proof. It does not prove it by itself; it is just one of the factors that go together to help make that conclusion. If I had nothing but just those two points, I would not consider the evidence to be very strong. It is that evidence, backed up with all the rest of the things that we knew about that tube—it is cumulative evidence. That is true of nearly all scientific work. It takes several different lines of research to prove a definite point. No one single thing is likely to make you certain of a conclusion. The real trouble with these measurements was, that they happened to come too close together in voltage, 200 volts and 250 volts are really not far enough apart to determine the slope of that line, with anything more than a rough degree of accuracy.

XQ. 514a. Then, why did you put that in your testimony?

A. Because it is significant, very significant.

XQ. 515a. In the Interference record, at the lower part of page 1589, you said that, certain work progressed rapidly, so that, long prior to October, 1913, we had built a large number of pliotrons, in 4- to 7-inch bulbs, which operated with anode voltages of 10,000 to 20,000 volts without showing the slightest signs of blue glow or other effects of positive ionization; are any of those in evidence?

A. I do not know just what you mean by "in evidence"?

XQ. 516a. Have any of those been produced in this case?

A. No. I have testified in regard to the first one of them, the tubes themselves are not in existence, I think.

XQ. 517a. And at the bottom of page 1590 of the Interference record, you said:

> "Long prior to October, 1913, we also built two electrode devices or kenotrons having plate-shaped anodes for the purpose of rectifying high-voltage currents with considerable power."

Are any of those in existence?

A. I do not believe so.

XQs. 518a-519a. And at top of page 1591, you said:

> "Long prior to October, 1913, in our work with high-voltage pliotrons, we found that we were able to use these devices for the production of high-frequency oscillations."

Those were the same ones referred to at the bottom of the preceding page, were they?

A. Why, no. At the bottom of the preceding page, it referred to kenotrons, which are two-electrode tubes.

XQ. 520. These are something different from those that I have mentioned just now. Then, are these the high voltage pliotrons, or were they the same as these——

A. They were the ones referred to at the bottom of page 1589.

XQ. 521. Very wall, and the earliest operative tube that you have produced as an exhibit in this case, is the one that was made in April, 1914, is it not?

A. Will you please read that question? (XQ. 521 repeated as recorded.) You mean by "operative one," that can now be operated?

XQ. 522. Yes. You may refer to page 1591 of the Interference record.

A. Yes. I think that is true. I think it is the only tube that we have produced that is operative.

XQ. 523. Are pages 1592 and 1492 of the Interference record——

A. Might I add in regard to that other question, of course I mean other than the commercial tubes that were discussed in the record for the purpose of getting the characteristics.

XQ. 524. And came considerably later?

A. Among the historical tubes of early date that was the only one which was produced as an exhibit.

XQ. 525. And this one that was made in April, 1914, was tested, the test running up as high as fifty volts, and that test is shown on pages 1592 and 1593 of the Interference record, is it?

A. Yes. The current was twenty milliamperes at fifty volts.

XQ. 526. And the grid was connected to the anode, was it not?

A. Yes, so as to be able to use it as a two-electrode tube.

XQ. 527. Which of those three lamps, distinguished as 3, 6 and 2, is shown in the photograph on page 1982 of the Interference record——

A. I have no way of telling.

XQ. 528. Do you recall the photograph? I have given the wrong page, your Honor. I can turn to it very rapidly.

A. This is it (indicating).

The Court: Page 2096.

XQ. 529. Thank you. On page 2096.

Mr. Davis: Now, let the question be read. I have not followed it.

(XQ. 527 repeated as changed as follows: "XQ. 527. Which of those three lamps, distinguished 3, 6 and 2, is shown in the photograph on page 2096 of the Interference record——

"A. I have no way of telling.")

XQ. 530. In those experiments with lamp No. 2 in November, 1912, I understand that sometimes you used one of your two anodes and sometimes the other anode, and sometimes both of them connected together as one anode. When you used only one, how was the remaining one disposed of? Was it connected in any way?

A. No, I think it was allowed to float.

XQ. 531. And did it charge up negatively?

A. It would charge up to about approximately the negative end of the cathode.

XQ. 532. And did it then exert a grid action on the current that was flowing?

A. To some extent, yes.

XQ. 533. I understood you to say that your work of November 19th, recorded shortly thereafter in the year 1912, was so important that you wrote twenty pages of notes about it; was it important enough to disclose it to any one?

A. Yes. I discussed it with a great many people in the laboratory.

XQ. 534. To whom did you disclose it?

A. Probably to pretty nearly every one around that I was working with.

XQ. 535. Give us half a dozen names?

A. Mr. Sweetser, Mr. Mackay, and then at later times, I think it was the next day, we had a lamp committee meeting at which I discussed the results that I had obtained. There were several men present at that time. Later on, after I had obtained more complete data in this experiment 317, I talked it over with Coolidge and I certainly must have talked it over with Dr. Whitney, although I do not have any distinct recollection of the time. I know Dr. Whitney was thoroughly familiar with the work that I was doing.

XQ. 536. Mr. Sweetser is the only one of those who has testified as a witness in this case, is he not?

A. No, I think Mr. Mackay testified in addition to Mr. Sweetser and possibly Mr. Robinson testified.

XQ. 537. It was the practice in your laboratory for Mr. Gartner to witness your notebook whenever you recorded an invention in it?

A. From time to time Mr. Gartner might if he happened to come around the laboratory, he might witness some pages in my notebook. It would not have to be Mr. Gartner. Anybody might do so. I had no very definite system in regard to that.

XQ. 538. On page 2128 of the Interference record Mr. Gartner entered a table of places where he had signed as a witness in your notebook, did he not?

A. I do not remember.

XQ. 539. Here it is.

A. Yes.

XQ. 540. Did any one sign as a witness for these twenty pages of such importance in November, 1912?

A. I do not think so.

XQ. 541. On your direct deposition I understood you to refer to a book by Wilson as a source of information. I hand you Defendant's Exhibit I for identification and ask you if that is the book.

A. Yes, that is the book. And the equation given at the top of page 7 of that book is the equation which I copied into my notebook in the middle of page 123.

XQ. 542. And on the opposite page of that notebook which was published in that same year it says:

> "The variation of the thermionic current from hot platinum in a vacuum with the temperature of the platinum was first investigated by O. W. Richardson, who at the same time put forward an elegant theory to account for it which is now firmly established."

Is that correct?

A. Yes, you have read correctly from page 6 of this book.

MR. RICHMOND: For my information, Mr. Davis, have you introduced the paper by Wilson on which you rely for your statement that Wilson doubted Richardson's law or something of that sort?

MR. DAVIS: I am not relying on this paper but on Arnold's own statement to the Commissioner of Patents in one of the early papers in his application file.

MR. RICHMOND: And you do not pretend to produce the paper by Wilson?

MR. DAVIS: I do not know. Mr. Lunt may know, but I have not been looking after these things. I will try to find out for you.

MR. RICHMOND: At your convenience, Mr. Davis.

XQ. 543. When you had your notebook before you, you referred to a part of it where the mathematical work was done by you for calculating the 3/2 power law for parallel plate electrodes and I understood you to remark that that part of the work had previously been done by Child. Then I understood you to refer to some more computation for the case of the cylindrical anode and the axial cathode. Will you please point that out again for me?

A. The place in the notebook where those calculations occur?

XQ. 544. Yes, Dr. Langmuir.

Mr. Davis: In accordance with Mr. Richmond's request, I do not find in the list of exhibits this Wilson paper in question, and I do not know whether it will be introduced or not.

Mr. Richmond: Thank you, Mr. Davis.

The Court: Suppose we take our afternoon recess now.

(After a short recess.)

(XQ. 543 was repeated by the stenographer.)

A. The equations applying to this case are worked out on pages 313 to 323 of my notebook 413 under date of February 28, 1913.

XQ. 545. And does the final equation, that is, the conclusion of this line of inquiry appear on those pages and if so point it out particularly.

A. Well, at about three-quarters of the way down, page 320, is given the equation in terms of a quantity which is designated by β, the Greek letter Beta, and then about 6/10 of the way down the page 321 the full equation is written out in which for β is substituted its value in terms of the radius of the cylinder of the filament.

This form of the equation is not very convenient for use when the wire is a very small wire or when you are dealing with a small wire in the axis of the cylinder because it is difficult to calculate an accurate value of β for use in the equation in that case without adding together a great many terms of the mathematical series.

Therefore I set Mr. E. Q. Adams, who was working for me at that time, to work, shortly after that, to devise a better way of calculating the value of β for the case where you are dealing with a very small wire in the axis of a cylinder, and he did that, and the results of the calculations he made were published in the form of a table in my *Physical Review* article on page 458.

The lower values of β^2 squared that are given in that table can be calculated directly from the mathematical expression that I gave in my notebook. But the higher values given in that table, although they theoretically could be obtained from that expression, it would be rather difficult to do so. Mr. Adams found an improved method of calculating them.

XQ. 546. Then the matter was not worked out to an equation in your notebook as it appears in your *Physical Review* paper of December, 1913?

A. The correct equation was given. But Mr. Adams worked out a much more convenient method of obtaining the numerical values.

XQ. 547. I understood you to say that this work on the case of the cylindrical anode and axial cathode was "new, that is, so far as I know, nobody had worked it out." Do you mean that you did not know that Arnold worked it out at an earlier date?

A. No, I did not know that, or at least, if I have ever known it I had forgotten it. I do not remember at all when Arnold worked it out. In fact, I do not believe that Arnold did work it out. It seems to me that it was Kendall as I remember the record. I do not remember the date at which he did that.

Mr. Richmond: Your Honor, I would rather not enter on that discussion.

The Court: Do you make a motion?

Mr. Richmond: I move to strike out the last part of the answer.

The Court: Will you begin the reading of the answer? (Answer to the last question was repeated by the stenographer down to "or at least if I have ever known it, I have forgotten it.")

THE COURT: The remainder of the answer is stricken out.

XQ. 548. I would like to call your attention back to that figure on page 470 of your *Physical Review* paper of December, 1913, for a point that I should have called your attention to in order, but I lost sight of it for the moment. Please notice this curve III, for which you say in the paragraph right below the figure:

> "The slope, instead of giving 3/2 as the exponent of V, gave 1.71. This difference is certainly due to residual gas."

Is it correct that the gas pressure for this curve was sixteen-hundredths of a micron of nitrogen?

A. That is the pressure that is given on the figure, yes.

XQ. 549. And it was nitrogen gas that you used in August, 1912, was it?

A. Yes.

XQ. 550. And this pressure compares how with the pressure that you had in August, 1912?

A. The pressures in August, after the sudden decrease in the current curve varied from about half a micron down to about one-third of a micron, I think, so that the pressure was from two to three times greater than the pressure designated on curve III.

XQ. 551. When you tried to make the vacuum worse for certain of those so-called lamps of November, 1912, was that with all three of them that were numbered 3, 6 and 2?

A. With lamp No. 3 I do not believe that I made any effort to make the vacuum worse in order to study the changes in the conditions. At least, there is no record of it in the notes. With lamp No. 6, as described on page 128, I did do so, by heating the bulb with an alcohol flame, and the same is true of lamp No. 2, which is the third lamp tested. That was both heated and sparked.

XQ. 552. Now, in your testimony you said that you burned out the intermediate section of the filament for two purposes, namely, to get separate electrodes and to affect a clean-up; is that correct?

A. Yes.

XQ. 553. And you recorded in your notebook only the first purpose; is that correct?

A. Yes.

XQ. 554. But you did make an entry in your notebook about "clean up" in connection with blue glow, did you not?

A. I think so.

XQ. 555. And at what stage did this clean-up that you mention occur, and with which lamps?

A. I think it may possibly have happened during certain stages of the early exhaust in each of the lamps, as for example, during the aging of the lamps, when they were first run up to—I may say, for example, when they ran up "to double voltage for one or two minutes to age."

XQ. 556. What page, Dr. Langmuir?

A. On page 124, the bottom of page 124 I say:

> "Running up slowly to avoid arcing."

That is the voltage across the lamp was run the double normal voltage which was probably 240 volts, and that is an extremely high temperature of the filament, four or five hundred degrees above normal operating temperature, so that tungsten vaporizes very quickly at that temperature, and when a gas is contained there, there may be some glow discharge or some positive ion bombardment, which would greatly increase under those conditions the rapidity of the clean-up gas, and then after that, the middle section of each lamp was burned out, one of the sections of lamp No. 2 was burned out during that aging process. Now, after that, in No. 6, blue glow occurred again in flashes as described on page 128.

XQ. 557. Did that improve the vacuum?

A. Yes, the vacuum ended up by being quite high, especially after the tip of the bulb was immersed in liquid air.

XQ. 558. Does your notebook say anything about blue glow, or about improving the vacuum in connection with the aging?

A. No, it does not mention that. It merely says "running up slowly to avoid arcing." It may be that no blue glow occurred if the current is run up slowly, it sometimes does not occur, it probably did occur, however. It was usual to observe blue glow under these conditions with lamps exhausted in the regular way that these were exhausted.

XQ. 559. Now, after you had done this experimental work, and after you had written up the experimental part of it, you carefully summarized the work in a series of ten facts, numbered paragraphs on pages 139 and 140 of your notebook, is that correct?

A. Yes.

XQ. 560. And the first of these facts was——

> "At first Edison current follows Richardson's formula well up to a certain temperature. Then suddenly blue glow appears and Edison current decreases greatly. Call this first and second stages."

Is that right?

A. Yes, that is in the notebook.

XQ. 561. Well, your answer suggests that I am wrong about it?

A. I do not know what question you asked in connection with it—is it right—I do not know just what you mean—is what right?

XQ. 562. I will make that clear. It did not occur to me that there was any question about your endorsing the statement, but I will now ask whether you now endorse that statement appearing in your notebook?

A. I think that summarizes pretty well what I observed.

XQ. 563. For the three lamps?

A. I do not know whether all three lamps had that effect or not. I rather think that the first lamp did not show it.

XQ. 564. And in the second paragraph of the facts you said, "In first stage Edison current decreases by raising bulb temperature and vice versa." That is written down so and is a correct statement, is it?

A. I believe so although again I do not know whether I had in mind the first lamp or possibly the last two lamps.

XQ. 565. And the fourth paragraph of facts says: "In first stage the blue glow seems to set in usually when maximum is reached." I have read that correctly and that is a correct statement in your notebook, is it?

A. Yes, that is a correct statement in the notebook.

XQ. 566. And the fifth paragraph of facts——

A. Again I do not know that the first stage really always occurred in all the lamps. There is no evidence that the first stage occurred in the first lamp. I am rather doubtful that it did occur. If it did occur it got over it very quickly.

XQ. 567. And the fifth paragraph of facts reads: "No blue glow during second stage." I have read that correctly and that is a correct statement, is it?

A. Yes.

XQ. 568. It was blue glow that cleaned up those lamps, was it not, Dr. Langmuir?

A. No. The blue glow accompanied the process that caused the lamps to clean up. The cleaning up of the lamp was due to tungsten that had evaporated from the filament as a result of the positive ion bombardment.

XQ. 569. I accept your statement as better and more accurate than the one in my question. And this clean-up that you have last mentioned is referred to in the notes as a clean-up. I refer you to the upper part of page 138 of your notebook. "Blue glow was prominent during this clean up of gas."

A. Yes.

XQ. 570. And any supposed clean-up in connection with the burning out of the intermediate filament is not mentioned in the notebook, is it?

A. I do not think it is mentioned specifically, no. Although that is largely one of the objects. It was the object in choosing those lamps in the beginning for that purpose. If the lamps were once chosen for that purpose the rest had to continue automatically, that is, the filament had to be burned out.

XQ. 571. I have understood you that there were two objects, isn't that correct?

A. There were two objects I had in mind when I chose those particular lamps for this particular experiment, but once having decided that the lamps would be used in that way then of course I could not do anything with the lamps until I burned out the filament in order to get two electrodes and that is the thing that was uppermost in my mind at that time.

XQ. 572. And that is the object that is recorded in your notebook?

A. Yes.

XQ. 573. Just what was it that you showed to Richardson when he visited your laboratory. Was it these three lamps, 3, 6 and 2?

A. I remember telling him about those lamps and showing the curves that I plotted. I do not recall whether I showed him the lamps themselves or not.

XQ. 574. And you do not remember whether you operated those lamps for him or not?

A. No, I do not think I can say that definitely although I do seem to have a recollection of having immersed some bulbs in liquid air when Professor Richardson was there and if so I suppose it must have been those lamps, but my recollection is not very clear on that point.

XQ. 575. If the lamps were spoiled it probably was not one of those lamps, was it?

A. I do not think they were spoiled. Of course, if the lamps were burned out I would not have made any further experiments with those lamps, but I do not recall that the lamps were spoiled.

XQ. 576. I had the impression that something had been said about deliberately overloading them so as to spoil them, is that correct?

A. Not for the purpose of destroying the remaining filament. The central filament was deliberately overloaded so that it was burned out, but there was no object in burning out the filament that was used as a cathode. I see no reference in this notebook to other filaments being burned out and I do not think they were burned out.

XQ. 577. Then it is your impression now that when you got through with those lamps on November 19th as recorded in your notebook within a very few days following, they were left in good condition ready for the kind of work you had been doing?

A. I think that is probable. I do not remember definitely what was done with the lamps after that date. I do not think they would have been destroyed. As I said before, I have a vague recollection of having dipped some bulbs in liquid air to show Professor Richardson some effects resulting from that. It may well have been that they were those lamps or some other lamps somewhat like them, but I am not sure.

I know that the experiment that Sweetser was carrying out at that time as experiment 317 was in progress and I showed Professor Richardson that apparatus and I think at that time we took some measurements on the lamp that was being studied in that way in experiment 317. I know distinctly that I showed him the flat top temperature curve and showed him a lot of measurements that we had taken, probably records of experiment 317.

XQ. 578. Then all the work that you did with those lamps as recorded in your notebook in the days immediately following November 19, 1912, left them in the condition of high vacuum tubes, did it?

A. I think so as far as I remember.

XQ. 579. I understood you to say that the DeForest audion that you worked with in the early part of 1913, had all its leads brought out at one press in one end. Are you sure you are right on that?

A. No. It may be that the filament leads are brought out at the other end. In fact, I think it was probable that the filament lead was brought out at one end and the grid and plate leads from the other, but I am not at all sure.

XQ. 580. I think that yesterday you testified about some General Electric UV-200 tubes containing argon. Have I got the designation right and am I right in my recollection?

A. I think so.

XQ. 581. Were those UV-200 tubes always made by introducing argon?

A. I think so.

XQ. 582. Is it not a fact that at an earlier stage you pumped tubes, I say you, but I mean the General Electric Company, pumped tubes that were structurally just alike and then sorted them and called them UV-200 if they had a poor vacuum and called them UV-201 if they had a good vacuum?

A. I never heard of any such thing being done.

XQ. 583. So that is not to your knowledge?

A. I think that is extremely improbable and I never heard of any such thing being done.

XQ. 584. You testified about a conversation with Alexanderson. Did you testify about that in the testimony taken on the Interference?

A. No.

XQ. 585. In regard to seeing blue glow in a lamp, your work has always been with a brilliant incandescent tungsten filament, had it not, and would not that make it quite difficult to see a blue glow unless it were quite pronounced?

A. It is undoubtedly harder to see blue glow with a tungsten filament than it is with a Wehnelt cathode.

XQ. 586. You have discussed the correction to the 3/2 power law which you sometimes find desirable to make to correct for the drop in the potential along the filament. As I understand it the commutator used in a few instances and which is now an exhibit in this case was used by you as a sort of automatic corrector for this filament drop in the cathode; is that correct?

A. When?

XQ. 587. In connection with exhibits produced in the Interference record?

A. Yes. We wanted to get information as to how the tubes are operating to separate the various disturbing factors that might occur and particularly where the voltage drop in the filament was larger than usual, we frequently used the rotating commutator.

XQ. 588. In the simple case of a two-element tube or in a three-element tube, when the grid is attached to the plate and where the connection to the anode is made at the negative end of the filament, this particular correction can be made by subtracting from the applied plate volts one-half of the filament drop; is that correct?

A. It can, if the voltage on the plate (as measured from the negative end of the filament) is say 30 per cent. higher than the potential on the positive end of the filament. It is not satisfactory if the plate potential lies below the positive end of the filament or very close to it.

For example, if there is a filament having a ten-volt drop and you measure the potential from the negative end of the filament, if you have fifteen volts or more on the plate then it is quite satisfactory to measure the potential from the mid-point of the filament, but if you have seven or eight volts on the plate we should not measure from the mid-point of the filament because there is a certain part of the filament which is not affected at all.

XQ. 589. Your exception represents rather an unlikely case in practice, does it not?

A. But not in the tubes that have been produced in this record. In some cases there were thirty or forty volts drop in the filament.

XQ. 590. Please look at page 1168 and page 1170 of the Interference record. Page 1168 shows the departure from the 3/2 power law when this correction is not made with the rotating commutator and page 1170 shows how much better the points fit the 3/2 power law after you have used the rotating commutator to make the correction. Is this correct?

A. The two points are obtained in the way that you suggest, one with the rotating commutator and the other without the rotating commutator and the curve with the rotating commutator does agree with the 3/2 power law better than the curve taken without the rotating commutator.

XQ. 591. Now, please, turn to page 1176, which follows shortly after in your deposition on the motion. In this case you did not use the rotating commutator, did you?

A. In the preceding one the voltage drop on the filament I think was 21.4 volts. In this case it is 10.8 volts. The rotating commutator was not used.

XQ. 592. Now, I show you a copy of that page 1176, with black ink crosses to show the changes by correcting for half the filament drop, as we mentioned a few minutes ago. Can you readily verify one or two representative points to see if the correction has been properly made in that instance?

Mr. Richmond: Your Honor, Mr. Davis suggests letting this witness go now, and that is agreeable to me.

Mr. Davis: Dr. Alexanderson would like to get home.

The Court: You may call another witness, now.

Mr. Davis: I will ask Dr. Alexanderson to take the stand.

136

Pat

65867
S.B.

Vol. III

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DeFOREST RADIO COMPANY, PETITIONER,

vs.

GENERAL ELECTRIC COMPANY

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT

PETITION FOR CERTIORARI FILED JANUARY 8, 1931

CERTIORARI GRANTED FEBRUARY 25, 1931

(35,552)

INDEX.

PLEADINGS AND TESTIMONY.

	Vol.	Page
Docket Entries in No. 589	I	1
Docket Entries in No. 598	I	3
Bill of Complaint in No. 589	I	5
Answer as Amended in No. 589	I	10
Defendant's Bill of Particulars	I	14
Defendant's Supplemental Bill of Particulars	I	20
Bill of Complaint in No. 598	I	22
Answer as Amended in No. 598	I	29
Stipulation	I	36
Stipulation	I	133
Plaintiff's Prima Facie Proofs	I	35
Defendant's Proofs	I	145
Defendant's Depositions	II	959
Plaintiff's Rebuttal Proofs	II	1073
Defendant's Sur-Rebuttal Proofs	III	1789
Plaintiff's Sur-Rebuttal Proofs	III	1910
Appendix to Plaintiff's Record	III	1940
Opinion of the Court	III	1943
Decree in No. 589	III	1981
Plaintiff's Petition for Appeal in No. 589	III	1982
Order Allowing Appeal	III	1983
Plaintiff's Assignments of Error in No. 589	III	1984
Citation on Plaintiff's Appeal in No. 589	III	1985
Stipulation as to Transcript in No. 589	III	1987
Order Approving Stipulation	III	1988
Decree in No. 598	III	1989
Plaintiff's Petition for Appeal in No. 598	III	1991
Order Allowing Appeal	III	1992
Plaintiff's Assignments of Error in No. 598	III	1993
Citation on Plaintiff's Appeal in No. 598	III	1995
Defendant's Petition for Appeal in No. 598	III	1996
Order Allowing Appeal	III	1997
Defendant's Assignments of Error in No. 598	III	1998
Citation on Defendant's Appeal in No. 598	III	1999
Stipulation as to Transcript in No. 598	III	2000
Order Approving Stipulation	III	2001
Clerk's Certificate	III	2002
Opinion	III	2005
Order Affirming Decree in Case No. 3799	III	2009
Order Affirming Decree in Case No. 3800	III	2010
Order Affirming Decree in Case No. 3801	III	2011
Petition for Rehearing in Cases Nos. 3799 and 3800	III	2012
Order Allowing Petition for Rehearing in Case No. 3799	III	2024
Order Allowing Petition for Rehearing in Case No. 3800	III	2025

INDEX—Continued.

	Vol.	Page
Opinion	III	2026
Order Reversing Decree in Case No. 3799	III	2065
Order Affirming Decree in Case No. 3800	III	2066
Order Affirming Decree in Case No. 3801	III	2067
Clerk's Certificate	III	2068
Order allowing certiorari	III	2069

PLAINTIFF'S PRIMA FACIE PROOFS.

	Vol.	Page
Hogan, John V. L.—		
Direct Examination	I	39
Cross-Examination	I	94
Re-Direct Examination	I	126
Re-Cross-Examination	I	135
Re-Direct Examination	I	144

DEFENDANT'S PROOFS.

	Vol.	Page
Arnold, Harold D.—		
Direct Examination	I	553
Cross-Examination	I	628
Re-Direct Examination	II	746
Re-Cross-Examination	II	765
Re-Direct Examination (Resumed)	II	783
Re-Cross-Examination (Resumed)	II	785
Beal, Ralph R.—		
Direct Examination	II	1044
Beck, Helene—		
Direct Examination	II	960
Cross-Examination	II	976
Re-Direct Examination	II	991
Blackwell, Otto B.—		
Direct Examination	II	804
Chaffee, E. Leon—		
Direct Examination	I	145
Cross-Examination	I	200
Re-Direct Examination	[illegible]	373
Re-Cross-Examination	I	388
Clark, Leland B.—		
Direct Examination	II	1016
Cross-Examination	II	1024
Colpitts, Edwin H.—		
Direct Examination	I	481
Cross-Examination	I	527
Re-Direct Examination	I	549
Colpitts, Edwin H. (Recalled)—		
Direct Examination	II	802

INDEX—Continued.

	Vol.	Page
Hewlett, Palmer—		
Direct Examination	II	1005
Cross-Examination	II	1012
Re-Direct Examination	II	1015
Hyde, Ralph—		
Direct Examination	II	993
Cross-Examination	II	998
Re-Direct Examination	II	1003
Re-Cross-Examination	II	1004
Jewett, Frank B.—		
Direct Examination	I	393
Cross-Examination	I	431
Re-Direct Examination	I	436
Re-Cross-Examination	I	437
Kelly, Marvin J.—		
Direct Examination	II	811
Cross-Examination	II	857
Re-Direct Examination	II	910
Lamont, G. E.—		
Direct Examination	II	1025
Direct Examination (Resumed)	II	1065
Cross-Examination	II	1067
Re-Direct Examination	II	1067
Millikan, Robert A.—		
Direct Examination	I	440
Cross-Examination	I	459
Re-Direct Examination	I	479
Rodman, Harold Lee—		
Direct Examination	II	1057
Sarnoff, David (Stipulated Testimony)	III	1446
Tuel, Austin Y.—		
Direct Examination	II	1060
Waterman, Frank N. (Stipulated Testimony)	III	1486
Watkins, James O.—		
Direct Examination	II	1053
Cross-Examination	II	1055
Re-Direct Examination	II	1055

PLAINTIFF'S REBUTTAL PROOFS.

	Vol.	Page
Alexanderson, Ernst F. W.—		
Direct Examination	III	1448
Cross-Examination	III	1461
Coolidge, William D.—		
Direct Examination	III	1496
Cross-Examination	III	1532

INDEX—Continued.

	Vol.	Page
Hogan, John V. L.—		
Direct Examination	III	1563
Cross-Examination	III	1639
Direct Examination (Resumed)	III	1659
Direct Examination (Resumed)	III	1721
Cross-Examination (Resumed)	III	1767
Langmuir, Irving—		
Direct Examination	II	1073
Cross-Examination	II	1299
Re-Direct Examination	III	1436
Re-Cross-Examination	III	1439
White, William C.—		
Direct Examination	III	1467
Cross-Examination	III	1490

DEFENDANT'S SUR-REBUTTAL PROOFS.

Arnold, Harold D. (Recalled)—		
Direct Examination	III	1867
Cross-Examination	III	1878
Becker, Joseph A.—		
Direct Examination	III	1789
Cross-Examination	III	1824
Re-Direct Examination	III	1847
Re-Cross-Examination	III	1847
Folk, George E.—		
Direct Examination	III	1852
Cross-Examination	III	1862
Re-Direct Examination	III	1867
Hunter, Frederick L.—		
Direct Examination	III	1893
Cross-Examination	III	1905
Re-Direct Examination	III	1907
Re-Cross-Examination	III	1907
Langmuir, Irving—		
Direct Examination	III	1848

PLAINTIFF'S SUR-REBUTTAL PROOFS.

Bayard, Fairfax—		
Direct Examination	III	1910
Cross-Examination	III	1911
Langmuir, Irving—		
Direct Examination	III	1912

U. S. District Court, Wilmington, Del.,
Thursday, November 4, 1926,
10 o'clock A. M.

SIXTEENTH DAY.

Before:

Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

The Court: Are you ready, gentlemen? Will you renew the cross-examination of Dr. Langmuir?

Irving Langmuir, resumes the stand.

Cross-Examination (Continued).

By Mr. Richmond:

Mr. Richmond: My impression is there is a question outstanding. It is XQ. 592.

"XQ. 592. Now, I show you a copy of that page 1176, with black ink crosses to show the changes by correcting for half the filament drop, as we mentioned a few minutes ago. Can you readily verify one or two representative points to see if the correction has been properly made in that instance?"

A. I notice that half the drop in the potential along the filament, that is, 5.4 volts, has been subtracted from the observed voltages, and the original points as plotted on the curve have been displaced 5.4 volts to the left, that is, the lower voltages, in order to express the voltages with reference to the mid-point of the filament, instead of the negative end of the filament. As I pointed out in my answer yesterday, this, I think, is a justifiable procedure in this case down to about fourteen volts; that is, down to currents of about fifteen milliamperes; but below that, the potential of the plate is too nearly the same as the potential of the filament to make it justifiable to correct in that way. You will notice that these points go down to observed potentials of six volts, and when the anode was at a potential of six volts it was 4.4 volts *negative* with respect to the positive end of the filament. In other words, it was intermediate in value between the negative and positive end of the filament, and in that case it is not a proper way to correct the results to make the subtraction of 5.4 volts. So that I believe that if a rotating commutator had been used, the curve that would have been obtained by the actual elimination of the voltage on the filament, would have agreed very well with the points that you have marked by crosses at currents above about fifteen milliamperes, but below that I do not think that they would have agreed with the points that you have shown by crosses. At these higher voltages, or with currents above fifteen milliamperes, the displaced curve which you have drawn, would have a slope a little less than that corresponding to the 3/2 power law, and as the voltage is raised, it approaches more and more closely to the 3/2 power law, and there is no indication whatever of a rise above the 3/2 power law at voltages above ionization, such as would have been characteristic of the effect of gas in the tube.

In this case there evidently are two factors that tend to compensate which have made the lower part on the curve come closer to the theoretical 3/2 power law than they would if either one of these factors alone were neglected or eliminated.

XQ. 593. You are referring now to the curve as it appeared originally?

A. Yes. In that case the good agreement with the

3/2 power law at the very low voltages, far below the positive end of the filament, was due to a more or less fortuitous balancing of the two factors.

MR. RICHMOND: I will ask to have the sheet which has just been shown to the witness and on which he based his reply marked for identification.

(Marked "Defendant's Exhibit L for Identification.")

XQ. 594. If I understand you in this case there were some factors tending to cause departures from the 3/2 power law but you consider that somewhat fortuitously they counteracted one another so that you get a tolerable agreement with the 3/2 power law?

A. At the low voltages below ten volts I think that was largely true.

XQ. 595. But how were these factors working at page 1168 to which I referred you yesterday?

A. This curve was obtained with a pliotron or three-electrode tube in which there was an unusually high voltage drop along the filament, the filament voltage being 21.4 volts. This fact caused the lower part of the curve to become unusually steep. According to the theory of the effect of the voltage drop along the filament when the voltages of the plate become below the voltage of the positive end of the filament, the theoretical slope of the line should be 5/2 instead of 3/2 and I think it is for that reason that this slope below about thirty volts, particularly below twenty volts, does become steeper than the 3/2 power law.

That is borne out of course by the comparison of the curve on 1168 with the curve on 1170 where the rotating commutator was used and therefore the effect of the voltage drop along the filament has been eliminated.

XQ. 596. Then, when these factors that tend to modify the expression of the 3/2 power law one way or the other, when they fortuitously neutralize one another so to speak or nearly cancel out, you do not use the rotating commutator, but when they do not fortuitously cancel one another out, you do use the rotating commutator, isn't that right?

A. That is not right. That is not what I do.

XQ. 597. Will you please tell us, then, in general, when you use the rotating commutator in these demonstrations and when you do not use it?

A. As I recall what we did at that time, we first took all the curves of those tubes without the rotating commutator and in certain cases, particularly those tubes that had a large voltage drop along the filament, it was obvious that that voltage drop along the filament was causing marked increase in the slope at the lower part of the curve and in a few of those cases additional readings were taken with the rotating commutator in order to find to what extent the voltage drop along the filament did modify these results.

In the illustration which you have given of type P pliotron which had the highest voltage drop along the filament that any of them have, both curves were given in order to show the magnitude of the effect that resulted from that. I think in some of the other cases we gave curves obtained with the rotating commutator only. To the best of my recollection in all cases where we did use the rotating commutator the curve obtained with the rotating commutator was the one that was given.

I would like to point out furthermore that the significant part of the 3/2 power law plot is in the neighborhood of the ionizing voltage and higher, and in all of these cases, that is, at the voltages above ionizing voltage, that is from fifteen to twenty volts upwards, the effect of using the rotating commutator is relatively small, except possibly in the one case of the type P pliotron, where there is a voltage drop of twenty volts along the filament.

XQ. 598. When did you first become aware, as you have testified, that the particular entries in Sweetser's notebook for August, 1912, relating to the current of reduced value, as is shown in Exhibit 163—when did you first become aware that those entries represented as you have said, "a condition of current flow largely governed by the space charge effect"?

A. Why, of course, by that time I had no idea of the theory underlying these effects. I think I have already testified that it was about the twentieth of November or the twenty-second of November, I believe, when I first had the idea of the cause of the low currents that were obtained as the vacuum was improved. In regard to these particular measurements that you refer to, I do not believe that I thought of those particular measurements as proving that the current is limited by space charge, that is, I had that interpretation of these results until, oh, several years after 1912. I do not know just when. I do not remember exactly.

XQ. 599. Is your memory refreshed as to that date by reference to Mr. Davis's telegram which was filed in the Patent Office, which asked for additional time for an extensive investigation? I think you will notice that the date of that is September 15, 1916, and it bears the Patent Office stamp September 16, 1916 (handing book)?

A. No. I do not remember this telegram. That does not suggest anything.

XQ. 600. That does not help you to fix the date any more definitely?

A. It may be that date, but I do not remember the telegram. That particular telegram does not help me to fix the date, but as far as I know, it may have been that date or thereabouts.

XQ. 601. Referring to your notebook record for lamps 3, 6 and 2, with which you worked on or about

November 19, 1912, does the notebook record show the duration of the clean-up process that you mentioned in your testimony?

A. Will you read that? (XQ. 601 repeated as recorded.) Why, only in one case, I think, and at the beginning of the—may I see the notebooks (inspecting books)? On page 124, there is the description of the aging process, in which the filaments were "run at double voltage," that is 240 volts, "for one or two minutes running the voltage up slowly to avoid arcing." That is the only reference I find to a definite time during which any clean-up process took place. Of course, in a few other cases—I think that is the only definite statement.

XQ. 602. And was it that aging for one or two minutes that affected the clean-up as recorded on page 124, rather than when you "burned out Section B so as to have two separate sections," as recorded on the next page following?

A. No, we cleaned up in both cases. Probably more clean-up during the burning out of the filament. That was probably more effective than the first one.

XQ. 603. Is there any record of filament temperature during this clean-up?

A. No, I think not. Except the fact that it is under double voltage and calculate the temperature from that during the first case. That fixes the temperature definitely. I can calculate what it would be but I cannot give it from memory. The temperature would have been extremely high, probably over 2800 degrees, very likely 2900 degrees.

XQ. 604. Is there anything in those notes for the lamps of November, 1912, that have been referred to as lamps 3, 6 and 2 to indicate that they had any better vacuum than the tube of August, 1912?

A. I know from the method of preparation of this lamp that it had a much better vacuum but the pressures are not given in the notes. There was no way of measuring the pressure so that there is no single definite statement in the notes which tells exactly what the pressure was.

The method of exhaust, for example, cooling the bulb in liquid air and vaporizing large amounts of tungsten, I know is a method of exhaust which would give an extremely good vacuum. I believe that the pressure in the lamp during most of these runs particularly those which are recorded in the curves on pages 133 and 134, I believe that the pressure was considerably below 0.01 micron.

XQ. 605. But so far as the records go, your answer is that there is no indication of a better vacuum than in August, 1912?

A. The agreement with the 3/2 power law is sufficiently good to make me believe that the pressure from that fact alone was lower than 0.3 of a micron, somewhat lower than that.

XQ. 606. Then you mean in November, 1912, you think there was much better agreement with the 3/2 power law than in August, 1912?

A. I cannot say that definitely because the degree of agreement of the August experiments were subject to a good deal of experimental error, that is, the data do not fix the exponent closer than between 1.5 and possibly 2.0.

No, the conclusion is based more on my knowledge of the conditions, that resulted from the experiment 317 where we had rather similar conditions. In that experiment different amounts of nitrogen were placed in the bulb and I have studied carefully the effects that were produced by these different pressures of nitrogen on the departures from the 3/2 power law or the exponent to which these pressures of nitrogen produced that ionization sufficient to modify the space charge effect, and from those results I believe that 0.3 or 0.4 of a micron of nitrogen at 250 volts would have produced a perceptible, perhaps five or ten per cent. increase in the current over what it would have been in the highest vacuum at these voltages.

I do not find any evidence, I think, without having investigated that point particularly or more definitely, that the data of November 19th agrees more accurately with the 3/2 power law. (After inspecting notes.) In this case the data on the exponent are somewhat more accurately determined than they were or can be determined from the August experiments. I rather believe that the November experiments fix the value of that exponent closer to the 3/2 power law than you would get with pressure as high as 0.4 of a micron. The difference, however, I think is relatively insignificant.

My real belief that the pressures in the November 19th experiments were much lower than 0.3 of a micron is based on my knowledge of the effectiveness of the clean-up process when relatively large amounts of tungsten are evaporated.

XQ. 607. In the original specification filed with your application on which Patent No. 1 was issued, you said on page 4: "I have found that deleterious gases may be removed by electron bombardment even at a low temperature." Is that correct?

A. I believe there was such a statement in the original specification, but I do not believe that the fact described there is true. I think that that statement was based on something which later on I found was not true. In other words, I do not believe that gases can be removed from metals effectively by electron bombardment without heating the metals.

XQ. 608. At another place in the specification, that is at page 6, I suppose the same answer applies: "However, heat alone will not remove all the gas liberated by the electron discharge, but this gas is driven out even at ordinary temperatures by the discharge itself." Is that right or wrong?

A. Do you mean the facts stated there or whether it is in the specification?

XQ. 609. That is what I mean. First, is that correctly quoted and second is it now true?

A. It is correctly quoted.

The statement consists of two parts and the first one has a certain element of truth, or has considerable truth in it and the second one has very little. Take the second statement. It says: "This gas is driven out even at ordinary temperatures by the discharge itself." I do not believe that an electron discharge by itself will drive gases out of metal electrodes unless the intensity of that discharge is sufficient to heat the electrodes. However, the passage of the discharge itself even without heating the device is an important element or at least a useful element in the exhaustion of tubes in this way, that if an electron discharge is passed through the tube a certain amount of positive ionization occurs. The positive ions formed bombard the glass and if the pump is working quickly and rapidly some of that gas which is knocked off the walls will be removed by the pump. So that the passage of the discharge while the device is on the pump is a factor in freeing the walls of gas.

In regard to the first statement, the first statement is: "Heat alone will not remove all the gas liberated by the electron discharge." For high voltage discharges that is quite important; that is, to get the best results it is not sufficient—and by high voltages I mean thousands of volts—it is not usually sufficient merely to heat the electrodes. It is very important to apply to the tube high voltages in order to subject the glass to all the positive ion bombardments that it is going to receive in practice and more besides so as to free the glass from deleterious gases.

XQ. 610. This matter of positive ion bombardment of the glass is not pointed out in the specification, is it?

A. The theory of those things was not understood at that time at all.

XQ. 611. And again near the bottom of page 6 it says that "heating . . . may be omitted when the devices are not heated during normal operation." Is that true?

A. No.

XQ. 612. Of course, you believed these statements were true when you executed the oath to this application?

A. Yes.

XQ. 613. Did you still believe them to be true when you executed the supplemental oath on June 24, 1914, that appears on page 54 of the Interference record?

A. No, I do not think I believed it at that time.

XQ. 614. You notice that this oath refers to the apparatus as disclosed in the specification and claimed in certain claims. Did you make a mistake in executing that oath?

A. I really do not understand what all this means now and I do not believe I did at that time as to what is covered by Claims 6 to 9.

XQ. 615. I am referring more particularly to the annexed specification.

A. I do not know whether that is the specification as originally filed or as amended. I am not very familiar with the legal practices in these patent matters. I usually leave such matters to the Patent Department.

XQ. 616. You mean you execute affidavits without checking them over and the papers that they refer to?

A. I read them over but I may not realize the full legal significance or the full significance of everything in them.

XQ. 617. And for the supplemental oath that you executed on March 10, 1916, shown on page 67 of the Interference record your answer would be the same?

A. I suppose in signing these statements my attention was called entirely to changes that were contemplated at the time this statement was made, that is, certain changes in the—I do not remember anything about these particular supplemental oaths. I can hardly tell what I had in mind at that time but I do not suppose at that time I read over the whole original specification. What this supplemental oath seems to say is that the apparatus as disclosed in the specification and claimed in Claims 1 to 18, are submitted by the accompanying amendment and constitute a part of this invention.

> "Also that it was not used or known before my invention was patented."

Now, all of those statements seem to me not to relate at all to any statements in the specification regarding whether or not it is possible to free a gas from metal by cold bombardment; that it does not seem to me to have anything to do with Claims 1 to 18, or have anything to do with whether the apparatus disclosed in the specification was new or old. So that I do not believe that in signing this thing that I had the slightest thought in my mind of any such subjects or questions as to whether or not the specification contained a statement that cold bombardment would or would not free an electrode from gas. The whole object of the supplemental oath, as I understood it, and the statements in it, have no reference to such minor points as theories of method of exhaust. The device and the novelty of the device, those seem to me to be the important matters.

XQ. 618. But among those claims 1 to 18, which were covered by your supplemental oath, executed on March 10, 1916, was one which then read as follows:

> "The process"——

A. When do you mean by "then"?

XQ. 619. It had been amended previously to that, and it stayed in the case at the date of your supplemental oath, as follows:

> "The process of removing ionizable gas from an anode of an electron discharge device which consists in subjecting said anode to prolonged electron bombardment with an energy input below the value necessary to appreciably heat said anode an impressed voltage below the value at which considerable gas ionization occurs, and coincidentally removing the gas thereby disengaged."

So it seems to me perfectly clear that your affidavit referred to that claim and others of that sort, and all I am asking you now is whether you made a mistake when you signed that affidavit, or not?

A. I really am not at all clear as to what was really in the affidavit that I signed or claimed. I have no recollection of the matter at all at present.

XQ. 620. But if that claim was in there then, then your affidavit was wrong, was it not?

A. I do not know. I do not get the significance of the affidavit and the claim. I mean you say that there is a certain claim. I do not know at present what the relation is between the affidavit and the claim. I am not at all clear in the matter.

XQ. 621. I think I can make that clear. The affidavit reads that Irving Langmuir

> "deposes and says that the apparatus as disclosed in the specification and claimed in Claims 1 to 18, inclusive, . . . constitutes a part of his

> invention, was invented before he filed his original application, above identified, for such invention, was not known or used before his invention."

and so on. You were making an affidavit to that very claim that I read just then, according to the wording of this oath, and I want to know whether you knew what you were doing, and whether that was correct?

A. Was this in 1916?

XQ. 622. Yes.

A. Was that claim first introduced at that time, or when was it first introduced? Was it part of the original specification?

XQ. 623. A claim was part of the original specification which a few months later was amended to read as I showed you. This paper that I hand you gives the full history of the thing (handing paper)?

A. This is what—Claim 10?

XQ. 624. It was originally Claim 1.

A. In the original specification as filed in 1913? What you have in black ink here was Claim 1?

XQ. 625. Right. To keep the record clear, I think I had better read Claim 1.

The Court: May I make this inquiry, Mr. Richmond? It seems to me that possibly you have gotten the fact that you want from the witness when he tells you that he learned at least probably before 1914, and surely before 1916, of the incorrectness of the theory stated in the original specification. Now then, I am wondering whether or not your immediate question is not asking the witness to construe the affidavit, which is a judicial function, and not one required of the witness, and whether you have not gone as far in this matter as it is necessary for you to go, even from your point of view?

Mr. Richmond: I think that is the correct position. I am ready to withdraw the question.

THE COURT: Very well.

XQ. 626. Having made that mistake in your original application——

MR. RICHMOND: Mr. Smart, will you read the first part of the question? (Question repeated as recorded.)

XQ. 627. Having made that mistake in your original application by stating that the bombardment without heating might be sufficient, and having become aware that that was a mistaken view, what steps did you take to correct it?

A. I have no precise recollection of what I did. I believe that I called the attention of somebody in the Patent Department to it.

XQ. 628. When?

A. I do not know when, or to whom. That is, the fact that our Patent Department did make subsequent changes, and that I had changed my idea, makes me believe now that I called it to the attention of somebody in our Patent Department, but I have no further recollection of it.

XQ. 628a. Is your recollection as to the date of when you called their attention to it refreshed by the fact that the record shows that those statements in the specification and the claims carrying the same statements were never cancelled until July 30th, 1925?

MR. DAVIS: If your Honor please, this raises the point which we discussed a day or two ago, and while Mr. Richmond's views and mine are not quite the same, I think it proper to state my view. My understanding is—I was an Examiner once myself in the Patent Office, so that I go back to those days some years ago—my understanding is that when an Interference is declared, the papers pass out of the custody and control of the Primary Examiner, in exactly the same sense that the papers on an appeal would pass out of your Honor's custody when the case was certified to the Court of Appeals, and a transcript filed there; even more so, because the actual physical papers are taken away, and there is nothing remaining in the Examiner's room, except such notes as the Examiner may have made to remind him that there was such an application there. They are then put in the jurisdiction of the Examiner of Interferences, and there they remain except that they are taken away from him, of course, on appeal.

Now, while it is physically possible to file a paper with the Examiner at any time during the progress of the Interference, it is about the same thing as though a paper were filed here in this court with reference to a case which was in the Court of Appeals of the Third Circuit on Appeal. I should think your Honor would regard that as an impropriety in any ordinary case. I do not know the practice, but I certainly regard it as an impropriety in the Patent Office unless there is specific reason for it. It causes the Primary Examiner to go up to the Interference Division, and he has to get an Order of the Commissioner, as I understand it, before he can take any action, that is, get his jurisdiction restored by the supervisory power of the Commissioner, and I may be entirely in error as to what is proper to be done, but my understanding is you make notes through the progress of the Interference, and when the Interference is over, you do it.

The Court: So far as I know here, the only time any application has been made while a case has been pending in the Court of Appeals of this Circuit, has been made only—I think an application has been made, but I think the applicant has been sent to the Court of Appeals to make his aplication there for leave to make the application here.

Mr. Davis: Yes, you can do that in the Patent Office.

The Court: I beg your pardon?

Mr. Davis: Yes, you can do that in the Patent Office.

The Court: But I do not remember what this question was, so let me see if you are getting away from the fact—read the question. (Question repeated as recorded.) I think that question can be answered, because I think that calls for a fact; it is not when the application was made, but when Dr. Langmuir, the witness, communicated the fact he had made a mistake to the Patent Department of the General Electric Company, as I understand it, is it not?

Mr. Richmond: Yes, your Honor.

The Court: So what they did seems to me another matter, so I will overrule the objection on that ground. Read the question.

(Question repeated.)

A. I believe that I called the attention of the Patent Department to these matters, most probably in 1913, certainly the date of 1925 that you suggest does not bring any recollection of the matter to my mind. In fact, I do not remember having known that the changes were made in 1925.

Mr. Richmond: I would like to add just a word, your Honor, to the discussion a moment ago. I am quite sure that I remember instances of giving notice on the record in the Interference proceeding of an intention to amend at the first opportunity, a very simple thing to do; and it seems to me that when an error is discovered, that is a very obvious and a very appropriate procedure.

The Court: I am wondering how I can take judicial notice of that practice any way. That is, assume that you are right, assume for a moment that you are right, and assume for a moment, on the other hand, that Mr. Davis is right. Can I get the proper practice or procedure from judicial notice? Or must I have proof of it? Or can I take judicial notice—I assume that I can, of the rules and regulations of the Patent Office, but if it is not expressly laid down in any rule, then would it not be an inference from the practice—not the practice, but the law, it would not be law so much as practice probably——

Mr. Davis: If your Honor please, I suppose that Mr. Richmond and we could agree on that; that is, if Mr. Richmond agrees, as I am sure he does, with my statement which I just made, I can agree that anybody has the power [illegible] dictate such notice as he suggests on the Interference record any time he wants to.

Mr. Lunt: If your Honor please, I would like to say that I too was an Examiner in the Patent Office, and familiar with the practice, and I never heard of any such practice as this.

Mr. Davis: You are not a witness.

The Court: My difficulty is this—as counsel I cannot hear you on the practice in the Patent Office unless I can take judicial notice of it. I think there is no difficulty, because I think there is really no substantial disagreement between you on this, namely, that when an Interference is declared, that takes the whole jurisdiction of the case over to another department, to the Examiner of Interferences it is called, is it not?

Mr. Richmond: The whole thing is under the jurisdiction of the Commissioner. All communications are always addressed to him.

THE COURT: Surely. I see.

MR. DARBY: The same relation of the District Court and the Court of Appeals in no sense exists in the Patent Office.

MR. HAIGHT: May I suggest this, in order to clear up and I hope it will not complicate. I understand Mr. Davis' proposition is that the amendment could not have been made after the Interference was declared. It seems to me that that does not affect the case at all because the Interference was not declared until 1916, and Dr. Langmuir says he discovered this defect in 1913 or 1914, so that they had two years to make the amendment if they had been mindful to do so, whatever effect it may have had on the case.

THE COURT: The statute having begun to run it continued to run.

MR. HAIGHT: Yes, sir. I do not think it makes any difference what the practice in the Patent Office is.

THE COURT: I see.

By MR. RICHMOND:

XQ. 629. I understood you to state in your direct deposition that in 1912 you understood that heating of an anode to 400 degrees was entirely inadequate; is that correct?

A. I think that is true. I certainly was in the practice of heating anodes to 2400 degrees and more and attached a great deal of importance to this heating of the anodes. I had had no experience with heating large metal plates used as anodes.

XQ. 630. So that this view that crept into the patent application when it was filed in October, 1913, arose in your mind after that?

A. Yes, it arose during February, 1913.

XQ. 631. This same error appears in the patent that was issued to you as reissue 15,278 on an application filed originally July 23, 1918, and for which the reissue application was filed on April 23, 1919. I direct your attention especially to page 2, lines 67 and 68 of the specification where it says: "But heating is not essential." Is that correct?

MR. RICHMOND: I will withdraw the question. I see my mistake.

XQ. 632. When did you say it was that you discovered this error or did you say?

A. I have no definite recollection of having as you say discovered an error. In February, 1913, I remember distinctly having had a theory, based upon two or three different things, that electron bombardment would remove gases from the very surface of the metal electrodes. I did not think that it would remove gases from the deeper layers inside of the metal but I thought it would remove gases from the surface layers of metal electrodes and I believed that the gas in metal electrodes that was in the interior of the electrodes would come out when those were heated during operation and therefore I concluded that if an electrode was to be run at low temperature with very little energy the gas in the interior would not be able to come out and it would be merely necessary to clean the surface so as to make it free from gas and that this could be accomplished by pure electron bombardment without necessarily heating it.

Later on in 1913 we made up tubes with plate shaped anodes. The first three-electrode tubes that were made beginning in March, 1913, had anodes that were heated by the passage of current through them because that was a sure way of getting good results and as a matter of fact, we continued that process in making small audions for 250 volts well into 1914, but we also in 1913 made audions, and these "hot cathode relays" that were used for higher voltages, with plate shaped anodes. When we made these we very soon came to realize that it was very important to heat the electrodes to very high temperatures during the exhaust and it became our practice to heat them to a white heat and used tungsten or molybdenum plates and heated them by high voltages and high currents until they were very hot.

So that this idea of bombarding cold was not used in practice and my attention went off it and I practically forgot it. I believe in discussion with men in the Patent Department I told them that we used high voltage discharges but I do not remember ever having told them specifically to take those statements out of the patent.

XQ. 633. But when was it, what I want to know is when it was that you abandoned this incorrect theory?

A. I do not remember. The theory sort of petered out and died gradually. I do not think I ever made a definite—I do not think the time ever came when I said, "Now, I will abandon this theory. The theory is wrong." I think the theory died a sort of natural death in my mind and I think that in my conferences with the Patent Department men I probably expressed increasing doubt as to the effectiveness of that method.

XQ. 634. Now, in my effort a moment ago to frame a question I got some dates mixed and opposing counsel kindly directed attention to it and I withdrew the question. I will try again. I direct your attention to Langmuir reissue patent 15,278, filed originally on an application dated October 16, 1913, and reissued on an application filed April 23, 1919. This same error appears in the specification of this reissue patent, does it? Please refer particularly to page 2, lines 67 and 68 where it says: "But heating is not essential."

MR. RICHMOND: This patent has already been offered.

A. I think this statement is incorrect and that I overlooked it in reading the specification. I really do not remember now whether I reread the specification in 1919 or not. I suppose I probably considered it was the same specification that I had originally filed and did not remember that statement in it.

XQ. 635. I understood you to testify that in the literature up to but not including 1912, there were quite a large number of papers being published which expressed great scepticism or doubt as to the possibility of getting electrons out of the metal in a perfect vacuum. Can you remember the names of the authors of these papers and mention them to us?

A. They are referred to in the various papers that are published. Some of them are mentioned in my *Physical Review* article published in 1913, and others are mentioned, I think, in my 1915 article that was read before the American Institute of Radio Engineers.

Mr. Richmond: Mr. Lunt, those have been put in evidence, have they?

Mr. Lunt: I do not remember about that.

Mr. Richmond: They are in the Interference record?

Mr. Lunt: Yes.

Mr. Richmond: That is all right.

A. (Continued): There are probably a few others. I do not recall them at the present time.

The theory that you speak of was that electrons were emitted only as a result of some secondary effect tied up with the presence of gas. Some people referred to that as a chemical theory but so far as I know practically all of those people that referred to that as a chemical theory were physicists and I believe the state of affairs was about this——

Mr. Richmond: I ask that the last part of the answer be stricken out as not responsive.

THE COURT: Strike out all the answer after the point that he does not recall the others at this time.

By MR. RICHMOND:

XQ. 636. Is it not a fact that even including the year 1912, Soddy and Pring and Parker were the only ones expressing doubt of the Richardson theory of electron emission?

A. I do not remember exactly at present the dates of the other publications that are referred to. My impression is that some of the others were in 1912. There were some papers by Fredenhagen and by Hallwachs and there is a paper by Marsh and possibly others and it is my impression that these were in 1912 or before. I believe the paper by Marsh is referred to in the transcript. All of these references are discussed in the transcript record on the motion.

XQ. 637. I believe you have the *Physical Review* paper of December, 1913, there, and here is a copy of the radio engineers paper that you referred to. Now, I would like to get a complete list of those names from you and verify the ones that you have mentioned. I do not want them after 1912.

THE COURT: You want 1912 excluded or included?

MR. RICHMOND: Included.

A. May I refer to the transcript record to find out about that paper by Marsh?

XQ. 638. Yes.

A. In my paper before the Institute of Radio Engineers I find that the references I made, that is, limiting myself to those before 1913, were Soddy in 1908, Fredenhagen in 1912, Pring and Parker in 1912, and then in the transcript record 1374 up to 1376, there is a discussion of two papers by Sidney Marsh, one in his Doctor's Thesis published at the University of

Göttingen in 1909 and part of which was reprinted or was the basis of a new paper published in the *Annalen der Physik* in 1910. Those are the only references that I find in my paper or in that record up and including 1912.

XQ. 639. I believe that you have said that you read a paper at the meeting of the Physical Society on October 18, 1913. About how long did it take you to read that paper, how long were you speaking on that occasion?

A. The paper itself was probably ten or fifteen minutes and there was probably twenty minutes of discussion.

XQ. 640. Discussion by others and yourself?

A. Yes.

XQ. 641. Then what you read was not the paper that was published in the *Physical Review* in December, 1913, because that would have taken far longer?

A. I did not give all of the data that are in that paper as published in December, but I summarized the main points and illustrated them with lantern slides.

XQ. 642. And it is your practice when you do what they call reading a paper before the society to speak extemporaneously, is it not?

A. Yes, but with very carefully prepared notes and lantern slides illustrating my points.

XQ. 643. And I show you first an abstract of a paper presented at the New York meeting of the Physical Society, October 18, 1913, by yourself, and ask you if you prepared that abstract (handing paper)?

A. Yes, I prepared the abstract.

XQ. 644. And of course you intended to make that abstract correspond to what you said, did you not?

A. I do not think so particularly. I made the abstract to cover the subject matter but I do not think I had any particular intention to make it cover precisely what I said. That is, of course I said in ten or fifteen minutes a great deal more than is contained in that abstract, and when you have the problem of writing down a short abstract of that kind, and have to make it readable as it stands, you have a great many other factors coming in, in determining what you say, when you have ten or fifteen minutes to present the paper.

XQ. 645. But of course, you tried to make the abstract representative of what you said, to make it truly an abstract of what you said?

A. I do not know that I particularly tried to do that. I tried to make it just as though it were a separate paper of very short length, dealing with the general subject, and giving information which I think would be particularly interesting to the readers of the *Physical Review.* I probably said in my paper all the things that are contained in the abstract, but I said a great deal more besides, and I do not think there is anything in the abstract which was not covered by what I said.

XQ. 646. Well, what was the purpose or object of preparing and publishing this abstract?

A. Well, it was the custom at that time for those who read papers before the American Physical Society, to publish very short abstracts in connection with those papers, and I wished to avail myself of that privilege at that time by publishing a short account of the work that I had been doing. Of course, the Physical Society, is a society of pure scientists, interested in physics, primarily.

XQ. 647. And this abstract was prepared for the purpose that you have just stated?

A. Yes.

Mr. Richmond: I ask to have this marked for identification as "Abstract of Paper presented by Dr. Langmuir on October 18, 1913, published in *Physical Review* for November, 1913."

(Received and marked "Defendant's Exhibit M for Identification.")

XQ. 648. That abstract gives two 3/2 power law equations, and you worked out some of the mathematics for those on the blackboard at the time you made this presentation, did you?

A. I do not believe I worked that out. I think I probably stated the results.

XQ. 649. And you did not give any of the mathematical steps leading to those results.

A. I do not remember at all whether I did or I did not. I think it is rather quite improbable that I did, because it is not my custom as a rule, in lectures, to give mathematical derivations. Most people find them very uninteresting to listen to.

Mr. Richmond: Cross-examination closed.

Mr. Haight: Now, Mr. Darby.

Mr. Richmond: Excuse me, my part of it.

Mr. Darby: I will be very brief.

Cross-Examination.

By Mr. Darby:

XQ. 651. As I understand it, Dr. Langmuir, referring to electron bombardment of, let us say, a plate electrode to free it from gas, it is the heat that frees the electrode from gas, is it not?

A. Yes.

XQ. 652. And one way of imparting or giving to the electrode the necessary heat, is by bombarding it with electrons?

A. Yes.

XQ. 653. Now, if you bombard a plate electrode for a given period of time, say at 100 volts, you can operate that device, assuming it is a three-electrode device, at eighty volts thereafter, without having the plate electrode give off gas, can not you?

A. No.

XQ. 654. You can not?

A. No. Not in general, no.

XQ. 655. What is that?

A. Not in general.

XQ. 656. Is it not a fact that after you bombard a plate electrode for a certain necessary length of time at one voltage, that that electrode will not give off gas when operated normally below that voltage?

A. No. There is no relationship.

XQ. 657. There is no relationship between the——

A. Between the voltages, no.

XQ. 657a. Is there no relationship between the voltages and the heat?

A. No, not necessarily.

XQ. 658. Then as I understand you, I could operate, or I could bombard a plate electrode at a high voltage for a short length of time, and get a certain amount of heat thereby, or I could bombard a considerably longer length of time at a lower voltage, and get the same amount of heat; is that right?

A. Not necessarily.

XQ. 659. It is possible?

A. Why—you have not mentioned anything about current. The bombardment does not depend on voltage; it depends on the product of voltage and current.

XQ. 660. All right. Then, suppose we have a given current value, and a given period of time. That is, the remaining constant, if I bombard at 100 volts, will I thereafter be able to employ that vacuum tube at the same or smaller amount of current under 100 volts?

A. Not usually. At some voltage under 100 possibly, depending upon whether you have used a sufficient amount of current and voltage. That is, in order to tell whether or not the electrode has been sufficiently freed from gas under any given conditions, there are many factors that are more important than mere voltage and time. Thus, the amount of the energy, the actual temperature to which the electrode is raised are more important factors than even voltage or current.

XQ. 661. That is what I understand. And in the ordinary practice of manufacturing the so-called high vacuum tubes today, do you bombard the plate electrodes?

A. Yes.

XQ. 662. Electron bombardment in all types of tubes that you make?

A. No, I do not think so—most of them.

XQ. 663. What do you employ to heat the electrodes outside of the bombardment?

A. The most effective method used today is the high frequency induction devices by which the electrodes can be heated red hot by means of a high frequency alternating field applied from outside the tube.

By Mr. Darby:

XQ. 664. And that high frequency field does not heat the glass vessel, does it?

A. Only in so far as it becomes heated by the radiation from the electrodes.

XQ. 665. By conduction?

A. By radiation.

XQ. 666. Do you likewise heat the plate; to your knowledge, do they heat the plate electrodes to free them from gas by conduction through gas in the tube itself?

A. No.

XQ. 667. You do not know of anybody that employs that process?

A. No.

XQ. 668. You do not know of a process being manufactured today manufacturing vacuum tubes where they employ the gas that is in the tubes to conduct heat to the plate electrodes?

A. No.

XQ. 669. To get them hot?

A. No.

XQ. 670. Do you see any reason why that could not be done?

A. I do not see—I can not imagine why it should be done. It seems to me a very ineffective method.

XQ. 671. That was not my question. Do you see any reason why it could not be done?

A. Why what could not be done?

XQ. 672. Applying heat to the outside of a vessel and employing the gas inside of the vessel to conduct that heat to the plate electrode to free it from gas, or at least partially free it from gas?

A. I do not see that the gas would serve any useful function at all, nor do I see how the result obtained by it——

XQ. 673. That does not answer my question.

Mr. Davis: Let the witness answer.

XQ. 674. To avoid any possible dispute, Doctor, will you answer my question first, and make any explanation you desire?

A. I do not think the question can be answered without qualification. May I have the question read?

XQ. 675. Answer it and qualify it. I do not want to cut off your qualification.

A. Read the question. (Previous part of the record repeated by the stenographer as recorded.)

Mr. Davis: I submit, if your Honor please, that he is entitled to answer that question and was answering it while he was interrupted.

The Court: Mr. Darby's objection was the technical one that he did not answer the question before explaining it. He is entitled to a categorical answer, and followed by the explanation that he did not give, so I think he is entitled to that right. You may answer.

The Witness: My difficulty is that it seems to me there are several things you ask that are more or less incompatible to one another.

Mr. Darby: All right. We will drop that for a minute then.

XQ. 676. Let me ask you this: If an electrode has been heated to 400 degrees C., to free it from gas, can that electrode thereafter be employed in normal operation, where its heat does not exceed 80 degrees C., let us say?

A. In general, not; it can not be. That is, it can be employed but I mean to say—of course, you can employ it, but you do not get a useful result.

XQ. 677. You answered before I concluded my question, Dr. Langmuir. My question is, if an electrode, a plate electrode, a three-electrode device has been heated to the proper degree of heat, which I understand from you is in excess of 400 degrees C., is that correct to free it from gas—an excess of 400 degrees C. will free a plate electrode of gas if it is connected at that heat a sufficient length of time?

A. Certainly not.

XQ. 678. What degree of heat is necessary?

A. A good, bright red heat.

XQ. 679. Which is about?

A. 700 or 800 or 900 degrees.

XQ. 680. I consider that to be an excess of 400 degrees C. If we heat the plate electrode to 700 or 800 or 900 degrees C., sufficient to free it from gas, and keep the heat there long enough, and I employ that electrode as the anode of a three-electrode vacuum tube in normal operation, it will not thereafter give up gas, will it?

A. I think it will give up some.

XQ. 681. But not enough to cause harmful ionization?

A. It depends on the conditions.

XQ. 682. What is the normal heat of a plate electrode in operation on a three-electrode tube?

A. It depends upon the size of the tube and the heat coming from the cathode.

XQ. 683. Take your standard UV-201?

A. I hardly know definitely, but it is probably 300 or 400 degrees C.

XQ. 684. Well, now, does that plate electrode, when it is heated up to three or four hundred degrees C. in normal use give off sufficient gas to cause harmful ionization effect in the operation of the tube?

A. Not if it has been properly treated for gas beforehand, otherwise it does.

XQ. 685. Therefore, if you once heat the electrode, getting back to my main question now, to the necessary degree of heat and maintain it at that heat sufficiently long enough to free it from gas, when you thereafter use that electrode as the anode of a three-electrode device which in normal operation does not become heated to anywhere near the degree of heat to which it was initially heated to free it from gas, that anode will not thereafter liberate sufficient gas to cause harmful ionization, ignoring all other parts of the tube for the purpose of this question. Do you agree to that?

A. It may or it may not. The point that I want to bring out is that you need a very great factor of safety for the reason that the tube is to be operated——

XQ. 686. I think, Dr. Langmuir, you have answered my question. When you heat you can of course, and in fact in practice you do heat the plate electrode while there is some gas in the tube?

A. During exhaust, do you mean?

XQ. 687. Yes.

A. Yes, there is always some gas in the tube.

XQ. 688. And the heat of the electrode is brought up gradually, it is not instantaneously applied, referring to electron bombardment?

A. That is correct.

XQ. 689. And while it is gradually being brought up to a high temperature it oxidizes to some extent, does it not, the surface of the anode?

A. No, I do not think so.

XQ. 690. You do not consider that it is possible for the surface of that anode to oxidize because of some oxygen that is in the tube?

A. No, not in any reasonably good exhaust treatment. The heated filament would consume oxygen sufficiently to prevent that action. But as a matter of fact, with any reasonably good pump the pump will remove the oxygen.

XQ. 691. When you heat the anode does it change its color or appearance?

A. Not as a rule.

XQ. 692. If it does change its color or appearance what causes it?

A. I am not familiar with the phenomenon of anodes changing color during exhaust.

XQ. 693. If you raise a metal to a substantial heat it changes its color in air?

A. Yes, some metals.

XQ. 694. That would be true of nickel, would it not?

A. Only heat at a pretty high temperature.

XQ. 695. Only if you heat it to a pretty high temperature?

A. Nickel stays bright and clear until heated to a pretty high temperature.

XQ. 696. I show you the original DeForest audion which was left with the Western Electric Company by Dr. DeForest in 1912, marked Defendant's Exhibit

139 here, and I ask you to look at the plate electrodes in that tube. Do they show discoloration?

A. Yes. I notice that the plates are soldered to the leads, which means that they have been heated in the air before being mounted in the tube and presumably oxidized.

XQ. 697. Can you give an idea as to what kind of solder that is employed there?

A. Not very well. It does not look like ordinary tin lead solder.

XQ. 698. Would it in your opinion be silver solder?

A. I do not think so. Silver solder usually has a yellower color than that. I do not know very much about the solder from looking at it. It is probably not made of lead and tin. That is about all I can say.

XQ. 699. Now let us consider a moment a vacuum tube that has mercury vapor in it. The mercury vapor will in any circumstances readily form an amalgam with a great number of metals, will it not? In other words, mercury amalgamates with silver, gold, platinum, copper, very readily?

A. Mercury amalgamates with silver. Not I believe with platinum. It does readily amalgamate with gold. It does not usually amalgamate with copper unless the copper is chemically cleaned so as to remove all traces of oxid.

XQ. 700. And if we are working with a mercury pump and evacuating an audion tube and the audion tube is not heated while it is being evacuated, the mercury vapor tension, unless some means are taken to keep the mercury out of the tube, such as by charcoal and liquid air, would be very high when that tube is sealed off, would it not?

A. It would be a few microns.

XQ. 701. Which is very high compared to the pressure in a so-called high vacuum tube?

A. Mercury vapor is particularly effective in forming——

XQ. 702. Will you answer my question first, then?

A. It may or may not be. I cannot answer it without qualification.

XQ. 703. If I heat the vacuum tube while it is being evacuated by the mercury pump, will that make any difference in the mercury vapor that is in the tube after it is cooled and sealed off?

A. I suppose it would make some.

XQ. 704. In which direction? There would be less mercury vapor in the tube?

A. Somewhat less mercury vapor.

XQ. 705. Now, if you employ a thoriated tungsten filament let us say—first let me ask you this question. Can you evacuate a tube without the employment of a vaporizable reagent such as potassium or magnesium or anything of that nature, can you evacuate a tube sufficiently high so that you can use a thoriated tungsten filament in it?

A. Yes.

XQ. 706. And the thoriated tungsten filament if properly activated, aged, will emit electrons and operate in a three-electrode tube?

A. I suppose when you speak about emission from a thoriated tungsten filament you refer to emission at a low temperature which is made possible only by the thoriated filament.

XQ. 707. I was not confined to temperatures or anything of that kind. My inquiry is this. Can you construct a three-electrode vacuum tube that you can turn over to me and I could use in a radio receiving set, let us say, employing a thoriated tungsten filament where the necessary degree of vacuum or where the degree of the vacuum of the device you turned over to me was turned out without the employment of any vaporizable reagent such as potassium and magnesium?

A. It seems to me very important to understand definitely that a thoriated tungsten filament can always be operated as a tungsten filament without any beneficial results of the thorium.

XQ. 708. I want to get the beneficial results of the thorium?

A. That means that you want to operate at low temperatures.

XQ. 709. I want to get the beneficial results of the thorium including everything that you have in your mind.

A. The full benefits of the use of thorium.

XQ. 710. I want the benefits of thorium.

A. The appreciable benefits?

XQ. 711. Any benefits, anything that makes it better than the pure tungsten would be?

A. With that in mind, may I have the question again?

(XQ. 707 was repeated by the stenographer.)

A. I think I can do so, in fact I am sure.

XQ. 712. In other words, the benefits to be derived by using the thorium contained on a thoriated tungsten filament in a high vacuum tube are not in any sense dependent upon the employment of a vaporizable reagent; is that correct?

A. The vaporizable reagent is of very great use.

XQ. 713. I understand that, but my question is that it was not entirely dependent?

A. It is not absolutely essential to use those reagents that you spoke of.

XQ. 714. And as a matter of fact, the reagents are employed to keep the filament from oxidizing and water vapor or any oxygen or other gas that may become evolved in the tube irrespective of their source, is that correct?

A. Not so much to prevent the filament from oxidizing as to prevent the thorium film on the filament from oxidizing.

XQ. 715. And in other words, they would perform that same function, for example, with other types of filaments, would they not? Strike that out. Let us take the case of magnesium. You employ magnesium to take up water vapor or any other gases that might be evolved from any of the electrodes within the tube; is that correct, or from the walls of the tube?

A. More than that, but that is one of the things for which the magnesium is used.

XQ. 716. And the same is true of potassium, only magnesium goes much further than potassium; is that correct?

A. Except the second statement. I do not think magnesium goes any further than the potassium.

XQ. 717. But let me withdraw the second statement. The same thing is true of the potassium?

A. The potassium does those things and may do other things besides.

XQ. 718. And they would perform those functions, both magnesium and potassium would perform those functions irrespective of any particular type of filament that you employed, would they not?

A. The functions that I am speaking about are the prevention of oxidation of the thorium film.

XQ. 719. I am talking about the functions that I was speaking about a minute ago which were to take up any gases which may be evolved from any of the electrodes from the interior construction of the tube, those materials would perform those functions irrespective of what type of filament was employed?

A. You broaden your question into any gases coming from any electrode. That is not what you were talking about before. You are talking about water vapor and oxygen containing gases.

XQ. 720. Confine it to water vapor and oxygen containing gases.

A. Then it is true that the function of magnesium or potassium in removing those gases would not be dependent on the material of the filament.

XQ. 721. Now, in preventing oxidation of thorium, for example, or the surface film of thorium as you call it, by means of potassium, you prevent that by having the potassium take up or get the oxygen containing gases as soon as they are evolved from any portion of the interior construction of the tube including the electrodes; is that correct?

A. Yes.

XQ. 722. So that in preventing the oxidizing of the filament you do that in that manner by having the potassium or magnesium or whatever else is employed combine with any gases that are given off from any part of the interior of the tube?

A. By any gases again you are referring to oxygen bearing gases.

XQ. 723. Yes.

A. Yes.

XQ. 724. And as I understand you, you never possessed a three-electrode audion until some time in February, 1913?

A. Not the DeForest audion. The tube that we had——

XQ. 725. I am referring to a three-electrode vacuum tube consisting of a filament and a plate with a grid electrode interposed between them?

A. We had a three-electrode tube on November 19th, and to some extent that was actually used as an audion.

XQ. 726. You consider that to be a three-electrode tube of the DeForest audion type?

A. I think the DeForest audion is broad enough to include such a tube.

XQ. 727. But in February, 1913, was the first time you actually possessed a filament grid plate audion?

A. Yes.

XQ. 728. Is that the first time that you had ever seen one?

A. Yes.

XQ. 729. Had you read anything about it prior to that time that you recall?

A. I believe I did in January after Mr. Alexanderson had told me about the audion. I think I looked up DeForest article at that time. January, 1913.

XQ. 730. In your 1915 paper in the proceedings of the Institute of Radio Engineers you made this statement, did you not:

> "My active interest in thermionic currents began in connection with some experiments on electrical discharges occurring within tungsten lamps."

And then you made reference to Richardson's data and then you stated this:

> "It was known that the vacuum in a tungsten lamp is extremely high, and measurements indicated that in well exhausted lamps after one hundred hours life the pressure was probably less than one-millionth of a millimeter of mercury."

That is correct, is it not?

A. Yes.

XQ. 731. That is what you stated in your paper?

A. Yes.

XQ. 732. What is one-millionth of a millimeter expressed in terms of microns?

A. One one-thousandth of a micron, 0.001 micron.

XQ. 733. One one-thousandth of a micron?

A. Yes.

XQ. 734. And then your paper proceeded to state:

> *"Taking these two facts into account, the very existence of a tungsten lamp seems strong evidence that thermionic currents in high vacuum must be very small, if not entirely absent."

Is that correct?

A. Yes.

XQ. 735. So that you recognized at the time you started your investigations on the thermionic vacuum tube, that the very existence of a tungsten lamp meant the existence of a vacuum as high as one one-thousandths of a micron—was that the correct figure?

A. Yes.

XQ. 736. One one-thousandth of a micron, is that correct?

A. No. I did not get that question. Will you please read it? (Question repeated as recorded.) I do not think there is really a question there.

XQ. 737. I will re-put it. Then you knew at the time you began your experiments which led up to the work concerning which you have testified, that the very existence of a tungsten lamp which had been in operation one hundred hours, meant the existence of a vacuum equal to one one-thousandths of a micron?

A. No, not exactly.

XQ. 738. All right.

A. Shall I go on? Do you want me to?

XQ. 738a. You do not have to on my account, if it is your impression——

A. I mean the conclusions are a little different from that. First, I say where any vacuum as good as that existed in a tungsten lamp, but that was not concluded from the existence of the tungsten lamp, that conclusion was drawn from measurements that we had made pressures in lamps; the existence of the tungsten lamp, the very existence of the tungsten lamp, proved that thermionic currents under those conditions were smaller, but did not themselves prove that the vacuum was high.

XQ. 739. Did it not prove that the very presence of tungsten as a filament in an incandescent lamp, due to its operation, would automatically lower the vacuum in the tube?

A. No.

XQ. 740. It did not?

A. No, it was not automatic.

XQ. 741. Oh, I see. You object to my use of the word "automatic"?

A. I mean that it was only because there were a great many other things in that lamp besides the tungsten filament that the vacuum became good. Many lamps having tungsten filaments showed vacuum that did not become good, but became worse. The mere presence of tungsten is not sufficient to get a good vacuum.

XQ. 742. Due to the improper exhaust of the lamp in its manufacture; is that right?

A. Or due to the presence of larger masses of metal. We never would have been able to build a lamp with large masses of metal, such as plate electrodes.

XQ. 743. Take your standard methods of exhausting incandescent lamps that were employed up to 1912, or were being employed at the time you began your first investigations, if the lamps and the interior of the lamps had been treated and processed and evacuated in accordance with the most approved methods employed up to that time, would that limit in use have decreased the pressure in the tube?

A. Yes, because of all these different factors taken together, not merely because of the tungsten.

XQ. 744. As a matter of fact, I think that you have stated somewhere that you had to have a high vacuum —no, you had to have a high vacuum in a tungsten lamp, because if you did not have it, you would break the filament by bombardment; is that correct?

A. You would get a shorter life if you had so much gas ionization that you had no space charge, then you would get too large currents flowing across the lamp, and the life of the lamp would be short, and might be destroyed immediately on a constant voltage circuit.

XQ. 745. And it was because of that that I think you testified that it was a very serious problem, and it was necessary to get the vacuum down so low that it would not happen; that is in effect correct, is it not?

A. I do not know what it is that you refer to as a "serious problem." I think I was talking there about the change in the conditions that were brought about by the introduction of tungsten as a filament material in place of carbon.

XQ. 746. I am not concerned with that problem, I am concerned with the proposition that that is the reason why you had to get as much air out of the lamp as possible?

A. I would not say as much as possible. We had to get the vacuum so good that this Edison effect would not unduly shorten the life of the lamp; that is as far as we needed to go.

XQ. 747. In other words, that bombardment due to ionization, bombardment of the filament due to ionization, would not unduly shorten the life of the lamp?

A. Yes, but that did not necessarily require the best possible vacuum.

XQ. 748. Now, you have referred to flashing and aging in connection with the incandescent lamp manufacture. I think we all understand what flashing means. You described that in your direct examination, did you not?

A. Raising the temperature of the filament, whether sudden or not, up to an abnormally high temperature for a short time.

XQ. 749. And what was aging?

A. Running the lamp for a certain length of time either at normal efficiency or normal voltage, or somewhat above normal voltage, in order to bring about whatever changes were going to take place during the early period of the life of the lamp.

XQ. 750. And you can describe them both as "heat treatment of the filament before they are commercially completed"; is that correct?

A. Partly that and partly to bring the vacuum in the lamp to a steady stage.

XQ. 751. And they were standard practice in the incandescent lamp art? At least, they were practiced and employed by the General Electric Company?

A. I think at that time, I think all lamps were given some aging treatment before they were shipped.

XQ. 752. Now, with reference to the work of Dr. Alexanderson, you stated in answer to Q. 108:

> "Mr. Alexanderson told me that he wanted to use an audion if an audion could be obtained that was not 'sluggish' in its action, for the purpose of using what he called tuning in geometrical progression."

And when asked to fix the time of this conversation, you answered:

This was in answer to Q. 109:

> "A. On February 4, 1913, I received a copy of a letter from Mr. Alexanderson."

Now, was the letter that you received from Mr. Alexanderson, which enabled you to fix the date, the letter dated February 5, 1913, from Mr. Alexanderson to Miss Orford of the Patent Department which

Mr. Davis has offered in evidence as Plaintiff's Exhibit No. 169 (indicating)?

A. I think I was mistaken as to the exact date. It was probably February 5—no. But that is not the letter. No, that is not the letter I had reference to, and perhaps the letter that I had reference to—in fact my recollection was that it was February 4, but it may possibly be February 5.

XQ. 753. Who was the letter from and who was the letter addressed to?

A. I think the letter was addressed to Mr. A. G. Davis, and a copy was sent to Mr. Hawkins and he turned that over to me at the same time that he gave me the audion.

XQ. 754. Have you got the copy of the letter that you referred to in your testimony with you?

A. No, I have not. I remember testifying about the letter in the case up in Trenton on the Alexanderson patent, which was where it came into my mind.

XQ. 755. You testified in the Alexanderson Interference case, the other parties to the Interference being Mr. Colpitts of the American Telephone & Telegraph Company, and Dr. DeForest?

A. I do not remember.

XQ. 756. I show you a record of that Interference. and I might state on the record that the testimony of Mr. Alexanderson that I read to him last night, was given September 17, 1919. Does this refresh your recollection as to whether or not you testified in that matter?

A. I suppose I did, but I do not really recollect it at present.

XQ. 757-58. Let me read this testimony that you gave, a portion of it. You may check it up.

"Q. 6. What was the disclosure which he made to you in February, 1913?

"A. At that time he told me that he proposed controlling the output of an Alexanderson high frequency generator by means of hot cathode, high vacuum electron discharge apparatus of the three-electrode type, applying potentials obtained from a telephone or microphone on the grid or three-electrode of the thermionic device. The plate or anode of the device was to be supplied with alternating current potential from the high frequency alternator and the alternator at the same time was to be used to excite an antenna for the purpose of sending radio telephonic signals. Alexanderson at that time had clear ideas as to how this could be accomplished as soon as proper thermionic devices were available. He knew that we were developing thermionic apparatus of the pure electron type which could operate at very high voltage and it was for that reason that he took up with me the question of building such high voltage, high powered thermionic devices. He wished particularly to know whether such devices would respond well to high frequency currents, or whether they might show a sluggishness in their action. I assured him that with the pure electron discharge such sluggishness would not occur."

Then you were asked:

"Q. 8. What steps, if any, did you take toward carrying into effect the ideas which Mr. Alexanderson disclosed to you?

"A. I undertook the development of high voltage three-electrode thermionic devices, having in mind that one of the main applications of these devices would be in connection with the radio telephony in the manner that Alexanderson had disclosed to me. This work progressed quite steadily from February, 1913, onwards. To illustrate the progress that we made in this direction I will refer to a few other entries in my notebooks. On pages 100 and 101 of my notebook 458, under the dates May 9th and 12th, 1913, I find entries which describe some tests made with some improved audions that Mr. White had made. These tests showed that these audions could be used for relaying or controlling high frequency currents with frequencies up to at least 75,000 cycles per second.

"On page 112, under the date May 12, 1913, I referred to some work which showed that the 'improved audions' which we had made, operated satisfactorily for high frequency currents. I stated: 'In this way we should be able to telephone by wireless: Using audion to magnify telephone vibrations and thus control the waves sent out by Alexandderson's alternator.' "

"On page 176 of notebook 458 under the date June 17, 1913, I refer to the fact that a new assistant of mine, Mr. William Rogers, is now working with Mr. White on audions. I said: 'At present the program is: Try out Alexanderson's plan of using telephone to control high frequency current and thus send telephone messages by wireless.'

"This work progressed steadily and Dr. Dushman and Dr. Hund, at my request, developed the high voltage, three-electrode tube and its application for radio telephony. On November 11, 1913, on pages 48 to 50 of my notebook 504, I made an entry describing the use of such a high-voltage three-electrode thermionic device 'with 10,000 volt high frequency current from Alexanderson's machine.' This entry describes the satisfactory nature of the results which proved that a high frequency power of about 300 watts could be controlled by the expenditure of a very small amount of energy applied to the grid. This work showed clearly that such a tube was suitable for use for radio telephony."

That is correct reading?

A. Yes.

XQ. 759. You so testified?

A. I believe so.

XQ. 760. And it was true to the best of your knowledge and belief at the time you gave it?

A. Yes.

XQ. 761. I want to ask you just one question in connection with Plaintiff's Exhibit No. 168, which was the curve of the output against the plate voltage of a three-electrode device, as an amplifier with gas, and a three-electrode device as an amplifier without gas, and I think that you testified as the result of the experiments on which this curve was based, that there is a point in a gassy tube where it operates in a very successful manner as an amplifier; is that correctly stated?

A. Yes.

XQ. 762. And I notice that your curve stopped on the gassy tube when you brought the voltage up to forty volts, the point being well below the steep part of the curve, which I understood you to state was the operating portion of the curve; is that correct?

A. Of course this is not a volt ampere characteristic at all.

XQ. 763. I understand that it is the amplifying quality of the tube, is it not?

A. Yes, but in your reference to the upward bending part of the curve, I think you were referring to volt ampere characteristics that I had previously spoken of and this is not at all comparable with that.

XQ. 764. I see, but as I understand this curve, the higher up on the millivolt ampere output ordinate that you go, the more sensitive the amplifier is; was that the purport of your testimony?

A. Why, we were plotting as ordinates the amplifying power, the amplifying power reached to a maximum at about twenty-seven volts.

XQ. 765. And the amplifying power of the tube at forty volts reached how much?

A. Well, it was very small; about 0.34.

XQ. 766. And what would have been the amplifying power of the tube, if you had raised it to fifty volts?

A. Probably very much less.

XQ. 767. In accordance with the slope of the last portion of the curve, it would be practically nothing, would it not?

A. Very likely. I do not know that. You can not safely extrapolate, because you go to higher voltages, the current becomes limited by saturation from the filament, and then the amplifying power becomes zero and remains zero, as higher voltages are reached.

XQ. 768. You referred to Dr. Lilienfeld's X-ray tube in your direct examination, and you expressed as your opinion, as I understood it, that Dr. Lilienfeld's X-ray tube operated because of gas ionization; is that correct?

A. That particular X-ray tube that we were talking about at that time—he has made many.

XQ. 769. I am confining myself to your testimony, the one that he showed in that article is the only one you considered in giving your testimony, was it not?

A. At that time, yes.

XQ. 770. Because if you are considering something else that was not in the case in giving your answer, I would like to know it now. In giving your answer to Mr. Davis' direct examination——

A. I thought maybe you were referring to other tubes besides that.

XQ. 770a. The testimony that you gave as to that was based entirely on that article?

A. Yes.

XQ. 771. All right. And your opinion that you expressed was based on assumptions that you made as to the dimensions of the tube and as to the voltages employed; is that correct?

A. I think they were hardly assumptions.

XQ. 772. Well, does the article state what the dimensions were?

A. It gives a figure, a diagram.

XQ. 773. No. Does the article state what the dimensions were?

A. No.

XQ. 774. Does the article state what voltages were employed?

A. It says the voltage was the city supply line.

XQ. 775. And you assume that to mean 250 volts or thereabouts?

A. Yes. It would not have made any difference whether it had been higher or lower in my conclusions.

XQ. 776. But it would have made a lot of difference if the dimensions were different, would it not?

A. No.

XQ. 777. Your conclusions—just a minute. You do not want me to understand from that that you reached your conclusions first, and then drew up the dimensions afterwards, to fit the conclusions, do you?

Mr. Davis: If your Honor please, I move to strike out the question.

Mr. Darby: I won't press it.

By Mr. Darby:

XQ. 778. Your conclusions would not have been altered in any respect if you had ignored entirely any dimensions or any value of voltages; is that correct; is that what you mean?

A. What I mean is this: I looked at the diagram that is shown there, and which Professor Chaffee has testified about, and Professor Chaffee has made an estimate of the dimensions of the tube I used——

XQ. 779. May I interrupt you there? As I recall Professor Chaffee's testimony, he made a guess as to the dimensions of the tube. I think those are his exact words.

A. I do not know the difference between a guess and an estimate.

XQ. 780. Well, he was requested to make a guess.

Mr. Davis: I beg your pardon. I do not think he was requested to guess.

Mr. Darby: I do not know whether your Honor recalls Professor Chaffee's language at that time.

The Court: I recall that with reasonable clearness, but is not your statement objectionable?

Mr. Darby: Yes, sir.

A. What I mean is this, or what I did was this, I looked at the diagram of the tube which tells us all we can ever find out about that tube as far as I know. I have no way of telling the dimensions of the tube in any other way than what is said in the article about it. A diagram is shown.

I first of all assumed a certain size for the bulb and from that drew the conclusion as to the distance between the anode and cathode in the auxiliary circuit. I also made the provisional assumption that the voltage was 200 volts and upon that I made a calculation from the space charge equations to find out how big the current flowing through the tube would be under those conditions and I obtained the result, I think, about five milliamperes as the reasonable current.

Then I saw from this result that it would not have made any difference in the final conclusion, that is, it would not have been any more possible to account for the observed current of 180 milliamperes if I had assumed any higher voltage within reason or if I had assumed different distances or different sizes of the electrodes within the reasonable range of possibilities.

In other words, I feel that I was justified in the conclusion, regardless of the specific assumptions that I may have made in my preliminary calculations. I know not only from those calculations but from my general experience with tubes of that sort that a pure electrode discharge current of 180 milliamperes is an impossibility with voltages of two or four hundred volts with a device of that character.

XQ. 781. And what size for the tube did you assume?

A. It does not make any difference.

XQ. 782. What size did you assume?

A. I think I assumed five or six inches as the diameter of the bulb but from the very nature of the problem if I had assumed one inch and taken the proportions as the same the results would be the same.

XQ. 783. The conclusions that you stated that you had arrived at with respect to the Lilienfeld article are not in any sense based upon the assumptions that you made as to the size, distance between electrodes and voltages employed, is that a correct statement?

A. I have stated exactly what I meant in my previous statement and all I can do is to repeat it.

XQ. 784. Then what is wrong with my statement?

A. There is this trouble, if I had made utterly unreasonable assumptions——

XQ. 785. I am not asking you whether your assumptions were reasonable or unreasonable. I am asking you if the conclusions that you advanced——

A. I want to say this, that the conclusions that I reached did not depend upon any assumptions that I could have made within reason, if I had made unreasonable assumptions I might have ——

XQ. 786. You are not answering my question.

(XQ. 783 repeated by the stenographer.)

A. In the first place——

THE COURT: That may require some explanation afterwards, but you can answer that first.

A. There is more than one conclusion that I reached and it is not clear which one you are referring to.

XQ. 787. The only one that I have mentioned thus far is that the Lilienfeld X-ray tube was a gas tube and operated because of the gas in the tube and was not a high vacuum tube?

A. Now, then, may I have the question again?

(XQ. 783 was repeated by the stenographer.)

A. I do not see how I can answer that yes or no.

XQ. 788. Let me reframe it then.

AFTER RECESS.

By MR. DARBY:

XQ. 789. With reference to the Lilienfeld X-ray tube I understand it was your opinion that its operation depends upon positive ions heating the hot cathode to free the electrons from the hot cathode; is that correct?

A. No, I did not say that. Positive ion bombardment of the cold cathode.

XQ. 790. Does positive ionization—its operation depended upon the presence of positive ions, that was your opinion, was it not?

A. Yes.

XQ. 791. And that the positive ions came from gas ionization in the tube?

A. Yes.

XQ. 792. Now, did you understand that Dr. Lilienfeld employed in his tube a Wehnelt cathode?

A. I think there are references to both Wehnelt cathodes and metal filament cathodes, but I think in the particular article that we were discussing at that time there was a definite statement that there was a metal filament.

XQ. 793. Metal filament?

A. I think there is a statement to that effect. Perhaps it may be in the Rosenthal article that goes with the Lilienfeld article.

XQ. 794. And you took that into consideration in reaching your conclusion, did you?

A. I did not say that it has anything to do with the reaching of the conclusion.

XQ. 795. Then you did not take it into consideration?

A. I think I took it into consideration, but I do not think it was pertinent.

XQ. 796. In other words, your conclusion would not have been different if you had known that he used a Wehnelt cathode?

A. No, it would not have been different.

XQ. 797. You know, do you not, that a Wehnelt cathode may furnish a considerable supply of positive ions in a high vacuum?

A. No, I do not know that. If it is not properly made it probably gives off gas and thereby leads to ionization.

XQ. 798. With reference to the Lamont tubes, you know what I refer to by that name, the tubes made on the Lamont pump in California?

A. Yes.

XQ. 799. I think you stated that they may possibly have been heated a little hotter than some of the DeForest bulbs, because of the Bunsen burner under it. If they were heated a little hotter by means of the Bunsen burner under it, would that have tended to free more water vapor from the interior of the walls?

A. It is a question not only of temperature but time and with proper provision for taking up gases. It is one factor that would tend that way but there are other factors that would have to be defined also.

XQ. 800. Taking into consideration the mercury that he had there.

A. The mercury pump would not remove water vapor.

XQ. 801. It would not remove water vapor?

A. No.

XQ. 802. So that in your opinion the mere heating of the bulb of Lamont with the Bunsen burner while it was on the pump would not have tended to relieve the interior walls of the glass of water vapor?

A. Of course, the more you heat it the more that factor would tend to remove water vapor from the bulb.

XQ. 803. And if the pump was operating it would remove water vapor from the bulb?

A. Not the pump but the pentoxide or the sulphuric oxid would have been more effective than the pump.

XQ. 804. At the present time in manufacturing vacuum tubes they use what is called the automatic exhaust machine, is that the correct name?

A. I think so.

XQ. 805. And do they not employ phosphorus pentoxide tubes in the exhaust lines of those machines?

A. Yes, sir, I suppose they do. I do not know about it. They may in some cases use liquid air.

XQ. 806. Do you know of any instance where they actually do use phosphorus pentoxide in the automatic exhaust machine?

A. I am not familiar with the practice in the automatic exhaust machine.

XQ. 807. Have you ever used phosphorus pentoxide in a portion of the machine which admits dry air into the tube?

A. What machine do you refer to?

XQ. 808. In any pumping system for evacuating three-electrode tubes?

A. I do not remember ever having done so.

XQ. 809. Are you familiar with the tubes manufactured on the Pacific Coast, the tube known as the Cunningham tube?

A. No.

XQ. 810. You do not know how it was made?

A. I have been told that the Cunningham tubes are made, a great many of them are made by the General Electric Company, but I do not know where.

XQ. 811. Have you ever heard of the expression rainbow flash?

A. I do not think I have.

XQ. 812. Do you know what kind of a flash material Cunningham employs in his tubes?

A. No.

XQ. 813. Have you yourself ever employed a flash containing sugar syrup, phosphorus and magnesium?

A. No.

XQ. 814. Never heard of its being used?

A. No.

XQ. 815. I think you testified this morning that you read over your specification before it was filed and believed at that time that the statements therein contained were true?

A. Is that a question?

XQ. 816. Did you?

A. Yes.

XQ. 817. Did you so testify?

A. Yes.

Mr. Darby: If your Honor please, I have completed the examination of this witness except with reference to one subject, namely, the disclosure by this witness to Dr. Coolidge, and in the interest of economy of time I do not want to examine Dr. Langmuir on that subject if Dr. Coolidge is going to be called, because it would merely require covering the same ground. If Dr. Coolidge is not going to be called, then I am not completed with this witness.

The Court: In the absence of assurance from the other side——

Mr. Davis: I am quite willing to agree that if Dr. Coolidge is not called, Dr. Langmuir may be recalled for cross-examination.

Mr. Darby: That will be entirely satisfactory.

Mr. Haight: With just one reservation on Dr. Langmuir's cross-examination. As I recall, the cross-examination of Dr. Arnold was not concluded, but the right to cross-examine him further was asked for and granted in the event that an examination of some of the notebooks of the Telephone Company would seem to make it advisable for the plaintiff to call him and we do not want the cross-examination of Dr. Langmiur concluded until that of Dr. Arnold is concluded.

The Court: Is that satisfactory, Mr. Davis?

Mr. Davis: Yes, if your Honor please. Of course the cross-examination of Dr. Langmuir—the only difficulty I have is that I assume the cross-examination of Dr. Langmuir should be with reference to his testimony.

The Court: Of course, it would have to be. I suppose Judge Haight has in mind the further cross-examination of Dr. Arnold may make advisable at least further cross-examination along certain lines of Dr. Langmuir's own testimony.

Mr. Davis: I think that is quite fair, your Honor, that it should be done.

Mr. Haight: That is all, then.

Re-Direct Examination.

By **Mr. Lunt:**

RDQ. 818. You have been asked as to certain flat-topped curves appearing in your *Physical Review* article for December, 1913, and I believe you were asked to look up certain further facts in connection therewith. If you have done so, will you please state what you have found?

A. I stated yesterday that I thought it was possible that the distance between the anode and cathode might have been changed between the time that the two curves were taken which were illustrated on page 463 of the *Physical Review* article. I find by examination of the notes of experiment 317 that that is actually what did take place.

The first curve which is referred to as curves 1 and 3 is obtained from the data which is on the record sheet 1348 of these notes and the curve marked 2 and 4 is from the data on record sheet 1364.

On record sheet S-1432-1 in the summary there given it is clear what the sequence is of the two curves and in between those two curves a magnet was applied to the bulb and the results show distinctly before and after that magnet was applied that the characteristics of the tubes changed in such a way as to indicate that the distance between the electrodes had been changed and I remember distinctly that that was one of the effects that occurred when the magnet was applied.

The way in which the curve changed at that time was in the direction that is indicated by the change in the space charge current indicated on page 463.

RDQ. 819. Referring to the DeForest audion with which you worked early in the spring or winter of 1913 and to the matter of sluggishness of such an audion which has been referred to, will you explain briefly what is this sluggishness and how it manifests itself?

A. I originally had been told by Mr. Alexanderson in January, 1913, that he had learned from Mr. Hammond that the audion was sluggish. I did not know the explanation of the phenomenon, but I believed that if such a phenomenon did exist it was probably in some way connected with the positive ionization in the audion which I felt sure existed from the fact that blue glow had frequently occurred.

When I visited John Hayes Hammond, Jr.'s laboratory in April I asked particularly what evidence they had that the audion was sluggish. And I found that the evidence was simply of this kind that if a strong signal was received, as for example, a static, or the result of static or any other sudden disturbance, the audion ceased functioning or its sensitiveness was decreased and it took some perceptible time before it came back to its original condition and that had convinced, or that was the reason given by Mr. Hammond and also by Professor Pierce, whom I met there, that was the reason that they gave for their conclusion that the audion was sluggish.

Later on, or shortly thereafter, I realized that that sluggishness that they had observed was not the sluggishness of the tube itself at all, but was the sluggishness of the condenser discharge itself, and that effect could be overcome by using a grid leak. In regard to whether or not the audion itself was sluggish, I did not know at that time, and I really never gave the matter any consideration. But I know now from a general knowledge of the theory of the tube, and also from the fact that gas-filled tubes such as the 200 tube, which contains a relatively large amount of argon is not inherently sluggish. It can be used for example as a radio frequency amplifier perfectly well. It makes a perfectly good amplifier for radio frequency currents even when there is positive ionization and thus the electrons respond to high frequency potentials.

RDQ. 820. Did you demonstrate to Mr. Alexanderson during the early part of the year 1913, one of your tubes, and if so, what tube, and what are the circumstances?

A. In notebook 458, on page 100, under date of May 9, 1913, I made an entry that I showed some of the audions that White had made up to Mr. Alexanderson. I remember that conversation that I had with him at that time very well, and I remember that very shortly thereafter, judging from my notebook, probably on May 12, 1913, I took these tubes over to Mr. Alexanderson's laboratory and worked with him in studying their response to high frequency currents and I know that the tubes that I used at that time were high vacuum tubes of the type illustrated by audion No. 2. I believe, as a matter of fact, that one of the tubes used was actually audion No. 2.

Mr. Lunt: That is all.

The Court: Any further cross-examination?

Mr. Richmond: Yes, sir.

RE-CROSS-EXAMINATION.

By Mr. Richmond:

RXQ. 821. In regard to that Figure 3 on page 463 of your *Physical Review* paper of December, 1913, it is a fact, is it not, that before this change in the filament spacing to which you refer, the high vacuum value of the current in amperes per square centimeter, was 0.0100, and——

A. I beg your pardon?

RXQ. 822. (Continuing.) 0.0100——

A. Yes.

RXQ. 823 (Continuing.) —and after the change in the filament spacing, the high vacuum value of the current was 0.0109; is that correct?

A. I may be looking at a different thing from what you are, Mr. Richmond, but I get the first figure but not the second one. I do not see where you get that figure. Perhaps you will read the question. (Previous questions repeated as recorded.) I do not see the point of the question. The voltages were different, and the pressures were different, but the mere change in voltage alone would have caused the change, and I do not see where the 0.0109 is on the diagram at all. Do you want me to go into detail to discuss these results? I can tell you everything that happened at least.

RXQ. 824. First, tell us how you get that value 0.0100, to which you agreed, I understand?

A. The curve which is marked 3, as the temperature is raised, approaches the limiting value which is 0.01 amperes per square centimeter; that is ten milliamperes per square centimeter, that was at 177 volts on the anode. Now, later on, with hydrogen in the tube and with 148 volts on the anode, a current of—about 15.5.

RXQ. 825. What page of the notes?

A. I am not looking at the notes. I am looking at the *Physical Review* article, the diagram in the *Physical Review* article——

RXQ. 826. All right. Thank you.

A. The corresponding part of the curve, flat part of the curve was 15.5 milliamperes per square centimeter. Now, as I said in between those two runs, the distances between the two filaments had been changed; in fact, the filaments had been brought closer together by the forces that had acted on them as the result of the magnetic field. Now, another fact that I want to call attention to is that the pressure during that run was not constant, but as noted on page 464 of the *Physical Review* paper, the pressure decreased from 7 microns down to 4. Now, looking up the data of record sheet 1364, I find that the current was actually 5.4 milliamperes and the pressure during that part of the run where the curve was flat, was 3.8 microns, that is, it had gone down from about 7, and I gave a round figure of 4. Actually it was 3.8 microns at that time.

Now, if you wish to make a comparison—I suppose that's what you wish to do in asking me about these curves, was to make a comparison between the currents on the flat-topped part of the curve—the changes in current that resulted from the gas pressure, disregarding facts such as the distance between the electrodes, I would suggest that that comparison can be more fairly made by comparing the curve 4, which is the one that occurs in Figure 3, page 463 of the paper, where the current was, as I have just said, 5.4 milliamperes at 148 volts, you can make the comparison better by comparing that curve with the curve obtained just after that, and which is referred to in the middle of page 464, where the value *b* is given as 55,600. Now, those data occur on the records of Experiment 317, on page 1366, and there again, there is a flat-topped part of the curve. You see the vacuum was good in that case. It was relatively good. It was one-quarter of a micron as compared with the 3.8 microns in the run above. The voltage was 167, and the current on the flat-topped part of the curve was 4.1 milliamperes, and the difference between the 5.4 and the 4.1, as the vacuum improved, was due to the effect of positive ions in modifying to some extent, the electron space charge; that is, with the 4.1 milliamperes, the current was limited by space charge practically independently of positive ionization, and then the pressure was 3.8 microns of hydrogen, there was enough positive ionization to have raised the current from 4.1 up to 5.4. That much of effect can be said to be due to the effect of positive ions.

I have gone over the data in Experiment 317 with a great deal of care, and I find that on the last few pages, there is a very complete summary of all the experiments on just this effect. With 3.8 microns of hydrogen the space charge was only partly neutralized. With eight microns of hydrogen, even with a very much lower voltage, a little over 100 volts, the space charge was completely destroyed and removed, so that the current rose right to the saturation value no matter how high the filament temperature was, but at 3.8 microns, you only had partial neutralization of space charge, that is, there is an intermediate region between the region where positive ionization has no effect, and the place where positive ionization completely neutralizes the space charge.

RXQ. 827. Now, please turn to page S-1374 of the notes, for Experiment 317, and I understand that this relates to a time after the change in the spacing of the electrodes, does it?

A. Yes.

RXQ. 828. And from the data on that page, can you calculate the current at 177 volts?

A. Well, there are two sets of data given on this page, one on the top and one on the bottom. Which one do you refer to?

RXQ. 829. The top of the page.

A. I do not see any figure of 177 volts but I see a figure of 181 volts. According to these notes I find that when the filament temperature was raised to 2390 and above (the temperature actually went up to 2620) at these very high filament temperatures the current was independent of the temperature, that is, it was a flat-topped curve and the value of that current was practically exactly four milliamperes and the voltage was 181 volts.

RXQ. 830. And how much is that per square centimeter?

A. 11.2 milliamperes per square centimeter.

Mr. Richmond: That is all.

(Witness excused.)

Mr. Davis: If your Honor please, I entered into an engagement the other day to ascertain the facts with reference to the sale of thoriated filament lamps as distinguished from Battersea lamps and I have a letter from Mr. H. B. Rogers, of the Harrison Works, or of the Incandescent Lamp Department of the General Electric Company, which I have shown to Mr. Darby and it is agreed, as I understand it, that this letter is to be treated as evidence in this case.

Mr. Darby: I did not exactly mean that. For my purposes I would like to have it appear on the record some date on which there will be no controversy at which time thoriated tungsten filament lamps were on the market. Mr. Davis is now in a position to authoritatively state, as I understand it, that they were on the market at least as early as the fall of 1912, and his statement to that effect, irrespective of any letters would be entirely sufficient for my purpose.

The Court: All you have inquired for is the date?

Mr. Darby: Is a date.

Mr. Davis: I am sorry, but I dislike to make that statement without making an additional statement, which while it is very obvious I think should be made and that is that while Mr. Rogers has given me the date as the fall of 1912 as beginning to market tungsten lamps he goes on and says that it was a long time before we stopped selling lamps made with the Battersea filaments. They were in stock and it takes some time to change over and I want it to appear that we did not dispose of our final stock of lamps made by the Battersea process until the end of 1913 or very early of 1914.

The Court: You are not concerned with whether they are on the market?

Mr. Darby: I am not concerned with the fact of whether they are on the market today.

The Court: Then I understand that you stipulate with Mr. Darby that as to the date on which the thoriated tungsten filament lamp was on the market was the fall of 1912 and you add of your own accord, Mr. Davis, the supplementary statement to which Mr. Darby does not object but asserts it is irrelevant.

Mr. Davis: Yes, sir, that is quite satisfactory. Also defendant's counsel have spoken to me and I think it appears on the record—Mr. Darby I have no doubt will agree with me, for the benefit of the Court of Appeals (it is not necessary here), that there was no thoria in the Battersea wire.

Mr. Darby: If that is the fact I will agree to that.

Mr. Davis: I will state it as a fact.

Mr. Darby: Then I agree to it.

Mr. Davis: On this question of the testimony given by Mr. Frank Waterman in a suit in New York we are willing to agree that the defendant may read into this case provided he does it today or tomorrow to give us reasonable opportunity to look it up, questions Nos. 18, 19, 20, 111, 120, 186, 195, 196 and 197 of the deposition of Mr. Frank Waterman given in behalf of plaintiff, the Marconi Wireless Telegraph Company of America in the suit brought in the Southern District of New York by that company against DeForest Radio Telephone & Telegraph Company, the testimony being given in the year 1916, and any or all parts of the answers to such questions with the same force and effect as if Mr. Waterman had testified in the present suit and had made these statements, understanding that that would mean that he had testified in this suit in the year 1916.

The Court: That is testimony would be given here as of that date?

Mr. Davis: Yes, sir, provided that the defendants stipulate that with like force and effect we may read into the case any other parts of the testimony of Mr. Waterman in that particular suit, and further——

Mr. Darby: That first is entirely satisfactory.

The Court: By first you mean up to this point?

Mr. Darby: Up to this point. That is, I think you correctly read the questions and answers that we went over. I mean you did not skip over any intentionally.

Mr. Davis: I hope that I did not. Provided that our expert Mr. Hogan may not only comment properly on Mr. Waterman's statements, as he may comment on any statement made by any witness of the defendant, but also may tell your Honor what it was that Mr. Waterman was talking about in each case. I do not mean by that anything more than to say that at this particular time Mr. Waterman was talking about a Fleming valve or at this particular time he was talking about something else, because I find myself in reading that testimony that they used names quite different from those we are using here and it is sometimes hard to find out what Mr. Waterman is talking about.

The Court: Then, of course, reserving to Mr. Darby the right to examine Mr. Hogan.

Mr. Davis: Oh, yes, and he may call a witness to show that Mr. Hogan is wrong.

Mr. Darby: That is perfectly agreeable. The only thing I want to make perfectly apparent is that I certainly will strenuously object to Mr. Hogan attempting to explain any of the testimony. If the testimony is ambiguous as to what he is referring to, whether it is a particular patent or structure, I am willing to have Mr. Hogan or counsel point out to the Court what he is talking about.

The Court: I rather suspected that there might be that reservation, but I wondered whether first if Mr. Davis had that mind, I think your statement was made out of an abundance of caution.

Mr. Davis: I wish to be very clear that Mr. Waterman used the word high vacuum and possibly highest possible vacuum and if Mr. Hogan can point out and show that he has used it in a certain way I think he is entitled to draw the inference and that he can leave to you the inference to be drawn.

The Court: I cannot make an abstract ruling now, an anticipatory ruling, but I think that the opportunity to do that should be equally open to both sides and that you mark the trail which the other side will be able to follow.

Mr. Davis: I certainly will not do anything that the other side will not be permitted to do.

The Court: So that it will be understood that as far as Mr. Hogan goes the other side will likewise have an opportunity to do the same.

Mr. Davis: The reason given, or one of the reasons given by Dr. Arnold's counsel for taking testimony on the motion to dissolve in the Patent Office was that the meaning of terms had changed.

The Court: I can understand that. And it may be that that testimony given in 1916 would not be intelligible to a layman in 1926.

Mr. Davis: Further, it is stipulated and agreed for the purposes of this case that David Sarnoff who was then the commercial manager of the Marconi Wireless Telegraph Company of America testified on December 12, 1919, in that same suit, which was just mentioned, but before the Master on the accounting, "How long has it been since they ceased the manufacture of the two-electrode device shown in the Fleming patent as distinguished from the Wegant type? A. I believe if my recollection is not faulty in this, that the America Marconi Company always acquired its two-electrode tubes from its affiliated company in Great Britain, and I think that the British Company still continues to manufacture two-electrode tubes," and that if called as a witness Mr. Sarnoff would testify to the same effect in this case.

Mr. Darby: That is correct. That is satisfactory.

The Court: That covers all that you want?

Mr. Darby: All that I want plus the additional statement to which I understand Mr. Davis has no objection, that Fleming——

Mr. Davis: The statement which my brother wants is that Professor Fleming had assigned his British patent to the British Marconi Company.

The Court: And that you stipulate?

Mr. Davis: Yes, and he also asked me to say to your Honor something about Mr. Frank Waterman but I think all the Judges in this part of the country know who Mr. Waterman is.

The Court: I think he testified to his qualifications in the other radio suit. I may read into this record the qualifications stated by him in this case.

Mr. Davis: Yes, I think what Mr. Darby wanted to say was that his qualifications were admitted in the suit to which we have referred and of course Mr. Waterman is a consulting-engineer who has testified in many patent cases.

My attention has been called during the last day or two to some statements contained in an application of Dr. Arnold which became a patent and it seems to me to be relevant and the sort of thing that one may put in evidence. If these were used to contradict the testimony of a party I would not be obliged to show them to Dr. Arnold, as I understand it, but Dr. Arnold is not personally technically a party to this case and I am wondering whether——

THE COURT: You may recall him back for the purpose of cross-examination and present that to him. You may do it now.

MR. DAVIS: I would like to do that if it is a proper thing to do.*

ERNST F. W. ALEXANDERSON.

ERNST F. W. ALEXANDERSON, was called as a witness in rebuttal on behalf of the plaintiff, and having been duly sworn, testified as follows:

DIRECT EXAMINATION.

By MR. DAVIS:

Q. 1. Your occupation, please, Doctor?

A. I am consulting engineer of the General Electric Company, chief consulting engineer of the Radio Corporation of America.

Q. 2. How long have you been employed by the General Electric Company?

A. I have been employed by the General Electric Company since 1902.

Q. 3. And what connection have you had with the Radio Corporation?

A. Since the formation of the Radio Corporation, I was chief engineer for four years.

Q. 4. And during that period, did you retain your connection with the General Electric Company?

---

*For further cross-examination of Dr. Arnold, see page 785.

A. Yes, I never left the employ of the General Electric Company.

Q. 5. You know Dr. Langmuir?

A. Yes, sir.

Q. 6. Did you ever get in touch with him so as to come in contact with any work which he was doing on vacuum tubes?

A. Yes.

Q. 7. Will you state the circumstances, and about when it happened?

A. I had been interested in radio development for many years. In 1904, Professor Fessenden requested the General Electric Company to develop a high frequency alternator, and I was assigned to the job of doing this work. One of these machines was built and used by Professor Fessenden in his first test of radio telephony. I thus kept in contact with the problems of radio telephony, and I realized that modulation of large powers, of large frequency, was one of the essential problems.

> Mr. Davis: Just a moment, Doctor. I want to be sure that the Court understands what is meant by modulation.
>
> The Court: I think practically some one explained that to me.

Q. 8. That is the impressing of the signal on the out-going radio wave, Doctor, is that a correct statement?

A. Yes, that is right. Professor Fessenden used a large water-cooled microphone in series in the antenna, and thereby he varied the antenna current in response to the human voice, but I could see the limitations of the use of the microphone when larger powers were desired, so I started to work in various ways of relaying high frequency power, so that it could control a large source of high frequency by a comparatively small energy, derived from the microphone.

Mr. Davis: Pardon me interrupting the witness a moment. I want to be sure that that is clear to your Honor. May I state it simply as I see it?

Q. 9. You have in a radio station normally an out-going high frequency wave, perhaps a million cycles. In order that the signal may go out, you must change that because as long as it is not changed, no signal goes out, and when they talk about modulation from the telephone standpoint,—they mean changing the amplitude or the energy of that high frequency out-going wave in accordance with the voice wave or the other sound wave which goes into the microphone, so that if you draw a curve which represents the sound current, that would be the envelope of the high frequency curve; is that correct, Doctor?

A. Yes, that is correct.

Q. 10. Will you please go on from there?

A. As a solution for radio telephony on a large scale, I therefore conceived it necessary to have a telephone relay, and I started to work to develop the several forms of telephone relays, one of these was a rotating machine, a high frequency generator, which had its field excited by the telephone current, and the output current was then tuned and represented a large amount of energy modulated in accordance with the telephone current. That device was tested with successful results, but I could see its limitations, and I took up work along different lines that led to the development of a device which I called the magnetic amplifier which is now used in all our high power stations in this country, and in many stations abroad.

Q. 11. That is a modulating device?

A. That is a modulating device.

Q. 12. And it is used in these stations in connection with what generator?

A. Of a high frequency alternator.

Q. 13. Which is usually called the "Alexanderson Alternator"?

A. Yes.

Q. 14. And the other scheme that you thought of, of modulation?

A. The other scheme was a three-electrode mercury arc tube, with which I attempted to control the flow of current in a mercury arc by the third electrode. I obtained a patent on one of these devices, but I observed certain practical difficulties in the development in any of the devices that I had used, and was looking for something that would be still more adequate and particularly more sensitive. About that time I came in contact with John Hays Hammond, Jr., and he bought two of our high frequency alternators. I had in mind the special problems of supplying the modulation, and we discussed the use of the magnetic amplifier as a solution for these problems. We also had in mind special methods of reception, and Hammond told me about the audion. In accordance with Hammond's description of the characteristics of the audion, I thought it might be promising as a relay of high frequency; but after discussing that suggestion with him, I received the impression that the audion was in many ways inadequate, and I thought that the defects of the audion might be overcome, and therefore I agreed with Hammond that if he would give me an audion, I would take it up with the laboratories of the General Electric Company and see whether a more practical device could not be produced.

Q. 15. And what happened next, Doctor?

A. I took the matter up with Mr. Hawkins.

Q. 16. Who was he?

A. He was the executive assistant of Dr. Whitney, with whom I often discussed the laboratory affairs, and with Dr. Coolidge and Dr. Langmuir.

Q. 17. And what resulted from that?

A. I thought Dr. Coolidge and Dr. Langmuir might be interested in these possibilities, and I particularly discussed with Dr. Langmuir the design of a special high frequency relay, and he explained to me that the new type of discharge, high vacuum discharge, which he had discovered, was instantaneous, and would undoubtedly give the result which I had in mind if the tube was developed with three electrodes along these lines. I therefore arranged to get the audion from Mr. Hammond, and give it to Dr. Langmuir.

Q. 18. Now, when was this talk with Dr. Langmuir, approximately?

A. In January, 1913.

Q. 19. Do you recognize this paper which I hand you, and if so, what is it? (Handing paper.)

A. Yes.

Q. 20. What is it?

A. It is a letter to the Patent Department, in which I record my conservation with Dr. Coolidge and Mr. Hawkins.

Q. 21. This is your letter, is it not?

A. This is my letter.

Q. 22. And it is dated February 5. Was it written on that date?

A. Yes.

Mr. Davis: I offer the letter in evidence and I understand that defendants having seen it, will accept the copy in place of the original. The date is February 5, 1913.

(Received in evidence and marked "Plaintiff's Exhibit No. 169." *See Volume IV, Plaintiff's Exhibits, page 57.*)

Q. 23. Now, what did Dr. Langmuir say to you he could accomplish by the changes which he proposed to make, or which resulted from the talk; what was the expected improvement in other words, as it was then discussed?

A. I had the impression that the audion was sluggish and therefore would not operate properly at high frequency, and he told me that the high vacuum discharge would not have that defect; also I had received the impression from Hammond that the audion would saturate at very low energy levels, and I was told that the high vacuum discharge could be used at high voltages and in high power.

Q. 24. Do you know as a matter of fact whether Mr. Hammond was right in his statement about the sluggishness?

A. I have no direct experience with the audion.

Q. 25. But at the time you believed it, and that is one of the things that led you to talk to Dr. Langmuir?

A. Yes.

Q. 26. Now, what were the two uses which you particularly had in mind for the audion, if it could be improved as suggested?

A. One use was regarding the system of reception, and the other was for modulation of high frequency for transmission of radio.

Q. 27. Let us talk first of the new system of reception; what is the name of that new system?

A. I called it tuning in geometrical progression.

Q. 28. And were you tuning the radio or the audio frequencies?

A. It was radio frequency. The object of the system was to attain selectivity of the higher order than had been realized previously, because I imagined the development of radio on a large scale, and I thought it essential to have ways of discriminating between a distant station and a nearby station.

Q. 29. And were tubes produced or not for this test, for a test of this geometric system?

A. Yes, I had worked out the theory for tuning in geometrical progression. I told Dr. Langmuir about it, and asked him to develop tubes by which a practical test could be made.

Q. 30. What was the result of that request?

A. He started work immediately, and quite soon he was in a position to make a test, which entirely confirmed my theory.

Q. 31. And did you actually operate this system of geometric tuning?

A. Yes, the system of geometric tuning was introduced——

Q. 32. I beg your pardon, Doctor. I want to make it quite clear whether or not at this time, when Dr. Langmuir produced these tubes, you actually used this system of geometric tuning?

A. Yes.

Mr. Darby: If your Honor please, I object; I do not see the materiality of this at all.

The Court: I will hear you, Mr. Davis.

Mr. Davis: Dr. Langmuir has testified that these tubes, one of the tubes which was introduced in this test, was audion No. 2, which is one of the audions in controversy here, and I am trying to show by this witness the proper operation of audion No. 2 in a geometric reception.

Mr. Darby: I will withdraw my objection to audion No. 2, if it was one of the ones that Dr. Alexanderson employed.

Mr. Davis: Dr. Alexanderson informed me last night that he has no recollection whatever of this arbitrary audion number, but Dr. Langmuir has testified, if I remember correctly, that audion No. 2 was so used, and Mr. White will testify. It is the question of the audion, if your Honor please.

The Court: Mr. Darby withdraws the objection.

Mr. Davis: And regardless of audion No. 2, it was these audions, whether it was No. 2 or 3, or 4.

The Court: That is where I——

Mr. Davis: May I ask a question, and see if I raise the question?

The Court: You withdraw the present question?

Mr. Davis: I withdraw the present question.

By **Mr. Davis**:

Q. 33. You have said that the test was made. Can you approximately fix the date of that test; I mean, about when it was?

A. Yes, the test was made in the spring of 1913.

Q. 34. Now, in that test, how many tubes were used?

A. I think two tubes were used.

Q. 35. And where did those tubes come from?

A. They were produced by Dr. Langmiur and his assistants, and the test was supervised by my assistant, in my laboratory.

Q. 36. And approximately what voltages were used on the B-batteries of these tubes?

A. I think they used a couple of hundred volts.

Q. 37. And how did the tubes operate?

A. The tubes operated as a repeating relay, transforming radio frequency energy from one circuit to the next, entirely as I expected.

Q. 38. And was the operation or not satisfactory?

A. It was entirely satisfactory.

Q. 39. Has this geometric tuning system gone into use on an extensive scale?

Mr. Darby: I object to that. That is not material to the issue.

(Discussion.)

Q. 40-42. You spoke of the desire to obtain a modulation of radio energy?

A. Yes.

Q. 43. What connection had that with these tubes that Dr. Langmuir showed you? What was the history of that situation?

A. I had been working with various ways and methods of modulating radio frequency energy and I saw in the three-electrode tube or discharge a possibility of realizing these intentions and so I discussed with Dr. Coolidge and Dr. Langmuir the design of the high power tube for that purpose and Dr. Langmuir took up the work immediately and set some of his assistants to work on producing such tubes.

Q. 44. I hand you here another paper. Do you recognize it?

A. Yes.

Q. 45. This is your letter?

A. It is my letter to the Patent Department.

Q. 46. Dated May 14, 1913?

A. Yes, sir. In that letter I gave the theory——

Mr. Darby: May I interpose an objection after the witness has answered the question?

The Court: Yes. You need not state what is in the letter, Dr. Alexanderson.

Mr. Davis: I will read one sentence of the letter.

Mr. Darby: And I will object.

The Court: Do you offer it in evidence?

Mr. Davis: Yes.

Mr. Darby: I object to its receipt as being wholly immaterial and irrelevant.

(Discussion.)

Q. 47. May I ask Dr. Alexanderson: Will you read the first page of the letter, the sentence beginning "Dr. Langmuir demonstrated"? Read it to yourself and then tell us if you remember that incident?

A. Yes, sir.

Q. 48. Do you remember the incident?

A. Yes.

Q. 49. Are you able to fix the date of the incident other than by the date of the letter?

A. Not exactly.

Mr. Davis: I have no desire to put the letter in if it is understood that that date is fixed as May 14, 1913. I am quite content to have the witness describe what happened.

Mr. Haight: I do not know what the question is.

Mr. Davis: May I read what the letter says?

Mr. Haight: No. We object to the letter.

(Discussion.)

Q. 50. Do you remember the demonstration referred to?

A. Yes, sir.

Q. 51. As a matter of your own recollection without any reference to this letter at all?

A. Yes.

Q. 52. Will you please state what the demonstration was?

Mr. Darby: I object to that.

The Court: That is the fundamental thing to which you object?

Mr. Darby: Yes, sir.

The Court: I will have to be informed about that.

Mr. Darby: My objection is on the ground that it is irrelevant and immaterial.

Mr. Davis: I do not know that my brother knows what it will be until the witness answers it. May I ask this question to clear the ground?

Q. 53. Did or did not this demonstration consist of a demonstration of a vacuum tube by Dr. Langmuir?

A. It consisted in the demonstration of a vacuum tube.

Q. 54. Now, will you please tell us what the demonstration was?

Mr. Darby: Will you carry it just one step further and would you ask the witness whether it was a demonstration by Dr. Langmuir using a vacuum tube for relaying high frequency current, the demonstration taking place presumably on or about May 14, 1913?

Q. 55. I ask that question.

A. Yes, I recollect the circumstances.

Q. 56. And it was a demonstration of a vacuum tube for relaying high frequency current?

A. Yes, sir.

Mr. Darby: I have no objection up to that point, but going beyond that point I object for the same reason that I advanced before. On the question of utility we have never denied utility of a three-electrode vacuum tube either with or without high vacuum.

The Court: There is no question pending now.

Mr. Darby: No, sir.

Q. 57. What was that demonstration?

Mr. Darby: I object to that as irrelevant and immaterial, what the demonstration was.

(Discussion.)

Mr. Darby: I will withdraw the objection.

Q. 58. What was this demonstration?

A. May I have the letter again to refresh my memory?

Mr. Darby: Does your offer of proof extend to this: I understood you to say that you would prove by Mr. White that the tube used in this demonstration was one of the tubes mentioned by Dr. Langmuir.

Mr. Davis: No.

Mr. Darby: Then I renew my objection.

(Discussion.)

The Court: My thought is that it does come down to that because it may show that if the tubes here used were Langmuir tubes that they were so far removed from the DeForest tubes in their functions and the work that they would do as to show invention existed somewhere between DeForest and Langmuir, and that would be another question as to who was entitled to the patent.

Mr. Davis, are you going to identify these tubes used in this demonstration as tubes made by Dr. Langmuir in conformity with the process of this patent?

Mr. Davis: Yes, sir.

The Court: Then you withdraw your objection.

Mr. Darby: On that assurance, yes.

Mr. Davis: We will have to recall Dr. Langmuir to do it unless Mr. White happens to remember it.

Mr. Haight: There is one point that I do not want to let go unchallenged and that is Mr. Davis' remark that they built the transmitting tubes that made possible transmission, because my friends of the Telephone Company utter wild protest to the effect that they did it.

By Mr. Davis:

Q. 59. What was this demonstration?

A. Dr. Langmuir demonstrated to Mr. Hawkins and to me one of the tubes which he made in accordance with my request and the tube proved to be capable of operating at high voltages and constituted a very promising solution of the problem which I had asked

Dr. Langmuir to solve, that is, to provide a modulator for high powers.

Q. 60. You fix the date as May 14th——

A. May 14th, 1913.

Q. 61. By the date of this letter?

A. Yes, sir.

Q. 62. Was any further work done in connection with Dr. Langmuir and his assistants in this same connection with the modulator?

A. Yes. I discussed the probable characteristics of some more powerful tubes and was informed that such tubes would operate to advantage at voltages as high as 40,000 volts.

Mr. Haight: I move to strike it out.

Mr. Davis: I want that simply as Dr. Langmuir's confidence of what he could do.

The Court: He did not say that that was a disclosure by Dr. Langmuir to him.

Mr. Davis: Then I will consent to have it stricken out.

The Court: Motion is granted.

Q. 63. Did Dr. Langmuir or did he not make any statement to you as to what voltage should be employed when the device went into use on a commercial scale?

A. He indicated voltages as high as 40,000 volts might be used.

Q. 64. And were any further later tests made on this modulator?

A. The tube was built which was tested in my laboratory at 40,000 volts with our high frequency alternator.

Q. 65. And that was when?

A. In the fall of 1913.

Q. 66. And about how much energy was utilized in that tube?

A. Two kilowatts alternator.

Q. 67. Does that mean that the tube was handling that power?

A. The tube controlled the power in the sense that it switched two kilowatts of power into the antenna and reduced it to nothing, but the tube itself did not consume all that energy.

Q. 68. The tube was handling all that energy?

A. Yes.

Q. 69. And how well did the tube operate in that test?

A. The tube operated entirely successfully.

Q. 70. And this method of modulation which you invented at that time did you patent?

A. Yes.

Q. 71. Was there some delay in getting the patent?

A. Yes, interference was declared with Colpitts and DeForest.

Q. 72. Colpitts of the Telephone Company?

A. Yes.

Q. 73. And DeForest of the DeForest Company?

A. Yes.

Q. 74. Who won the interference?

A. The patent was granted to me.

MR. HAIGHT: I object. It is immaterial. Mr. Ballard says they got half of it.

THE COURT: It is already in the record.

MR. DAVIS: You may cross-examine.

CROSS-EXAMINATION.

By MR. DARBY:

XQ. 75. In this modulator, how many volts did you employ on your plate in 1913?

A. We employed voltages as high as 40,000.

XQ. 76. 40,000 volts on the plate electrode?

A. Yes, sir.

XQ. 77. Did you use that in the form of a B-battery, that is, that took the place of the B-battery?

A. We applied the high frequency currents from the alternator.

XQ. 78. 40,000 volts?

A. Yes.

XQ. 79. As I understand your testimony you first saw an audion at Mr. Hammond's; is that correct?

A. I do not think I saw the audion at Mr. Hammond's, but I discussed the use of the audion with Mr. Hammond.

XQ. 80. You had seen an audion prior to that time?

A. No.

XQ. 81. You had not?

A. No.

XQ. 82. You do not recall whether you actually saw an audion the first time the subject was discussed with Mr. Hammond?

A. I do not recollect seeing an audion.

XQ. 83. When do you recollect that you saw an audion?

A. When the audion was sent—when I received the audion from Mr. Hammond.

XQ. 84. At Schenectady?

A. Yes.

XQ. 85. And as I understand you, you asked Mr. Hammond to send you that audion?

A. Yes.

XQ. 86. And the reason why you wanted to get it was so you could try out this geometrical tuning; is that correct?

A. That was one of the reasons, but I had in mind other uses of a high frequency relay.

XQ. 87. But you disclosed your reasons to Dr. Langmuir, did you not?

A. Yes.

XQ. 88. And the reason that you disclosed to Dr. Langmuir was a high frequency relay?

A. Yes.

XQ. 89. And that high frequency relay did not employ geometrical tuning, did it?

A. The geometrical tuning was one of the objectives for which I needed the high frequency relay.

XQ. 90. But you disclosed to Dr. Langmuir only the high frequency relay. You did not disclose to him the geometrical tuning?

A. Yes, I discussed the geometrical tuning with him.

XQ. 91. Then, as I understand you, the reason why you obtained the audion from Mr. Hammond was that you wanted to obtain not only a high frequency relay but a geometrical tuning arrangement and that you told that to Dr. Langmuir before you got the audion; is that correct?

A. I told him in advance before I got the audion that the geometrical tuning and high frequency relays and other purposes were some of the objects I had in mind.

XQ. 92. And those objects are what you told Dr. Langmuir before you got the audion?

A. Yes, sir.

XQ. 93. You have also mentioned sluggishness. You have used the word that the audion was sluggish. What did you mean by that?

A. I had been working with mercury arc devices before and I had found some difficulties in its use which I explained in my mind as sluggishness. Then when Hammond told me about the inadequacy of the audion I also interpreted that as sluggishness.

XQ. 94. Then you had explained to your own mind that the audion was sluggish before Mr. Hammond told it to you; is that right?

A. I did not know about the audion until Mr. Hammond told me about it.

XQ. 95. Did Mr. Hammond tell you that the audion was sluggish?

A. Yes, I received that impression from him in discussing the use of the audion for a certain purpose that I had in mind.

XQ. 96. Did you explain to Dr. Langmuir this sluggishness of the audion as it had been explained to you by Mr. Hammond?

A. Yes, I told him that I understood that that was one of the defects of the audion.

XQ. 97. And did Dr. Langmuir tell you that that was due to gas in the audion, when you made that explanation to him?

A. I think he indicated that as a probable explanation.

XQ. 98. Are you quite sure that he indicated that to you?

A. That is my recollection.

XQ. 99. And he indicated that to you before you made any such suggestion to him, did he not?

A. I do not remember how the matter was mentioned in our conversation, but I recollect that we both came to the conclusion that if the audion was defective it was very likely owing to the presence of gas.

XQ. 100. See if I can refresh your recollection in the testimony which you gave in the Interference proceeding. Do you recall testifying in the Interference proceeding in your own behalf, do you not?

A. Yes.

XQ. 101. Do you recall testifying as follows in answer to Q. 5:

> "During the fall of 1912 and the early part of 1913, I made several trips to the experimental

radio laboratory of John Hays Hammond, Jr., of Gloucester, Massachusetts, where two of my 100,000 cycle alternators were installed for experimental purposes."

You may check up with me to make sure I am right, Doctor, and that I am reading it correctly:

"During the progress of the tests I conducted with Mr. Hammond we had various discussions of radio problems in general and particularly of the problem of telephonic modulation of high frequency energy. During these discussions Mr. Hammond told me about the characteristics of the DeForest audion, and I gained from him the impression that while the audion had proven to be an efficient amplifier of telephone currents, it could not be used as a relay for radio frequency currents, because of an inherent sluggishness in its action. In connection with my experimental work with mercury vapor relays of the type described in my patent No. 1,042,069, I had noticed a certain sluggishness in the action of these tubes, and in my own mind I explained this sluggishness as due to the inertia of ionized vapor. I was, on the other hand, in a general way familiar with the results of the work of Dr. Langmuir and Dr. Coolidge in connection with X-ray tubes, and I was under the impression that the sluggishness which I had observed would not exist in vacuum tubes of the type that Dr. Langmuir and Dr. Coolidge were dealing with. I therefore conceived the idea that the three-electrode valve of the DeForest type might be improved by the methods of evacuation used by Dr. Langmuir and Dr. Coolidge, and that the tubes so improved might be substituted in the system for radio telephonic transmission described in my patent 1,042,069."

And then you were asked:

> "Q. 6. When did you first disclose this idea to others?"

To which you answered:

> "A. After one of the discussions with Mr. Hammond, which I referred to, I communicated my ideas to Dr. Coolidge and Mr. Hawkins. Dr. Coolidge confirmed my opinion as to the probable results of the use of a higher grade of vacuum in a tube of the DeForest type, and was in favor of research work being started along this line. For this purpose I obtained from Mr. Hammond a sample of a DeForest audion, which I gave to Dr. Langmuir, who had taken up this investigation."

That testimony was true at the time you gave it, was it not, Dr. Alexanderson, and is now?

A. Yes.

XQ. 102. And the patent that you referred to in the testimony, No. 1,042,069, is the one, a copy of which I now show you?

A. Yes, that is right.

Mr. Darby: I ask to have it marked for identification.

(Received and marked "Defendant's Exhibit K for Identification.")

Mr. Darby: I think that is all.

The Court: Any re-direct, Mr. Davis?

Mr. Davis: No re-direct, if your Honor please. That is all, Doctor.

(Witness excused.)

(Whereupon, at 6 P. M. adjournment was taken until Thursday, November 4, 1926, at 10 o'clock A. M.)

WILLIAM C. WHITE.

William C. White, was called in rebuttal as a witness on behalf of the plaintiffs, and after having been sworn, testified as follows:

Direct Examination.

By Mr. Davis:

Q. 1. What is your occupation, Mr. White?

A. Research engineer for the General Electric Company, employed in the research laboratory at Schenectady.

Q. 2. How long have you been employed by the General Electric Company?

A. Continuously since July, 1912.

Q. 3. And was it in the research laboratory all that time?

A. Yes.

Q. 4. Do you know Dr. Langmuir?

A. Yes.

Q. 5. And you have been working for him for how long?

A. I worked immediately under his supervision for a period of several years, and have been closely associated with his work until the present time.

Q. 6. And what is the time when this period began at which you worked immediately under his direction?

A. The early part of 1913.

Q. 7. And what had you been doing before that?

A. I had been employed on experimental work in connection with mercury arc devices.

Q. 8. I hand you a notebook which has been marked "Plaintiff's Exhibit F for Identification," and ask you if you recognize it?

A. I do.

Q. 9. What is it?

A. It is my notebook No. 452.

Q. 10. Covering approximately what period?

A. Covering approximately the period between January, 1913, and April, 1914.

Q. 11. And were the statements herein recorded correct at the time of the record, to the best of your knowledge and belief?

A. Yes.

Mr. Davis: I offer the notebook in evidence.

Mr. Haight: No objection.

(The notebook was received in evidence and marked "Plaintiff's Exhibit No. 171." *See Volume IV, Plaintiff's Exhibits, page 91.*)

Q. 12. I find in this notebook an entry on page 20. It is very short. Perhaps you had better read it, the last four lines.

A. On page 20, under date of Monday, February 10th, 1913, I wrote:

> "Spent afternoon in conversation with Dr. Langmuir in regard to some experiments I am to try with the DeForest audion."

Q. 13. Now, tell us about that conversation.

A. As stated in the previous answer, I had been engaged upon work in connection with mercury arc devices. Very shortly before making that entry, Dr. Whitney, the director of the General Electric Research Laboratory at Schenectady, came into the room where I was working and suggested that as soon as I could conveniently terminate the work I was then engaged upon, that I should spend all my time assisting Dr. Langmuir in connection with some thermionic work he was doing. Accordingly, the conversation recorded with Dr. Langmuir followed.

Q. 14. Did Dr. Langmuir or not show you any experiments or tests on this occasion?

A. At the same time that this conversation took place, or very shortly afterwards, Dr. Langmuir showed me some tests on a lamp with two filaments.

Q. 15. What was the general nature of the test?

A. The general nature of these tests was to illustrate how the current between a cold and hot electrode could be limited either by electron emission or space charge.

Q. 16. How did he illustrate this?

A. He illustrated this by putting a relatively high positive voltage on the cold electrode, and then slowly raising the filament temperature, showing that the current went up with this temperature. He also ran the filament at a normal temperature and increased the voltage on the cold electrode from zero to some relatively higher positive value, showing how also in this case the electron current increased with the voltage.

Q. 17. Were these increases indefinite?

A. No. He then illustrated that if the filament was run at a low temperature, an increasing plate voltage would only cause an increase of current through the tube up to a certain voltage value, and beyond that value, a relatively large increase of voltage did not cause appreciable increase in electron current.

Q. 18. What do you call that now?

A. I beg your pardon?

Q. 19. What do you call that now, that phenomena?

A. That is the phenomena we term "limitation of electron current by emission."

Q. 20. Is it also sometimes spoken of as "a saturation"?

A. Yes.

Q. 21. Now, Mr. White, in connection with the tests in which he varied the temperature, keeping the voltage constant, did that current go up indefinitely, or not?

A. No. He then used a normal positive voltage on the cold filament and raised slowly the filament temperature. Again, in this case, the electron current rose rapidly at first, and then above a certain point no appreciable increase of electron current was noted as the filament was raised to a still higher temperature.

Q. 22. You speak of the voltage being put on the cold filament; actually where were the terminals of the source connected?

A. As I remember it, this tube had two parallel hairpin filaments, so that it had four wires coming out of the stem. One of the pairs of wires went to the cold filament which was used as the positive terminal.

Q. 23. And what was the negative terminal?

A. The negative terminal was the hot filament.

Q. 24. Now Dr. Langmuir having shown you those things, did he ask you to do anything?

A. He told me that he wished to build tubes in our own laboratory, and that he would obtain for me a DeForest audion to make the tests with, as he believed such a device employed electron currents.

Q. 25. Did he say anything about a vacuum system?

A. He told me that for the type of tubes he wished to make, I would have to install a much better type of vacuum system than I was employing in my mercury arc experimental work.

Q. 26. What did you do in that direction?

A. Shortly afterward I was able to obtain a Gaede Mercury Pump.

Q. 27. I do not now want the details, but simply whether you did or did not get a better vacuum system?

A. I did.

Q. 28. And still referring to this first interview, did or did not Dr. Langmuir give you specific instructions in reference to building any particular device?

A. Dr. Langmuir sketched out a tube which he wished constructed, and he wished me to exhaust and test.

Q. 29. Now, I refer to the entry in your notebook on page 23, February 13, 1913, to February 25, 1913:

"Away from lab. on account illness."

Do you remember that incident?

A. I do.

Q. 30. What was the situation when you got back with respect to this tube?

A. As I remember, progress had been made by the glass-blower in the manufacture of this tube, so that I was able later to start exhaust work upon it.

Q. 31. What was Dr. Langmuir's habit in a case of this sort with reference to dealing with the glass-blower?

A. His habit was to make a sketch of what he desired, and either to take it in himself or give it to one of his assistants to take in the glass-room, and very often in devices in which he was particularly interested, he would frequently go in to learn what progress was being made.

Q. 32. Now, on Thursday, March 13th, that is on page 32, under the heading, "Thursday, March 13 to Saturday, March 15," I find an entry. Will you tell us what happened on that day, according to that entry which you need not read unless you want to?

A. The entry covering March 13 to March 15th, states that "Completed vacuum system and exhausted an all-tungsten audion."

Q. 33. What audion was that?

A. No. 2 audion that we have spoken of.

Q. 34. First, I will ask you if you recognize this exhibit, this tube, which is marked Plaintifff's Exhibit No. 105?

A. I do recognize it.

Q. 35. What is it?

A. It is this audion, tungsten audion referred to. It is given No. 2.

Q. 36. And that is the audion referred to in your notebook as audion No. 2, is it?

A. Yes.

Q. 37. Was Dr. Langmuir present at the exhaust?

A. Not throughout, but at intervals.

Q. 38. Now, I hand you a collection of papers which are marked for identification, "Plaintiff's Exhibit G," and ask you if you recognize them (handing papers).

A. Yes, those are some of my record sheets made at that time.

Q. 39. Is there any part of them which is not in your handwriting?

A. Yes.

Q. 40. Is there any part which is not contemporaneous?

A. That same part that I am referring to as not being in my handwriting is not contemporaneous.

Q. 41. And that is on sheet numbers——

A. Eighty.

Q. 42. And in what column?

A. The last column to the right.

Q. 43. Now, how did this column of figures happen to get on this sheet, if you know?

A. I do not know under what circumstances they were put on that sheet, but they are not in my handwriting, and the initials are appended, indicating that they were placed there by another man in the laboratory.

Q. 44. Yes, you recognize these initials "C. G. F."?

A. Yes.

Q. 45. Then it is clear that this column was a later entry, something later than the original record; is that right?

A. Yes.

Q. 46. So far as you know, is there anything else in this collection of papers which is not contemporaneous and original?

A. No.

Mr. Davis: I note in that connection, if your Honor please, that these sheets of that early spring and winter, bear little different dates.

Q. 47. Now, I will first call your attention to this card which is on top. Is it a library or catalog card, or something of that sort?

A. Yes.

Q. 48. What is the date of that? The date of the card, I mean.

A. The date?

Q. 49. Yes.

A. April 30, 1913, is given on the card.

Q. 50. And what are the letters before the date?

A. "O. K."

Q. 51. Now, what does that mean?

A. This card was one of a number of cards that I used to keep track of the different tubes that came to me from the glassblower for exhaust and test. I did not start this system until a few weeks after audion No. 2 was built, and then made up cards for the first few tubes.

Q. 52. What does the "O. K." mean?

A. The "O. K." simply means that on April 30th, this tube was in satisfactory operating condition, and fit to use for miscellaneous tests.

Q. 53. I call your attention then to the sheet R. S. W.-77, headed: "Tungsten wire audion." What is that sheet?

A. That sheet R. S. W.-77 is a very brief record of the exhaust proceeding on audion No. 2.

Q. 54. The first column is headed: "Date." The second column is headed: "Time." What does that mean, "Time," on it?

A. Time of day.

Q. 55. The next is headed what?

A. "Microns pressure."

Q. 56. That little sign means microns, does it?

A. Yes.

Q. 57. And the next heading is what?

A. "Temperature."

Q. 58. Now, the pressure is what pressure? Pressure where?

A. The pressure is read on the McLeod gauge which was attached to the system near the tube.

Q. 59. What do you have, if anything, between the McLeod gauge and the tube?

A. A liquid air trap.

Q. 60. And this column marked "temp," what temperature does that refer to?

A. The temperature of the oven used for baking out the glass.

Mr. Davis: I do not know if your Honor cares to look at this; it is just a schedule of the exhaust, showing how long it was pumped, and so forth, and when the current was turned on (handing paper).

Q. 61. What does it mean, "Flashed filament well"?

A. That means the filament was operated at as high a temperature as I deemed it safe to operate without burning it out.

Q. 62. Now this audion had how many filaments?

A. This audion had a V-shaped filament, which was to be the cathode of the completed tube. The anode or plate was also in the form of a filament, strung back and forth between metal hooks, so that it could be heated by a current to free it from gas.

Q. 63. Now, the exact language of this entry is: "Flashed plate filament well and filament one." What does that mean, if I have read it correctly?

A. It is difficult for me to know now just what that was intended to mean, but I think it was to represent one of the filaments.

Q. 64. It says "and filament one, plate filament and filament one"?

A. That probably referred to the cathode.

Q. 65. And "sealed off at .05 mn"; is that it?

A. Yes.

Q. 66. That means microns?

A. Yes.

Q. 67. Now, the next sheet R. S. W.-78, will you please tell us what these headings refer to at the top of the columns, just read them across and say what they are briefly?

A. This sheet covers early tests on this audion No. 2. Starting from the left, the first column is the date. The next column is headed "Lamp amperes," which means current through the filament. The third column is headed, "Degree C, Abs.," which stands for absolute temperature. The next column is, "Plate Volts." The next two columns have a common heading, "Edison I," signifying electron current or Edison current, as we called it at that time. The first of these two columns with this common heading, is headed: "Meter," which signifies the meter reading, and the second column under this heading, "Milli Amps.," which signifies the reading of the meter transferred into terms of milliamperes.

Continuing to the right, another test is recorded, the first column of which is again "Amps. Lamp." Next, "Degrees C. absolute." The next "Plate Volts," and again two columns with a common heading, "Edison I." The first headed "Meter," and the second "Milli Amps." The final column had no heading, but was used to denote the calibration constant of the meter used.

Q. 68. What pump did you use in pumping this audion No. 2?

A. The rotating mercury Gaede Pump.

Q. 69. Was there anything between the Gaede Mercury Pump and the tube?

A. Yes, the liquid air trap.

Q. 70. I notice on this sheet R. S. W.-78, on the right-hand column, some figures, "K-107, K-1," and so forth. Will you please explain what that means?

A. Those figures represent the calibration constant of the current measuring instrument used.

Q. 71. Why do they vary?

A. This is due to the fact that on this test, two instruments were used. One was direct reading, whereas the other required a correction constant.

Q. 72. That is, by "K-1," you mean it is direct reading?

A. Yes, sir.

Q. 73. Why were two instruments used, Mr. White?

A. Because the current range in the test was greater than could be accommodated on any one instrument I had available at that time.

Q. 74. That is, you would go up to a certain current on one instrument, and then what?

A. Change the instrument to one having the higher scale readings.

Q. 75. These readings were made and recorded by you on the date which that sheet bears?

A. Yes.

Q. 76. I hand you sheet R. S. W.-79, and that is dated 3/17/13, which I take it is March 17, 1913. Do the headings of the columns correspond in meaning to the similar entries on the last sheet that I showed you, sheet No. 78?

A. In general; there are additional columns on our R. S. W.-79.

Q. 77. Just tell us what these headings mean on those additional columns?

A. There is one column headed "Grid Volts"; another pair of columns headed "Grid I."

Q. 78. Which is what?

A. Meaning "grid current." The first of these two columns with this common heading have the word "Meter" at the top. The other column has the word "Milli Amp."

Q. 79. And these sheets record the tests that were made by you on that day?

A. They do.

Q. 80. What was the energy approximately in the audion in that last test?

A. In the last test?

Q. 81. On the test in that last sheet I should say, that is, sheet 79.

A. I notice in one case with a plate voltage of 115 a current of 11 milliamperes is recorded.

Mr. Davis: This sheet R. S. W. 80 we are putting in for completeness. I have already called attention to the fact that somebody has made some marks on it which are not contemporaneous and it also has the fault that Mr. White has forgotten to date it.

The Court: That is the 1-2/3 column.

Mr. Davis: Yes, it was very recent.

The Court: You are excluding that column from the offer?

Mr. Davis: Oh, yes. It is no part of the record and it is apparent that somebody up there who did not know any better simply made those marks on that sheet.

Q. 82. Do you know about when this particular sheet was made excluding this column?

A. Yes, it is a sheet following after R.S.W. 79.

Q. 83. And preceding 81?

A. Yes.

Q. 84. And 81 is dated when?

A. March 20, 1913.

Q. 85. So what do you know about the date of 80?

A. It was between March 17 and March 20, 1913.

MR. DAVIS: And the four columns in which we are interested here need not, I think, be explained. They have the same heading that the others had.

Q. 86. I hand you R.S.W. 81. Is that another of your original sheets?

A. It is.

Q. 87. And it is still recording tests on audion No. 2?

A. Yes.

Q. 88. And there are no terms there that you have not already explained, are there?

A. I notice one column is headed total current.

Q. 89. What does that mean?

A. There are no entries under the column so that I cannot be sure.

Q. 90. R.S.W. 98 is dated April 22, 1913. What is that?

A. This is another record sheet. Some of the entries refer to tests of audion 9-B and other readings of tests of audion No. 2.

Q. 91. I would like to go back for a moment to R.S.W. 81 and ask you what the nature of that test was, what you were trying to do when you made that test?

A. I was using a constant filament current and a relatively constant plate voltage and taking the readings of electron current and grid current with variations of grid voltage.

Q. 92. What was your object?

A. Probably to obtain the characteristic curve of variation of plate current with grid voltage.

Q. 93. There is an entry there "N.G. 115V not giving sat."

A. It is apparent that Dr. Langmuir had requested some particular curve showing saturation and that after carrying on a few readings this particular characteristic was not shown due to an improper choice of voltages and therefore the entry "N.G. 115-V not giving sat," meaning that this 115 volts was not giving saturation expected.

Q. 94. Why did it not give it?

A. Probably because the filament temperature was too high.

Q. 95. I notice on page 98 that the first quarter or perhaps sixth of the sheet has to do with another audion; is that correct?

A. Yes.

Q. 96. Otherwise the entries on that sheet refer to what?

A. Audion No. 2.

Mr. Davis: I offer the various sheets, which have previously been marked for identification G, in evidence.

(Received in evidence and marked "Plaintiff's Exhibit No. 172." *See Volume IV, Plaintiff's Exhibits, page 108.*)

By Mr. Davis:

Q. 97. I notice on page 34 of your notebook a statement that it was necessary to run the filaments for quite a time to get results consistent with previous day's results. First results 10 or 20 per cent. too high. What is that phenomenon?

A. It simply meant that plate currents were not the same immediately upon lighting the filament as they were a short time later. This effect very often occurred in some of our earlier tubes due to temperature effects on the mechanical construction causing expansion or contraction.

Q. 98. Will you illustrate that just what it might mean?

A. I think in those particular tubes it was due to the warping of the grid wires as the temperature of the parts was increased by the heat from the filament.

Q. 99. The grid was wound around the filament, was it?

A. Yes.

Q. 100. Has that happened since?

A. On well designed tubes it is not a common occurrence.

Q. 101. The effect would be to change the distance——

A. The probable effect was to change the relative distance of the grid either from the filament or the plate.

Q. 102. And thus change the amplification factor?

A. Yes, and also the plate current.

Q. 103. On pages 43 and 44 under date of April 7, 1913, there is an entry and I will first ask you, Mr. White, what these red ink marks which are I find on that page and in several places in the book?

A. They were placed there during an Interference proceeding in which this notebook was used some years ago.

Q. 104. That is, you were asked by counsel——

A. I was asked by counsel to mark certain places in the book for identification.

Q. 105. And any red ink in that book, is that sort of an entry?

A. Yes.

Q. 106. Now, tell us what the nature of these tests were referred to on those pages?

A. On page 43 there is recorded some notes of a scheme suggested by Dr. Langmuir to step up direct current from one voltage to a higher voltage. On page 44 an arrangement for a similar purpose is described.

Q. 107. That is, by means of what?

A. By means of a combination of a vacuum tube and an inductance in an associated circuit.

Q. 108. That is, you had this audion, which by the way was No. 2, was it?

A. Yes.

Q. 109. And also page 43 it is noted?

A. Yes.

Q. 110. And you put the plate circuit of that audion in series with the 250-volt shop circuit and with a heavy inductance?

A. Yes.

Q. 110a. And then what did you do?

A. The idea——

Q. 111. What did you do after you had done that?

A. I connected up a circuit so that the grid voltage could be suddenly varied and made negative so that the inductance would discharge suddenly.

Q. 112. Just a minute. Let us get this so that we all understand it. You are passing a current from the 250-volt shop circuit through the audion and through this heavy inductance and then you close a switch and that puts a certain voltage on the grid?

A. Yes.

Q. 113. What does that do to the main current?

A. That was a negative voltage placed on the grid which shut off suddenly the electron flow in the tube and this——

Q. 114. Just a minute, Mr. White. You put a negative voltage on the grid and made it impossible for electrons to cross that tube?

The Court: That is the purpose.

Mr. Davis: That is what they are trying to do.

Q. 115. There is energy stored in this inductance, is there not?

A. Yes.

Q. 116. That is, the iron of the transformer is charged with energy. It has to discharge itself somewhere?

A. Yes.

Q. 117. What did it do?

A. The energy stored in this inductance when released set up a very high voltage across the terminals of this inductance which discharges itself across a very small gap.

Mr. Davis: I think Dr. Langmuir has estimated what that was and I will not trouble you with it here.

Q. 118. I would like to bring out from the witness whether or not that strain was a strain on the tube?

A. Yes, this voltage set-up was very much higher than had been employed upon the tube during its exhaust or test.

Q. 119. I notice on page 46 an entry with reference to wiring up a 40,000-volt transformer, what was that, do you remember it?

A. Yes. Dr. Langmuir was very anxious to have work done on vacuum tubes in which plate voltages of the order of 10,000 and higher could be employed. At that time we had no convenient source of D. C. of this voltage and so we decided to use alternating current and this required a rather large and heavy transformer installation. I assisted in getting this up and wired up ready for use.

Q. 120. Did you have much to do with it afterwards?

A. No.

Q. 121. On page 63 there is an entry near the bottom of the page which I wish you would tell us about. First, tell us what the date is?

A. This entry on page 63 covered work between May 11th and May 17, 1913, and states that Mr. Alexanderson's idea of geometrical tuning using two audions had been made and referred to a report for further particulars.

Q. 122. Do you remember this test for geometrical tuning?

A. I do.

Q. 123. Was it successful or not?

A. Yes, it was successful.

Q. 124. What is this paper?

A. This paper which you hand me is my report on this test made in connection with Mr. Alexanderson's work.

Q. 125. The report is dated May 24, 1913. This particular copy does not appear to be signed by you but appears to be witnessed by whom and under what date?

A. It is witnessed by M. E. Christie, June 3, 1913, and by Dr. Whitney on September 25, 1913.

Mr. Davis: I imagine that a signed copy is in evidence in the other suit which was referred to before Judge Bodine. I offer this report in evidence.

(Received in evidence and marked "Plaintiff's Exhibit No. 173." *See Volume IV, Plaintiff's Exhibits, page 115.*)

Mr. Darby: Is that in connection with audion No. 2?

Mr. Davis: Yes, I should have brought that out. I will ask the question now.

By Mr. Davis:

Q. 126. Part of this report are four blueprints?

A. Yes.

Q. 127. At the foot of the first of the blueprints please read the last two lines.

A. "First audion No. 8, second audion No. 2."

Q. 128. What does that mean?

A. That means that on the above sketch the audion used in the first stage was No. 8 and the audion used in the second stage is No. 2.

Q. 129. And this report correctly describes, does it, the tests which were made at that time?

A. Yes.

Mr. Darby: I have no objection, but I submit I do not know how much additional evidence on the question of utility Mr. Davis is going to put in because the question of utility is not in issue.

Mr. Davis: I am not putting this in on the question of utility at all, this particular exhibit. If your Honor please, it is incidentally interesting as confirming Mr. Alexanderson's testimony, but what I am showing here is an audion No. 2, the first audion that was made with wire anode, which is exposed to this atrocious abuse of opening a 250 volt circuit through the primary of the transformer and which a few weeks later without any re-exhaust appears as a useful audion in one of these tests, again at 250 volts. It is to show that Dr. Langmuir knew how to exhaust audions.

Mr. Darby: I have no objection to that, but I will start objecting to every bit of evidence that is put in on the question of utility, being directed to an issue that is not involved.

By Mr. Davis:

Q. 130. Will you look at page 69? I think Dr. Langmuir has already referred to this page, which is the page in which he speaks of No. 2 as the only one which has shown this effect. I will ask you whether you remember these circumstances. Do you remember the entry and is it correct?

A. Yes, I remember the entry.

Q. 131. And is it correct?

A. Yes.

Q. 132. On page 149 under date of August 16th there are some tests described?

A. Yes, some tests are described using audion No. 2.

Q. 133. That is, were you testing audion No. 2 or what?

A. Using it as a tube to carry out certain other experiments.

Mr. Davis: You may cross-examine.

The Court: This is a good time for our short recess.

(Here a short recess was taken.)

(After a short recess.)

Mr. Haight: We desire to have the cross-examination of Mr. White, if there is to be any, deferred until Mr. Richmond can have an opportunity to look over his notebooks.

The Court: Is this satisfactory, Mr. Davis?

Mr. Davis: Yes, sir.

The Court: All right.

(Witness excused.)

Mr. Darby: Pursuant to the stipulation, if your Honor please, that was entered into today, it will take me just five minutes to read this portion of Mr. Waterman's testimony.

The Court: Which now has become and is read as part of the defendant's case?

Mr. Darby: Yes, sir. Frank N. Waterman under the stipulation, was a witness in behalf of the Marconi Company in a case which was identified as involving the Fleming Valve patent.

"By Mr. Hoguet:

Q. 18. Have you used, and are you familiar with the operation of detectors such as are illustrated in the Fleming patent in suit?

A. I am.

Q. 19. What was the structure of these detectors and where did you obtain them?

A. The detectors which I have used have also been furnished to me by the Marconi Company, and were the constructions ordinarily used in commercial practice. There have been two forms that I have used chiefly, one having the cylinder surrounding the filament, exactly as shown in the Fleming patent, and the other has one or two plates, located parallel to the filament. I have used both of these forms in considerable number; also a form in which the plate is used suspended immediately above or below the filament, according to which side up the lamp is used. These devices are excellent detectors. They vary in quality, as all such bulbs do. I found that a good bulb, one which performed satisfactorily, is equal to or somewhat superior to the best crystals, such, for instance, as cerusite crystal, which is the best crystal, the most sensitive crystal, which I am personally acquainted with. I have used these detectors in all the ordinary wireless telegraph circuits.

By The Court:

Q. 20. Were they made precisely in accordance with the drawings of the Fleming patent?

A. Some I think were literally like the Fleming patent with the exception possibly of the mode of staying the cylinder to keep it from rattling. I do not remember that I compared it in that respect. I have used considerable numbers in which there was the cylinder such as is shown surrounding the filament, in the manner shown. Others instead of having a complete cylinder, had two plates. Others had only one plate, and that sometimes parallel to the filament, and sometimes placed above or below it, according to which way we regard the lamp as hung."

Mr. Darby: The next is a portion of the answer to Q. 111:

". . . . I think I forgot to say yesterday that the action which Fleming was talking about was one which would take place to best advantage in a perfect vacuum, any space containing no gas whatever, because the electrons which Fleming referred to are derived from the filament. Now this molecular activity which DeForest speaks of throughout this patent, and the ionization, requires a gas as an indispensable requisite . . . ."

And the context of the remainder of the answer shows that this DeForest Patent No. 824,637, which is a patent different from the grid audion patent, No. 835,792—

"because the ions which DeForest employs are simply the electrified molecules of the gas, while the electrons which are referred to by Fleming and which constitute the active agent in the Fleming valve and in all of these incandescent lamp detectors, are electrons derived from the substance of the filament."

The next is part of the answer to Q. 120, and the context shows that he is referring to DeForest Patent No. 823,402:

"Everywhere throughout the patent, and there are seven places where I have noted where it is mentioned, it is a change of conductivity of a gas which is relied upon as the operating means, precisely as in the flame patents, and this is in sharp contrast to the explanation which DeForest found in the proceedings of the Royal Society for the operation of the Fleming device, where the conductivity is entirely independent of the presence of any gas whatever. It is due to electrons given off from the filament."

The next is part of answer to Q. 186:

"The action is, as Fleming stated, purely electronic, an action which gives us conductivity as the result of electrons emitted from the filament, and not as the result of any matter contained in the space surrounding the filament. That is the distinction."

And the next one is answer to Q. 195, and that is the last one:

"A. Yes; that is to say, you may adjust them at one potential of the local battery and show an increase, and another would show a decrease, upon receipt of signal. It can work extremely well in both cases. That is not apt to be a permanent condition, however. They usually decide what they will do, that they will do one or the other, and after they have been used for a few days, they permanently take a predilection to one way of working. That is another thing as to which there is no explanation at all. So that when I say I have no theories about this, I have, but they are note adequate. I am perfectly free to admit that. But one thing is very conclusively established, and that is that the action which takes place is an electron action just as Fleming said it was, and as most of the writers agree with this, and that is shown by the fact that the same action takes place exactly if we make bulbs which have what is now called the absolute vacuum which means a vacuum so high that no known test will reveal any attribute of gas.

Q. 196. Explain in this connection the relation of the electronic action of the device with the vacuum?

A. Well, in order that the electrons may have undisturbed passage across, it is necessary that there should not be too many gas molecules in the way. I am going in a minute to read what Fleming had to say about that, about the significance of the vacuum. If the vacuum is so high that the electron streams across from the filament to the plate are not seriously interfered with then the vacuum is sufficiently good for the purpose. But if there is very much gas present——"

Then there is an interruption by Mr. Bull with——

"Q. 197. What do you mean by very much?

A. I mean if a vacuum is not equal to a reasonably good incandescent lamp vacuum, for example, then the bulb gets freaky. It will work beautifully today and abominably, tomorrow, and pretty well the next day, perhaps, and its characteristics change with use. I have repeatedly taken characteristic curves of the same valve at successive periods and found that the shape varied very much, and such bulbs, on applying high pressure, showed at once that there was gas left in them to an obnoxious extent."

That was all of that part of the answer.

After Recess.

Mr. Davis: Now, Mr. White. If your Honor please, the examination which we have made of the records which defendants have given us, I am informed shows no record of any exhaust of any tube after the arrival of the molecular pump which Dr. Arnold testified arrived in the spring of the year 1913. I do not remember the exact date; and it is my understanding that I wish to have perfectly clear, that the defendants have given us all the records they have which are pertinent in this connection, and that they have no record of the exhaust of any tube after the arrival of that molecular pump.

Mr. Richmond: I will say that we have tried to find any such records, and have not succeeded in finding them.

WILLIAM C. WHITE, resumes the stand.

CROSS-EXAMINATION.

By MR. RICHMOND:

XQ. 134. In your notebook 452, which is Plaintiff's Exhibit No. 171, I find on page 34, a paragraph reading as follows:

> "In commencing tests for the day it was necessary to run filament for quite a time to get results consistent with previous day's results. At first results were five to ten per cent. high."

This refers to the audion that you have mentioned as No. 2, does it?

A. I believe it does.

XQ. 135. And the reason that you had to run the audion quite a time to get results consistent with the previous day's results, was because there was gas in the audion No. 2, was it?

A. Not that I believe.

XQ. 136. Well, then, what was the reason?

A. I think I have stated in my direct examination that it was the temperature effect due to probably expansion of some of the parts inside the tube.

XQ. 137. What parts?

A. The grid wires of this tube were very small in diameter, and were wound over a glass rectangle or rectangle made of a glass rod. The filament was relatively heavy, requiring about 2½ amperes, as I remember it, for heating; so that there was considerable heat energy dissipated from the filament. I believe that this heat energy warped the grid slightly so that the plate current or other characteristics changed during the first few moments of operation.

XQ. 138. Warped the grid wires, you mean?

A. I think that was the most likely explanation, yes.

XQ. 139. This time it was as much as five minutes, was it?

A. At this date, I cannot say, any more than remember it as a few minutes.

XQ. 140. I think it says five minutes on one of the small papers. I guess it was a card that has been offered in evidence as part of the records for audion No. 2; is not that true?

A. That is very possible.

XQ. 141. The date for the entry that I just read to you is Monday, March 17th, to Wednesday, March 19th, is it?

A. Yes, it signifies that that fact was noticed on tests conducted between those two dates.

XQ. 142. On page 232 of this same notebook under date of Monday, November 17th, to Saturday, November 22d, you wrote:

> "The perfectness of the vacuum in an audion can be told by the noises in the phone. Absolute quiet denotes a nearly perfect vacuum, slight frying some gas present, loud frying more gases, shrieking change of pitch with Eg and sharp clicking, poor vacuum, nearly at blue glow stage."

That is quoted correctly, is it?

A. Yes.

XQ. 143. And I do not remember that I gave the year for that.

A. 1913.

XQ. 144. And the statement is correct, is it?

A. I believe that the statement is correct provided there is no capacity resistance or inductance in the circuit which would otherwise account for the noises.

XQ. 145. Just explain a little more what you mean by that last statement.

A. There are a number of different circuit combinations in which a vacuum tube is employed that may cause variations in plate current, that will cause noise in a telephone receiver, through which the plate current passes. Inductance in the grid or plate circuit may cause oscillations; also combinations of resistance or capacity may cause noises. Under certain conditions noise is a good criteria of vacuum.

XQ. 146. And those other circuit conditions that may give noise give a sustained pure tone, do they?

A. Not necessarily. Particularly if there is any resistance and capacity in parts of the circuit you can get a charging up and discharging effect which may produce a series of clicks, a rattle or a rather strident musical note.

XQ. 147. When you were testing audion No. 2 within the dates Monday, March 17th to Wednesday, March 19th, which comprised the paragraph I have read, when I began the examination, you were not using one of those particular circuits that you mentioned, were you?

A. I believe in that particular paragraph I was taking data on characteristic curves. There is nothing in the notebook to indicate this, but that is my recollection.

XQ. 148. And you were not using one of those oscillatory circuits?

A. Not when that particular reference to five and ten per cent. variation in plate current is recorded, no.

XQ. 149. On page 35 of your notebook within the dates March 17th to March 19, 1913, I understand you wrote:

> "When filament is at about one ampere a low pitch sort of rattling is heard, as filament temperature is raised this raises in pitch until at about 1.3 amperes it is a sort of squeal."

Was that due to gas under the statement that you made on page 232 which I have just quoted to you?

A. I note the statement on page 35 at which the noise is referred to is preceded by sketch showing a circuit arrangement in which audion No. 2 was employed when this accoustic effect was heard. That circuit contains an inductance in the grid connection and a telephone receiver in the plate connection. With present-day knowledge it is very probable that this would set up oscillations.

XQ. 150. And those oscillations would depend in pitch on the magnitude of the filament current, would they?

A. It is difficult to state. They might.

XQ. 151. And they might also be due to gas, might they?

A. My reason for not believing that they were due to gas is because of the many uses to which I put this tube both before and after this test in which gas would have been indicated clearly. I believe that the circuit shown there, in view of present knowledge might easily cause oscillation.

XQ. 152. Will you please point this out?

Mr. Davis: I have no objection to it being marked but I suggest that it be marked in a way that clearly distinguishes it.

Mr. Richmond: I just asked Mr. Davis whether he had any objection to indicating points on the sketch with letters.

Mr. Davis: Perhaps the witness might use this red pencil.

Mr. Richmond: We will understand that his penciling is done only on the sketch of page 35 in this connection.

A. The sketch of this connection is preceded by a statement which reads as follows: "Tried to use No. 2 as a wireless receiver using a buzzer for sender. Could get no results." The sketch indicates that some form of antenna and coupling coil were used in an attempt to pick up the oscillations from the buzzer.

This sketch shows an inductance L in the grid circuit and a telephone receiver T in the plate circuit. This is the telephone in which the noises were heard. It is very possible that these two inductances in connection with the capacity between the grid and plate might set up oscillations and it is very possible that some of these noises were introduced into this system by the antenna which was a short length of wire in the room.

XQ. 153. I notice on page 252 of your notebook under the date December 22d to December 29, 1913, the paragraph reading as follows:

> "For patent reasons it is also desired to have a series of curves showing in every way possible the difference in action between the audion and the pliotron, the case of the detector pliotron will be taken up separately."

Will you please tell me just how those terms, audion and pliotron, are used there and explain what the paragraph means?

A. The audion referred to in that paragraph is the DeForest audion. That is the type of audion manufactured by DeForest at that time and sold and used under that name. By "pliotron" is meant devices of the type that I had been exhausting and testing under Dr. Langmuir's direction. You had better read the question again.

XQ. 154. I think perhaps I ought to apologize for asking you two questions in one. I want you to explain what the paragraph means?

A. As I remember, the Patent Department was investigating the pliotron, as we called our vacuum tube, and were anxious to get complete information on it and how it differed from the prior art. The last reference, speaking of the detector pliotron, referred to a special tube I had been working upon, which employed mercury amalgam, so that it operated as a detector on a little different principle than the high vacuum tube.

XQ. 155. That is the detector pliotron depended on gas, did it?

A. To the best of my knowledge it depended upon a very low pressure of mercury vapor, but it operated with a plate voltage between 150 and 250.

XQ. 156. When was it that the Patent Department began this investigation that you have mentioned?

A. I do not know.

XQ. 157. I understand that the General Electric UV-200 tube has gas in it, and depends on gas in its action, and that the General Electric UV-201 tube is a high vacuum tube that operates independently of gas; is that correct?

Mr. Davis: I am wondering what part of the direct examination relates to these tubes?

Mr. Richmond: The witness' testimony in the Interference record.

The Court: That has been my understanding, so far as I recall, that the cross-examination of any witness whether produced in the Interference case or not, is here restricted to the examination in chief here given.

Mr. Richmond: Very well. That distinction had not occurred to me.

The Court: I think that has been followed, so far as I know.

Mr. Richmond: That is all.

Mr. Davis: No re-direct.

(Witness excused.)

WILLIAM D. COOLIDGE.

William D. Coolidge, was called as a witness in rebuttal on behalf of the plaintiffs, and having been duly sworn, testified as follows:

Direct Examination.

By Mr. Davis:

Q. 1. You are Assistant Director of the General Electric Company Research Laboratory in Schenectady?

A. Yes, sir.

Q. 2. Since when?

A. Since the spring of 1908, as I remember it.

Q. 3. Nineteen hundred what?

A. 1908, as I remember it.

Q. 4. And how long have you been in the laboratory?

A. Since the fall of 1905.

Q. 5. Now, it has appeared in other testimony which you have given in this Court—and I do not want to take the time to go into it, that you did some work in connection with wrought tungsten; that is true, is it?

A. That is true.

Q. 6. When that work was well along, so that you had wrought tungsten available, what did you do with it; first, it was an incandescent lamp, was [illegible] not?

A. Yes, first as a filament of an incandescent lamp.

Q. 7. Now, I suppose nothing is ever through, but when you were well along with that, what did you next do with this wrought tungsten?

A. We used it as the target of an X-ray tube, and also as a material for contacts.

Q. 8. And by "target," you mean anode?

A. Yes.

Q. 9. What targets were then being used in X-ray tubes?

A. Targets for the most part, targets with platinum faces.

Q. 10. And made of what material?

A. Platinum. That is, usually copper with a facing of platinum, which might have been attached in many cases, and was in many cases attached first to a little disc of nickel, and then this nickel was in some way braised or soldered to a block of copper.

Q. 11. Was aluminum ever used?

A. Not so far as I know, Mr. Davis.

Q. 12. In the tube at all?

A. Yes, as a cathode, and as an auxiliary anode.

Q. 13. Well, what was the usual material of the cathode?

A. Aluminum.

Q. 14. And was there any means provided for heating the cathode?

A. No.

Q. 15. That is, we are dealing now with the old-fashioned X-ray tube?

A. Yes, sir.

Q. 16. Now, it has been already testified in this case, and we need not repeat it, that the tube operated by ionization, and also that as the tube operated, it tended to drive the gas in the walls and clean-up. You are familiar with that operation?

A. Yes, sir.

Q. 17. What was done when that happened?

A. Such tubes were usually provided with regulators, that is, the regulator consisted of a source of gas, which liberated either by the application of heat, usually by the application of heat.

Q. 18. And could that be continued indefinitely?

A. The gas could, of course be continuously admitted to the tube to raise the pressure, but the performance of the tube was not good after a certain time. It became, according to the language of the art, "cranky." This term meant that the tube was no longer stable; that is, the operator in using the tube had arranged the apparatus and the plate perhaps, if this was to be a radiograph, and expected when he closed a switch, to get, let us say, 30 milliamperes, for let us say one second at a certain voltage; but as a matter of fact, perhaps he got 30 milliamperes for one-hundredth of a second, and then no more current would pass through the tube. Under such conditions, the tube was spoken of as being a cranky tube.

Q. 19. Now, you spoke of using tungsten in the X-ray work. Did you mention the word "target"—yes, you did?

A. Yes.

Q. 20. Have you here among the exhibits, anything which will illustrate the target which you were speaking of?

A. Yes, the target in this tube here (indicating).

Q. 21. Just a moment, Doctor. Let me get the exhibit number—Plaintiff's Exhibit No. 48.

A. Is similar to the tungsten target which we developed and sold for use in the gas-filled X-ray tube to replace the targets which had been used prior to this time with a platinum face.

Q. 22. Now, when you say the target here, you are speaking of this copper mass, which is the most conspicuous mass inside the tube, are you?

A. Yes, sir, containing a little tungsten button.

Q. 23. And that button on the face of the target is tungsten?

A. Yes, and that receives the cathode ray bombardment, that little part there.

By The Court:

Q. 24. Yes, that is the target, the anti-cathode or anode?

A. Yes.

Q. 25. What I was about to ask, Mr. Davis, and really want to find out, is whether, in the old Crookes tube, the cathode was heated at all as it is in the Coolidge tube?

By Mr. Davis:

Q. 26. Will you answer that, Doctor?

A. The early Crookes tube had two electrodes, both of aluminum, a flat circular plate, as I recall it, as a cathode, and then either a little wire or ring, as I remember it, serving as an anode, the anode in that case being placed at one side of the tube axis. The cathode rays then coming from the cathode in the early Crookes tube went the length of the tube, and there collided with the glass wall of the tube, causing this beautiful green fluorescence, and of course there producing X-rays, although that was not known until later that X-rays were produced where the cathode rays collided with the glass wall of the tube, or with any other body that Crookes may have placed inside the tube in the path of the cathode rays.

Q. 27. That is, a cathode ray striking anything is apt to produce an X-ray, is that it, Doctor?

A. It does produce X-rays.

Q. 28. I do not think you have answered his Honor's question.

The Court: As I understand, in the Coolidge X-ray tube, the cathode is a wire as it is in the radio bulb?

Mr. Davis: Yes, sir.

The Court: Which is heated in order to cause the electrons to boil off, so to speak; but as I understood in the old Crookes tubes, that is, I have gathered from the evidence here, that a cathode was a solid mass of metal in the old Crookes tube, and was not a wire or filament that could be heated, and that the heat in the inside was the result of the bombardment and operative to that extent on a different principle from this tube.

By Mr. Davis:

Q. 29. That statement is corrected, is it not?

A. That is correct, your Honor. The mechanism of the emission of the electrons from the cathode was an entirely different mechanism. There was gas in the tube, the gas was ionized, and then under the influence of the electric field, positive ions were driven against the cathode, and there caused the electron emission.

The Court: In short, maybe I can express it this way—the old Crookes tube did not use the Edison effect, or start with the Edison effect?

The Witness: Did not use it.

The Court: And your tube does?

The Witness: Yes, sir.

Q. 30. It is a very accurate statement, is it not, Doctor, that there was no Edison effect in the old tube?

A. No, sir; there was no Edison effect in the old tube.

Q. 31. But the old tube is what was sometimes called a "self-sustaining discharge," was it not?

A. Yes, sir.

Q. 32. Which means a discharge sustained by the ionization in the tube?

A. That is correct.

Mr. Davis: Or perhaps more properly put, the conditions necessary to the discharge.

The Court: Yes, I think I have that now.

Q. 33. Now, did you or did you not, put this tungsten target embedded in copper on the market?

A. Yes, that was put on the market.

Q. 34. About what time?

A. As I recall, that was late in 1911.

Q. 35. Do you remember—and I think you have also testified to that in this Court—something about ordering an X-ray set?

A. Yes, sir. In connection with the development of this copper-backed tungsten target, it became necessary for us to do some experimental work on the X-ray tube. That is, for us to abuse the target as much as we could, so as to find, by experiment, a design of target which would stand the most punishment, and I did go to Philadelphia to order a so-called ten-milowatt snook machine for this purpose.

Q. 36. Doctor, you have not said something because it is so obvious to you. What is the strain, what is the abuse put upon a target? What does it have to stand?

A. The cathode ray stream in the X-ray tube is all concentrated in this case on the little tungsten button in the target. If I may go back one step, all of the electrical energy delivered, may I change that, because that would not apply to the tubes in which these tungsten targets were first used?

Q. 37. You are speaking now of the old X-ray tube?

A. Yes.

Q. 38. With your tungsten ~~target, if~~ you please?

A. Yes. And in those tubes a very large fraction of the electrical energy delivered to the tube terminals was put into kinetic energy of the moving electrons in the cathode ray stream and as these rapidly moving electrons collided with the target, two things happened; something like 99.9 per cent. of the energy of the rapidly moving particles was changed into heat delivered to the target and the other perhaps one-tenth of 1 per cent. went into the production of X-rays.

Q. 39. What is the difference between that and what we have spoken of in this case as heating the anode by bombardment?

A. In this case we are heating the anode, in the case that you speak of, we are heating the anode by cathode ray bombardment. We are not doing it in a very high vacuum. As I have already said——

Q. 40. Just for the moment I am trying to show or to bring out—we have talked in this case a great deal about electron bombardment of anodes and it has been testified that that heated the anode. Just thinking of that bombardment, is that any different from what you are talking about; in character, I mean?

A. No, sir.

Q. 41. There is, however, one difference that I would like to bring out and that is, will you discuss what you call the focal spot in the anode?

A. The focal spot is the area on the target on which the cathode rays are all made to impinge.

Q. 42. Why is it necessary that there should be a limited spot like that?

A. If the tube is intended for medical diagnostic use the size of that spot becomes very important because the X-rays are in that case to be used to produce a shadow picture and the sharpness of the shadows will be determined by the size of the focal spot and of course by the geometry of the thing.

Q. 43. Let us stop there and be sure we have made that clear.

The Court: Is that spot then like the shutter of the camera?

Mr. Davis: It is more like the source of light. You are very careful to have the source of light in a projector, a moving picture projector or automobile headlight, you are careful to have a small source of light because if you had a large source of light your beam would not be a straight beam but a ragged beam.

Q. 44. From the X-ray point of view, Doctor, could you compare this focal spot with the source of light?

A. Yes.

Q. 45. The X-rays come from all over this spot?

A. Yes.

Q. 46. You think of a shadow of an object coming from light coming from a point and you can draw a line from that point to the object and you would get a perfectly clear shadow, but if you had two points and drew lines from those two points through the object to the table under the object, then you got two different shadows differently located?

> The Court: If I understand it, I know very little more about cameras than I do about X-rays, but as I understand it, the more you close a shutter through which the light passes, the sharper a photograph you get on your plate, and I am wondering whether the smaller the area upon the anode in an X-ray tube upon which the cathode rays impinge, the better shadow graph you get as the result of the use of your X-ray tube.

Q. 47. Is that right, Doctor?

A. Yes. There is this objection to the case of the diaphragm in the camera, perhaps an objection to the comparison in that one of the functions of the diaphragm in the camera is to limit the portion of the lens which is used. The lens is not well corrected if you use a very large aperture. It is much more like the case which Mr. Davis mentions of the projection lantern where you use as a source of light for projecting a picture on the screen as small a source as you can get, as nearly a point source as possible. With the arc lamp that was very easy. You could use the tiny hot spot on the carbon. With the incandescent lamp, special lamps have been developed with that point in mind of getting the light from just as small an area as possible, so that there will be as little penumbra around the shadow as possible.

Q. 48. When you speak of abusing a target, you mean heating it by the cathode stream?

A. Yes. It is possible in the X-ray tube where you have by the construction of the tube limited the size of the focal spot to something definite, it is then possible to pass a great deal of energy through that tube if you will. So much so if you like that you will melt and vaporize any material that you put there at the surface of the target. There is such a concentration of energy.

In the case of the X-ray tube built for medical diagnostic work, you make that focal spot small enough so that under the conditions in which the doctor uses the tube the shadow of the bones, let us say, or other objects in the body shall be sufficiently sharp for the purpose, but on the other hand you must not make the focal spot too small, because if you do it will then not be possible to use sufficient energy so as to get sufficient X-ray intensity to make the picture in a reasonable time, in a time during which the patient or moving organs inside of the body can remain stationary.

I might add just one word to that. You use a tungsten target or a copper block containing a button of tungsten because of the high melting point of tungsten and the low vapor pressure which will then let you with a given amount of energy make that focal spot just as small as possible. That is, you will always use at that point, the element having as high a melting point and as low a vapor pressure as you can get hold of and you are also interested in the heat conductivity of that material, as the higher the conductivity of that material the faster heat can flow away from that spot.

Q. 49. And about when did you receive this X-ray outfit? I do not care for the exact date.

A. I think it was late in 1911, either late in 1911 or early in 1912.

Q. 50. When it came did you put it into use?

A. Yes.

Q. 51. Testing the targets which you made and so forth?

A. Yes.

Q. 52. What is this book?

A. That is my notebook, beginning with August 25, 1911, and extending to and through December 20, 1912.

Q. 53. And this was one of the regular laboratory notebooks kept by you in the course of your employment?

A. Yes, sir.

Q. 54. And the statements therein contained were correct to the best of your knowledge and belief at the time you made them?

A. Yes, sir.

> THE COURT: Before you go into that, may I ask one question to make sure that I am right? Is cathode ray bombardment synonymous with electron bombardment?

Q. 55. Is that right?

A. Yes, cathode rays are rapidly moving streams of electrons.

Q. 56. I think that that expression cathode ray bombardment is a rather old expression and we now speak of it as electrons.

A. Yes. We now say that, as far as we know, electrons are all alike no matter what their source is. At present we use the term cathode rays for high speed electrons in a tube, or coming from a tube, and beta rays for exactly the same thing, when the rays come from radio active matter.

MR. DAVIS: I offer the notebook in evidence.

(Received in evidence and marked "Plaintiff's Exhibit No. 174." *See Volume IV, Plaintiff's Exhibits, page 121.*)

Q. 57. I ask you to look at pages 171 and 172. What is the date of the entry beginning four or five lines down on page 171?

A. May 8, 1912.

Q. 58. Without taking the trouble to read that entry, will you explain it and tell what happened as recorded there on those two pages?

A. I say in this entry that I have received tube No. 594,036, from Wiggin. Mr. Wiggin was of the firm of McAllister & Wiggin in Boston. They were X-ray tube manufacturers and I had sent to Mr. Wiggin a tungsten anode, that is, an all tungsten anode and a dished, concave, tungsten disc to be used as a cathode.

I had had trouble prior to this with the melting of aluminum cathodes when I had operated tubes with a great deal of current and so had been anxious to try tungsten cathodes. This was my first opportunity to do it. This tube had been built for me by Wiggin in Boston. He reported to me——

By Mr. Davis:

Q. 59. You had a tube there which had two electrodes, both tungsten?

A. Yes, sir.

Q. 60. And they were both cupped, or not?

A. I think not, Mr. Davis.

Q. 61. Never mind, Doctor. It is not important, perhaps. The records show there that the tube was very cranky; is that right?

A. Yes.

Q. 62. Why was that tube cranky compared to an ordinary tube?

A. Because the tungsten cathode contained so little gas.

Q. 63. Is that the nature of wrought tungsten?

A. Yes, I would say so, because of the method of preparation used.

Q. 64. But you finally got that tube going?

A. By an artifice, yes, sir.

Q. 65. The artifice consisting of introducing gas from this gas-producing arrangement?

A. Yes, sir. Repeatedly introducing gas and operating the tube with high voltage.

Q. 66. And you finally got it going very well?

A. Yes.

Q. 67. And how did it run, that is, what were the circumstances or method of operation?

A. The cathode became strongly heated and then the tube ran very steadily.

Q. 68. What heated the cathode?

A. Positive ion bombardment.

Q. 69. On pages 173, 174 and 175 appear notes and suggestions of Dr. Coolidge to use a hot cathode in an X-ray tube.

The Court: What date is this?

Mr. Davis: May, 1912. I am not trying to prove any earlier date than we pleaded. I want to show the facts. As has been suggested, this perhaps may be immaterial and I will just call attention to these pages that mention this suggestion.

The Court: Does that mean to heat the cathode by external heat?

By Mr. Davis:

Q. 70. The cathode was heated how in this experiment?

A. Only by positive ion bombardment.

Q. 71. Was this a practical tube?

A. I should say not. It certainly was not a very convenient tube to handle as it was quite an art to get it started.

Q. 72. I notice the suggestion at the bottom of page 175 to have a tungsten cathode wound on a sort of spool made of what?

A. I think made of fused alumina or fused silica.

Q. 73. Would that as you now know have been possible?

A. It would certainly not have been an operative tube. That is, it would not have been a pure electron discharge tube.

Q. 74. At the end of all this it says, somewhere near the end it says: "I will do this tomorrow." Did you do it tomorrow?

A. No, sir.

Q. 75. Now, I call your attention to page 266 and ask you if you will describe that experiment. First, what is the day on which this experiment was made?

A. This experiment was made on September 24, 1912.

Q. 76. What was the experiment?

A. In this tube we had a tungsten cathode and a heavy tungsten anode, that is, both cathode and anode were tungsten. The tube——

Q. 77. Was there or was there not any means of heating the cathode externally?

A. No.

Q. 78. And it was a gas tube, was it?

A. It was a gas tube.

Q. 79. And you ran that tube with those two electrodes both of tungsten?

A. Yes.

Q. 80. Now, will you read the paragraph beginning "One effect"?

A. "One effect shows up clearly. Starting with a vacuum of say 20 microns the tube runs O. K. The electrodes both heat up strongly and there is a white hot focus spot on both cathode and anode."

Q. 81. Why was there a white hot focus spot on the cathode?

A. The cathode was heated by positive ion bombardment and there was a strong focusing action of the positive ions causing their bombardment to take place over a very limited area on the cathode.

Q. 82. Will you continue, please, reading that extract?

A. "The pump was running all the time but it was arranged so that by means of mercury the connection between the tube and the pump could be broken."

Q. 83. So now if the pump is turned on it means that you connect the tube with the pump and start the pump?

A. That is it. "Now, if the pump is turned on and the current kept on so as not to let the electrodes cool off"—by the current I mean the high voltage current passing through the X-ray tube—"the resistance of the tube quickly rises to a point where no more current will pass."

Q. 84. Just say in your own words what happened. You had this old-fashioned X-ray tube running with the cathode hot and the anode hot, each heated by bombardment from the other. You were running the tube along and what happened?

A. Suddenly it stopped carrying current.

Q. 85. Now, please read the rest of the paragraph.

A. "This shows pretty clearly that having a white hot spot at the active part of the cathode, does not even with the potential necessary for an eight-inch spark gap free electrons enough out of the cathode to hold down the resistance."

Q. 86. What does it mean, the potential of an eight-inch spark gap?

A. The potential was in this case being measured in what was then a customary manner for doing it in X-ray work by means of a spark gap, connected in parallel with the tube. That is, this spark gap consisted of a pair of pointed metal electrodes, the distance between which was easily regulatable from a distance, and the method of using the device was to simply, while the tube was running, bring these points closer and closer together until finally the high tension discharge took the path between the terminals of the spark gap rather than going through the tube.

Q. 87. Was that high or low voltage in those days for X-ray?

A. That was nearly as high voltage as was used on X-ray tubes at that time.

Q. 88. What did you conclude from this experiment?

A. It made it look to me as though we did not get electrons from hot tungsten in a good vacuum.

Q. 89. Is that your view today?

A. No, sir.

Q. 90. Then you must have deceived yourself in some way in this experiment. Will you please explain your present view and why you were deceived?

A. I think that as the vacuum improved after establishing the connection between the tube and the pump, the positive ion bombardment sank to such a low value that the temperature of the cathode very rapidly fell to a point where no more electron emission from the cathode took place.

(After a short recess.)

Q. 91. So as the vacuum got higher in the operation of this tube, what happened to the temperature of the cathode?

A. The temperature of the cathode sank very rapidly.

Q. 92. In layman's language, the cathode cooled off?

A. That is right.

Q. 93. Why did you not see it cool off?

A. I probably did see it cool off, but not until the high tension discharge had stopped; that is, that cooling off would have been such a very rapid process; that is, you must bear in mind that the very hot spot in the centre of the cathode where the positive ions were focused was a very tiny area and that the balance of the cathode, the surrounding metal, was probably only at red heat so that it would take a very small fraction of a second, a very small fraction indeed, when the positive ion bombardment ceased, for the temperature of that central very hot spot to sink to essentially that of the surrounding metal.

Q. 94. Was it a thing that you could conveniently and safely observe anyway?

A. Not as conveniently as one would observe in an incandescent lamp, because of the need of protecting oneself from the X-rays.

Q. 95. How cool would that hot spot on the cathode have to be, looking at it from the present knowledge, not what you knew then, to make it stop giving out electrons sufficient to maintain that tube in action?

A. It would still be very hot; let us say a little below 2000 degrees Centigrade.

Q. 96. You are talking Centigrade?

A. Yes.

Q. 97. We speak of the expression white hot. What do you call white hot in Centigrade?

A. That is a matter of definition. I would call melted iron white hot, at 1600 degrees more or less, depending on its purity.

Q. 98. Centigrade?

A. Yes.

Q. 99. Did you understand what was going on at the time this experiment was made?

A. No, sir.

Q. 100. What was the next thing that you did or the next discussion that you had in connection with an X-ray tube having hot cathodes?

A. That was a talk which I had with Langmuir, at which interview Dr. Langmuir told me about his pure electron discharge work.

Q. 101. What did he tell you in substance?

A. That he had found that——

Mr. Haight: May we have the date fixed for that?

Mr. Davis: I will fix the date. Do you want it fixed at this moment?

Q. 102. Doctor, if you will look at your notebook, page 325, it may be that gives the date?

A. December 10, 1912, I find an entry therein concerning this interview with Dr. Langmuir.

Q. 103. Now, what did Dr. Langmuir tell you at that interview?

A. That when these filaments had been carefully freed from gas in a high vacuum, he had found it possible to maintain a discharge, a pure electron discharge, from a hot filament, that the electron emission had instead of decreasing with the removal of gas from the tungsten filament, which was to be used as a cathode, had increased up to a certain point, and from there on it remained steady, and that this was a thoroughly reproducible condition.

Q. 104. You spoke about filaments. Were there more than one filament?

A. Two filaments.

Q. 105. What were they?

A. Of tungsten.

Q. 106. And how were they used respectively?

A. One was heated by the passage of current through it, and then the negative end of a circuit of a couple of hundred volts, as I remember it, was connected to the hot filament, and the cold filament was connected to the positive end of the circuit.

Q. 107. And you said that Dr. Langmuir spoke of having removed gas from these filaments or some such expression; did he tell you how he did it?

A. Yes, sir.

Q. 108. What was it?

A. By heating these filaments very hot in a very good vacuum.

Q. 109. Were you or not familiar with any work which Dr. Langmuir had been doing up to that time in connection with high vacuum?

A. Yes.

Q. 110. To what extent were you familiar with it.

A. I was very familiar with it.

Q. 111. What was the character of that work?

A. It was of a very high quality——

Mr. Haight: I object to the characterization of the witness in that way, and I would like to have your Honor admonish Dr. Coolidge that he must speak of his own knowledge.

Mr. Davis: I am asking of his own knowledge.

The Court: Yes.

Mr. Davis: I want to be quite sure that the last few answers were what Dr. Langmuir told him.

The Court: Yes, but it is this answer that Judge Haight is speaking about, and I think that answer should so far be stricken out and the question repeated, because I think Dr. Coolidge did not have in mind the limitations of his answer when he began.

(Discussion.)

By Mr. Davis:

Q. 112-13. What was the quality of the equipment which Dr. Langmuir had in his laboratory, so far as it had to do with vacuum work at that time?

Mr. Haight: I object to that. He can tell what the equipment was, but not characterize the quality.

The Court: I think that objection is good.

(Discussion.)

By Mr. Davis:

Q. 114. What did you do next, Dr. Coolidge, after this talk with Dr. Langmuir?

The Court: Do not understand, Mr. Davis, that you cannot have this witness tell all the facts that you want about the equipment.

Mr. Davis: If your Honor please, I think that Dr. Langmuir has described the equipment.

Mr. Haight: I will save time by saying that we do not question the fact that the equipment that Dr. Langmuir says he had, was there, nor so far as I know, is there any intention on the part of the defendant to question the fact that that equipment was adequate for the purposes for which Dr. Langmuir says he used it.

Mr. Davis: That is not exactly what I want.

Mr. Haight: Tell me what you want, and maybe I can give you that. Perhaps you had better let Mr. Richardson go into that.

Mr. Davis: I think I will pass the question, if your Honor please.

By Mr. Davis:

Q. 115. Dr. Coolidge, will you tell us what you did next in connection with those X-ray tubes, after this talk with Dr. Langmuir?

A. Dr. Langmuir suggested to me in the talk that I try such a pure electron discharge in an X-ray tube, and we immediately got busy and tried it out.

Q. 116. What was the type of anode with which you began your experiments?

A. It consisted of a circular disc of tungsten, perhaps an inch and a quarter or so in diameter, supported by means of a tungsten stem, and the disc was perhaps, as I remember it, perhaps 20 or 30 mils (twenty or thirty thousandths of an inch) thick.

Q. 117. I show you a copy of the patent drawing on page 2432 of the Interference record, being the drawing of the Coolidge patent, No. 1,203,495; is the anode shown in Figure 1 of that patent anything like what you are now describing?

A. Yes, Mr. Davis, except that in the first tubes the tungsten disc was mounted at right angles to the supporting stem, instead of being inclined at an angle of 45 degrees, as shown in that drawing.

Q. 118. What were the limitations of this anode?

A. I am not sure that I understand your question, Mr. Davis, but if you refer to the amount of energy which could be dissipated in such an anode, I will say that because of its thinness, it proved to be easy to melt holes which went right through it where the focal spot was, as small as it was, in some of these experiments.

Q. 119. Did that impose or not, any limitation on the output of the tube?

A. It did.

Q. 120. Would the tube with such anode otherwise be useful for any purpose?

A. Yes. After the tube had been developed to a certain stage, that is, where the design was right, and where the vacuum was sufficiently good and the electrodes sufficiently freed from gas, so that the tube was stable, it could have been used very nicely for medical diagnostic work or even for medical superficial therapy.

Q. 121. How long did it take you to do all these things, Doctor?

A. The work, I should say, was very encouraging after we had been—the tube I should say was very encouraging after we had been working on it for perhaps two months.

Q. 122. Now, how much effort and energy was put on the tube work during those two months?

A. A great deal. I had an assistant, Mr. Leonard Dempter, who worked with me, and during that time we were both putting in nearly all of our time into that work.

Q. 123. Now, why did not you use that large copper-backed tungsten target which you have shown us, and which you were then selling?

A. Because I did not know how to get the gas out of the copper.

Q. 124. Would it or not have made a tube having more utilities?

A. Yes.

Q. 125. Did you or did you not ultimately find out how to get your gas out of that copper?

A. Yes.

Q. 126. And then put out tubes with the copper anode, such as this tube, Plaintiff's Exhibit No. 48?

A. Yes, we did.

Q. 127. You also developed a special anode later of tungsten, did you?

A. Not later, Mr. Davis, than the development of this radiator type of tube, but later, than the experimental work on these first hot cathode X-ray tubes, with the thin targets.

Q. 128. I show you Plaintiff's Exhibit No. 42; that large mass of tungsten in the middle is what you are talking about, Doctor, is it?

A. Yes.

Q. 129. What is that?

A. That is a mass of wrought tungsten attached to a stem of wrought molybdenum.

THE COURT: Why is the face that face?

Q. 130. Why is the face cut off at an angle, Doctor?

A. It is convenient for the Doctor using the tube to have his patient placed in many cases horizontally with the photographic film underneath, and then the tube placed over it in this position.

Q. 131. That is horizontal?

A. Horizontal.

Q. 132. With the——

A. With the focal spot looking down.

Q. 133. And that will throw the X-rays down, will it?

A. The X-rays come from the focal spot in all directions, but it is better not to take them off at too nearly glancing incidence, because of interference from the roughness at the focal spot. For that reason, the 45 degree angle has come into common use.

Q. 134. And when you came to sell the tubes commercially, Doctor, the first tube sold commercially, had which anode?

A. They had a massive tungsten anode like the one in this tube.

Q. 135. Which is Plaintiff's Exhibit No. 42. What is this book I hand you?

A. That is my laboratory notebook covering the period from December 23, 1912, to August 25, 1914.

MR. DAVIS: Now, if your Honor please, I am going to suggest that I offer in evidence such pages of this notebook as can be agreed upon, that is, all pages which are relevant to this inquiry, up to the day on which Dr. Coolidge filed his application for the patent on the X-ray tube, and those extracts be given an exhibit number, and I fancy there will be no trouble going over the book with defendant's counsel.

Mr. Haight: I understand that that is vouched for by Dr. Coolidge?

Mr. Davis: It is another book. This is the second book. I offered the first one.

The Court: This one has now to be shown—the last question was directed to this book, was it not?

Mr. Davis: Yes.

Q. 136. I have not asked him whether the entries are correct, and now do so?

A. Yes, Mr. Davis, to the best of my knowledge and belief.

Mr. Davis: I offer in evidence the selected pages of this book to be supplied.

Mr. Darby: Do I understand that you offer this book up to the filing date of the Langmuir patent or Coolidge patent?

Mr. Davis: Coolidge.

Mr. Darby: I should think, but I do not know——

Mr. Davis: I am perfectly willing that my brother should inspect it up to the filing date of Langmuir, if he wants to.

Mr. Darby: I think I would like to.

The Court: All right. The pages to be supplied will now be given a number.

(Received in evidence and marked "Plaintiff's Exhibit No. 175." *See Volume IV, Plaintiff's Exhibits, page 128.*)

Q. 137. Will you tell me the date of the work recorded on page 59 of this last notebook?

A. February 17, 1913.

Q. 138. What was the character of that work, was it still working on that tube on the hot cathode X-ray tube?

A. Yes.

Q. 139. Now, will you read the paragraphs beginning from the very first?

A. "Work with tube 112"?

Q. 140. No. I mean the paragraph beginning with the words, "From the very first."

A. (Reading):

> "From the very first turning on of the current, this tube has focussed sharply. As a result, it has been easy to heat the target so as to get the gas out of it. The tube was therefore in excellent condition after perhaps one hour's work on it, after it had come out of the oven."

Q. 141. Go on.

A. (Reading):

> "The electrodes were fresh ones, so this experiment demonstrated conclusively that the target has been the troublesome source of gas, and the lack of focussing, when running as an ordinary tube, that is, before getting the ordinary vacuum, has been what has made the tube exhaust so tedious and precarious."

Q. 142. In a very few words, Doctor, what was the nature of the difficulties that you had been experiencing up to that time?

A. We had cracked and punctured tubes, due to local heating of the glass, which had come from faulty design, and from our operating the tube while the vacuum was too bad. That is, not waiting long enough for the pumps.

Q. 143. When you say "faulty design," do you mean it was a design which you regarded as faulty before?

A. No, sir. Which we had found bad in the course of these experiments or which we found bad in the course of these experiments.

Q. 144. Did you have any trouble getting the gas out of the electrodes?

A. We had a great deal of trouble; if the tube was operated while the vacuum was too poor, the glass which supported the cathode structure was bombarded and liberated gas. This, of course, increased the gas pressure in the tube, and hence the positive ion bombardment, and we had a more or less run-away effect, and in the first place——

Q. 145. I am not sure that is clear. I would like to be very sure that is clear. Your cathode bombardment heated what?

A. The glass tube supporting the cathode structure: that is, the positive ions are directed by the electric force towards the cathode end of the tube, and with the early designs which we used, these positive ions would bombard the glass support to the cathode.

Q. 146. That is, during the exhaust, Doctor, you are talking about, now?

A. During the exhaust, and by their bombardment would liberate from that glass more gas, and that meant more ionization. Therefore, more positive ion bombardment, and therefore more gas, so that our exhaust time was erroneously increased by that difficulty, and by our failure at the time to fully understand the source of the difficulty. Besides this, we had troubles from the——

Q. 147. Just a minute there, Doctor. There are some records in this book of puncturing the glass. Will you explain that in this connection?

A. Yes. The same positive ion bombardment to which I have alluded, did cause local heating of the glass envelop behind and in the neighborhood of the cathode, and that local heating gave rise to cracks and so-called punctures.

Q. 148. That is actually melting a hole through the glass, is it?

A. The hole is usually melted through after the crack has taken place. The electrical discharge then goes through as the air rushes in, and by its heat, causes a melting of the glass.

Q. 149. Will you go on and continue what you were saying when I interrupted you?

A. We had this trouble frequently, that the high tension discharge instead of confining itself to the tube—and bear in mind, please, that the tube was in these early experiments connected to the pump system—the electrical discharge instead of confining itself to the tube, would often go down this connecting tube towards the pump and puncture the glass connecting tube.

Q. 150. What pump did you use in the beginning of your work?

A. The rotary oil pump, such as used in the incandescent lamp exhaust.

Q. 151. And between that pump and the tube, what did you have?

A. A liquid air trap.

Q. 152. And was that pump of sufficiently high capacity to suit you?

A. It did not give a sufficiently high vacuum.

Q. 153. What did you do?

A. I acquired a Toepler pump.

Q. 154. Does that give the high vacuum?

A. It gave the high vacuum.

Q. 155. Was its capacity sufficient?

A. It is a very slow-acting pump. As I used it, it was operated by hand, and it also made the exhaust operation much more lengthy and tedious than it would otherwise have been.

Q. 156. Speaking of the length of these exhaust operations, were you talking of minutes or hours?

A. No. Usually days.

Q. 157. A matter of several days, was it?

A. Yes.

Q. 158. In this early work?

A. It might be several days.

Q. 159. What if any further pump did you acquire for this work?

A. At one time I acquired the Gaede mercury pump, that is, a rotary pump, and still later a Gaede molecular pump.

Q. 160. Now, Doctor, will you speak a little of the experience which you had of the action of the ions on the filamentary cathode during this work?

A. Yes, sir. From the beginning, we were considerably troubled by that. The vacuum not being good enough at the time—positive ions would bombard the cathode, and would thereby raise its temperature, and in that way increase the electron emission, and this would result in great instability of the tube. We experienced this difficulty in the very beginning, and felt that it was vital to study it, so that we used not only an ammeter to measure the current for heating cathode filaments, but also used a voltmeter connected in parallel with the cathode filament.

Q. 161. Now, just a moment. That gives you the resistance?

A. Yes.

Q. 162. And therefore the temperature of the filament?

A. Yes.

Q. 163. Doctor, did you have this difficulty only with the oil pump?

A. No, we had this difficulty for a long time, even after we had acquired the Toepler pump.

Q. 164. Did you find that there was any particular technique of exhaust as to the rate at which you could go forward and the rate at which you could put current on and so forth?

A. Yes. We found in the course of time that the thing to do was to go very slowly, increasing the amount of energy supplied to the tube, giving more time for the pumps to take the gas.

Q. 165. Now, when was it when you first put your tube into actual use outside of the laboratory? I do not care for the exact date, but was it during that year?

A. Very late in 1912.

Q. 166. 1913, was it not, Doctor?

A. Excuse me, it was very late in 1913. I think in December of 1913.

Q. 167. And from then on the exploitation was rapid or not?

A. I would call it pretty rapid, yes.

Q. 168. That is all I care for there. Do you remember filing a patent application for your tube?

A. Yes.

Q. 169. That is the Patent 1,203,495, which is in the Interference record and the history of the file wrapper and contents, is Defendant's Exhibit 67 the application as filed contained twenty-six claims. Some of the claims have to do with the focusing shield. In a word, what is a focusing shield?

A. It is the piece of metal used to so shape the electric field about the cathode as to cause the cathode rays to converge on a small area on the target.

Mr. Haight: The cathode in this Exhibit 42 is the larger piece of metal.

The Witness: No, this one here.

Mr. Haight: The disc.

The Witness: It consists of a little tungsten spiral placed within the molybdenum cylinder to the back of which a circular molybdenum disc is attached.

Mr. Haight: Now, where is the shield?

The Witness: That disc functions somewhat as a shield to protect the glass support to the cathode during the early stages of the exhaust.

Mr. Howson: You mean the focusing shield?

Mr. Haight: Yes.

The Witness: The member which has most to do with the focusing is the little cylinder of molybdenum in which the tungsten spiral is placed.

Mr. Davis: Let me refer to Exhibit 45 in which the focusing shield is removed and the spiral is exposed.

Mr. Haight: I see. Thank you.

By **Mr. Davis:**

Q. 170. The focusing shield, or at least an early form of focusing shield is shown in Figure 2 of the patent to which I have just been referring, is it?

A. That is correct.

Q. 171. And also 11 in Figure 1?

A. That is correct.

Mr. Davis: There, if your Honor please, is the gun barrel type at 11 in Figure 1. Other claims are specifically restricted to an X-ray tube, I want to call the witness's attention to two claims which are not so restricted.

By **Mr. Davis:**

Q. 172. I read you claim 3 of the application as filed:

"An electrical vacuum discharge tube, comprising an envelope and cooperating electrodes therein, at least part of one of which is adapted to be maintained at incandescence, the vacuum

> within said envelope being so high that the cathode is not sensibly heated by discharge current through the tube."

It does not appear on its face to be limited to an X-ray tube. Did you or not at the time you signed the application believe that this claim was broad enough to cover the tubes which Dr. Langmuir had disclosed to you in December, 1912?

A. No, sir. If I had I certainly would not have signed the application until that claim had been taken off.

Q. 173. Can you state what there was about that claim which led you to think that it referred to your work rather than to that of Dr. Langmuir?

A. I think that it must have been reference to the heating of the cathode. As I had already explained, I had a great deal of trouble from the heating of the cathode, in the experimental tubes, by positive ion bombardment. That positive ion bombardment was focused upon the little tungsten spiral and so constituted a source of instability if it existed.

Q. 174. Claim 9 of the application as filed read:

> "The combination of an envelope, cooperating electrodes therein, said envelope being evacuated to such degree that the mean free path between the residual gas molecules is greater than the distance between the electrodes, a source of energy connected to said electrodes, and means for heating at least part of the negative electrode to incandescence."

At the time that you executed this application, did you or did you not believe that this claim was broad enough to cover anything which Dr. Langmuir had disclosed to you in December?

A. I certainly could not have believed that it was broad enough to cover it, otherwise I would not have executed the application.

Q. 175. I hand you the claim and will you please explain what it was as far as you know that it led you to the belief that it referred to your work and not that of Dr. Langmuir?

A. I believe that it must have been this fact that in the——

Mr. Haight: May I suggest that possibly this kind of conjecture is in the same category that your Honor rather depricated while we were examining Dr. Arnold as to the reasons why he answered so and so or something or another of that effect, in the former proceeding.

Mr. Davis: I offer the statement that he may cross-examine him as much as he pleases.

Mr. Haight: I do not think I can really object. I suppose the witness may conjecture but I do not think it is of any weight.

(Discussion.)

The Court: That is different. If the testimony is predicated on knowledge or refreshed memory, all right, but not predicated on reason. I am not sure technically that even that would be admissible, but at the same time in the absence of objection it may be given.

By **Mr. Davis**:

Q. 176. Will you then answer the question?

A. I think it must have been due to the fact that I knew——

The Court: I am afraid, Dr. Coolidge, that that comes right within a line of reasoning rather than a line of memory and consequently is not evidence, unless there is no objection to that. Did you say there is no objection to that, Mr. Haight?

Mr. Davis: May I try again?

The Court: Yes.

By Mr. Davis:

Q. 177. I do not want your reason why you now think anything, but if you can state any scientific fact which was known to you at the time which we may now infer of our own free will, as a matter of our inference, might have caused this blunder on your part, if it is a blunder, I would like that fact as a scientific fact?

A. It was a scientific fact known to me at that time, that in a vacuum tube, containing a certain amount of gas, the resistance of the tube to the passage of current between the electrodes was enormously increased in the dark space surrounding the cathode was made to extend out so as to embrace the anode. That is in terms of the language of that time. In other words, if the vacuum became so good that the mean free path was greater than the distance between the electrodes——

Q. 178. May I interrupt you. I wonder if we need a definition of that expression, mean free path.

The Court: I think you do.

A. The distance that a gas particle would have to go before it collided with another gas molecule.

Q. 179. Go back to the Crookes or Geissler tube. You start it and you see light in the tube?

A. Yes.

Q. 180. What is the dark space?

A. At a certain vacuum, a rather poor vacuum, you will observe in such a tube luminosity between the electrodes extending up to a narrow zone surrounding the cathode.

Q. 181. And in that narrow zone you have no luminosity?

A. Yes.

Q. 182. And that is the dark space?

A. Yes. As the vacuum of that tube is improved that dark space is seen to grow more and more extensive and as it does so the resistance of the tube to the flow of current increases. It increases very greatly when the dark space extends out to the point where it embraces the anode as well as the cathode and it would then be useful in a hot cathode tube to have the resistance of the tube to gaseous discharge as high as possible so as not to mask the pure electron discharge which one wishes to use with such a tube.

Q. 183. I hand you what I understand to be a copy of Defendant's Exhibit 31, being an article by Dr. Lilienfeld and Dr. Rosenthal or a paper of 1912, with a paper by Dr. Rosenthal, both being together as one exhibit.

The Court: I wonder if I may get some help before he goes into that answer. Is there any difference between an X-ray tube and a Fleming valve other than the potential on the plate or on the anode. I was wondering just where the field of the X-ray tube blends with the radio tube and a subordinate question is whether a radio tube is not an X-ray tube to the extent of the energy employed in the tube. I was wondering where they melt one into the other and whether you can help me on that.

Mr. Davis: I am always wondering myself when I am standing around these high-powered kenotrons.

The Court: It is only as it bears on this case and you can tell me or have the witness tell me.

Mr. Davis: The old-fashioned X-ray tube was not like the Fleming valve because it was a cold cathode. The Coolidge X-ray tube is not the same as the Fleming valve, because it has a high vacuum. The structure is the same, you have a hot cathode and a cold anode.

The Court: A highly evacuated Fleming valve.

Mr. Davis: Yes, sir. The difference between a highly evacuated Fleming valve—take the kenotron. It is the modern three-electrode tube without the third electrode. We are running into questions of terminology, but my understanding is that if the voltage is high enough to get up a velocity in the electron to cause it to emit X-rays when it strikes the anode, that that is an X-ray tube whether you call it so or not.

By Mr. Davis:

Q. 184. Is that right?

A. That is right.

Q. 185. If you ran a kenotrone at 100,000 volts, you would want to protect people around it against the X-rays that would come from it?

A. There is this thing to be said, Mr. Davis, that when the hot filament of the kenetron is functioning as cathode, you have a voltage drop of only perhaps a few hundred volts between cathode and anode, so that the electrons then from the main discharge in the kenotron have a velocity corresponding only to a couple of hundred volts. On the next half cycle, assuming that the kenotron is operating on alternating current, it is the cold electrode which is functioning as cathode and there are no electrons coming from it and therefore when the voltage is high across the tube there are no electrons flowing across the space.

Q. 186. But if you should run a kenotron in such a way as to consume 100,000 volts in a kenotron——

A. Then it becomes an X-ray tube. To complete my answer to your Honor's question, you do get X-rays when these two or three hundred volt electrons strike the cold plate or anode, but they are of such low penetrating power that they cannot get through the glass walls of the tube.

Q. 187. That is, in one case you are using Doctor —in the kenotron you are using it in series with the load and you are consuming the voltage in the load?

A. Yes.

Q. 188. And in the X-ray tube you consume the voltage where?

A. In the X-ray tube itself. The less voltage that you consume in the kenotron the more efficient the device becomes.

Q. 189. But the kenotron must hold back the whole voltage?

A. Yes, on the one-half wave, and let it pass through freely on the other half wave.

Q. 190. Referring to this Lilienfeld-Rosenthal article, are you familiar with the disclosures of those two articles taken as one?

A. I am.

Q. 191. If the tube therein disclosed were at any time in a condition of exhaust such that if a discharge flowed in it it would be a pure electron discharge, would that tube operate as an X-ray tube?

A. No, Mr. Davis, it could not.

Q. 192. Why could it not?

A. It could not because there would be no positive ions to bombard the main cathode and to there liberate electrons for the main discharge.

Q. 193. The main cathode being cold in that tube, is that right?

A. Yes.

Q. 194. How many ions does it take bombarding the cathode of that tube to create a given discharge or current or to make it possible, as compared with the number of ions to do the same thing in an ordinary old-fashioned X-ray?

A. It would take just as many.

Q. 195. Would this tube disclosed in this article operate at a vacuum somewhat higher than that of an ordinary old-fashioned X-ray tube or not?

A. I should say that it would.

Q. 196. And as you continued to increase the vacuum, what would happen?

A. The number of available positive ions would decrease and the positive ion bombardment of the main cathode would decrease and the current then, the main discharge current flowing through the tube, would decrease.

Q. 197. In that tube as shown and described there is a certain auxiliary anode which is described as an aluminum sheath. Do you remember that description?

A. Yes.

Q. 198. What is the structure there described and illustrated, the structure and arrangement of the auxiliary anode?

A. Shall I read, Mr. Davis?

Q. 199. Tell us what it is, if you remember.

A. It consists of a tube of aluminum as I remember it, which is at one end in very close proximity to the glass.

Q. 200. What do you say as an expert as to the possibility of cleaning up that anode shield so as to have it reasonably free of gas?

A. I would not know how to do it.

Mr. Davis: That is all of the direct.

The Court: I understand that you want to defer the cross-examination of Dr. Coolidge, or will you begin that this afternoon?

Mr. Darby: I understand we are prepared to start the cross-examination, but we would like to have an opportunity to go through the notebooks. We will make every effort to complete his cross-examination today.

Mr. Haight: I think Mr. Richmond can conduct the cross-examination of Mr. White right after lunch and that will give us a little more time with the notebooks.

(Recess was taken until 2.15 P. M.)

William D. Coolidge, resumes the stand.

Cross-Examination.

By Mr. Darby:

XQ. 201. The X-ray tube, Dr. Coolidge, is an electron discharge device, is it not? That is, suppose I confine it to the so-called Coolidge X-ray tube; that is an electron discharge device, is it not?

A. I would say so, yes.

XQ. 202. And in those X-ray tubes of yours, did you always employ pure tungsten electrodes as distinguished from filaments containing beneficial additions?

A. For the cathode, I think so.

XQ. 203. You still do today?

A. Yes.

XQ. 204. And when did the so-called Coolidge X-ray tubes first come on the market, commercially, if you know?

A. As I remember it, the first tube to leave the laboratory went out late in 1913. I do not remember, Mr. Darby, when the first tubes were put on the market.

XQ. 205. Well, was that tube that left the laboratory, did it leave for experimental purposes, or leave for actual use?

A. Left for actual use.

XQ. 206. And that was the latter part of 1913?

A. As I remember it, very late in 1913.

XQ. 207. Around November and December?

A. As I remember it, late in December.

XQ. 208. Late in December?

A. Yes.

XQ. 209. As I understand your testimony, Dr. Langmuir disclosed to you in December, 1912, the results of work that he had been carrying on in connection with electron emission; is that correct?

A. That is correct.

XQ. 210. And that was the first disclosure he made to you of the results of work he had been carrying on up to that time?

A. The question seems a little bit vague to me, because you see——

XQ. 211. Let me make it more definite. I find on page 325 of your notebook:

> "Dr. Langmuir tells me that in his study of Edison effect, the current in the case of a hot cathode is greater with a very fine vacuum of one or two-hundredths of a micron than it is at higher gas pressures (excepting the case of argon). This Edison current becomes measurable at about 1600 degrees C., and gets to a maximum value at about 2300 degrees C."

You there recorded what Dr. Langmuir had told you; that is correct, is it not?

A. That is correct.

XQ. 212. And you then state thereafter, or immediately following:

> "I will try this out at once in an X-ray tube in which I can heat the cathode to any desired temperature."

That idea of trying it out in an X-ray tube was your own original idea, was it not?

A. Dr. Langmuir suggested to me that I try this type of device in an X-ray tube on this date, December 10th.

XQ. 213. Dr. Langmuir suggested to you to try it out on an X-ray tube?

A. Yes.

XQ. 214. The notebook does not so state, does it?

A. No, sir.

XQ. 215. That is your independent recollection of the conversation had that day, is that correct?

A. May I have the question once more. (XQ. 215 repeated as recorded.) I am just a little bit confused as to whether you mean the note here or what I have already testified to.

XQ. 216. I mean that it is your independent recollection of the conversation had that day in the absence of any statement to that effect in the notebook, that Dr. Langmuir told you to try this out in an X-ray tube?

A. That he suggested to me to try it out in an X-ray tube—yes, sir.

XQ. 217. And then the note in your notebook continues:

> "The above would be in line with my observations on pages 171 to 175."

That is correct?

A. That is correct.

XQ. 218. And the entries on pages 171 to 175 relate to work that was done on May 8, 1912; is that correct?

A. May I just have those pages once more?

XQ. 219. Pages 171 to 175, the same ones that you mentioned?

A. The entries relate in part to work actually carried out on that date, and in part to experiments which I think of trying.

XQ. 220. But the entire entry was made on May 8, 1912?

A. Certainly.

XQ. 221. And on page 173 in this entry the following appears:

> "I believe that the above points the way to the ideal X-ray tube. It looks to me now as though, with the tungsten cathode, the degree of vacuum would play an entirely subordinate role,

provided, of course, it is high enough, and that there will no longer be any such thing as a too high vacuum. The tube resistance will apparently be determined by the temperature of the cathode."

That is a correct reading of the entry in your notebook?

A. Yes, that is.

XQ. 222. And it is to that matter that you referred, in part, at least, in your entry under date of December 10, 1912, where you stated:

> "The above would be in line with my observation of pages 171 to 175."

A. That is correct.

XQ. 223. That portion of the entry that I have just read to you that appears on page 175, is not that exactly the same thing, or is not that the same thing that Dr. Langmuir told you, or at least that you testified Dr. Langmuir told you on December 10, 1912?

A. I should say no.

XQ. 224. Why?

A. On December 10th, as I remember it, 1912, Dr. Langmuir told me of definite experiments that he had tried, and how he had succeeded in producing a reproducible pure electron discharge, and told me how he had done it, and suggested that I try such a pure electron discharge in an X-ray tube.

XQ. 225. And you had suggested exactly the same thing on May 8, 1912; is ~~not that~~ correct?

A. In a way, yes. But after that, I had tried the experiment to which I referred this morning, which was very discouraging indeed, and which made me feel at that time that one would not get from pure tungsten heated to a high temperature in a good vacuum an electron discharge.

XQ. 226. You are referring to the experiment where the current stopped while the cathode was still hot?

A. Yes.

XQ. 227. You knew that the cathode was maintained at a high temperature by ion bombardment, did you not?

A. Yes, but I did not understand it as well then as I do now.

XQ. 228. You knew that if the ions became scarcer, the heating would become less, did you not?

A. Yes, unless there was some other cause of heating.

XQ. 229. And you also knew that the ions would become less as the vacuum got better?

A. Yes.

MR. DAVIS: I do not like to interrupt the cross-examination, but if my brother's purpose is to prove that Dr. Coolidge would have reasoned so and so, if he would have been more intelligent than he was at the time, I think it would be immaterial.

THE COURT: I do not understand Mr. Darby's questions to be to that effect. I understand them to be somewhat different, and for that reason I am not sustaining the objection.

XQ. 230. You were running your pump at the time that observation was made by you, were you not?

A. Yes, Mr. Darby.

XQ. 231. Did it or did it not occur to you that the reason that the electron current ceased, was because there was no longer enough ions to keep the cathode hot?

A. Apparently not. If it had, I would not have been so much discouraged.

XQ. 232. It did not occur to you at that time?

A. Apparently not.

XQ. 233. And as I understand it it was because of the fact that it did not occur to you at that time that you were so much impressed by the result of the current stopping; is that correct?

A. I think that is correct.

XQ. 234. If you can tell me, do so, but I do not want any guess on it, just what reason for this effect did you think of at the time, that is, of the current suddenly stopping?

A. I cannot tell you at this minute just what my state of mind was at the time, except that I drew this discouraging conclusion that I did not get electrons from hot tungsten in a good vacuum.

XQ. 235. Did this convince you that electrons would not come out of the tungsten at dazzling white heat in a good vacuum?

A. That was the conclusion that I drew at the time, yes.

XQ. 236. And was this the first evidence that you had ever obtained yourself that indicated this?

A. I should say so, yes.

XQ. 237. And up to this time you thought electrons might come out of hot tungsten in a high vacuum?

A. Yes.

XQ. 238. But this experiment convinced you that your former opinion was wrong, as I understand it?

A. That is correct.

XQ. 239. And of course you know now that your conclusions were erroneous?

A. That is correct.

XQ. 240. When did you become convinced that your conclusions were erroneous?

A. I should say on December 10th when Dr. Langmuir told me of his experiments in detail. I believed his story, every word of it.

XQ. 241. You now know, do you not, that if you happened to have your cathode heated from an outside source to very high temperature, you know that the tube would have kept on operating as the vacuum got better and would have kept on operating at just the time that you found the discharge actually stopped?

A. That is correct.

XQ. 242. I understand that there would have been still enough gas to produce some ions under such a condition and that this hitting such a hypothetical hot cathode might have caused it to have a short life unless the filaments were quite large, but without considering that phase——

A. Excuse me, Mr. Darby, you confuse me a little bit by talking about filaments. I thought you were talking about this plate of tungsten that was used in that early tube.

XQ. 243. Did you not employ also a filament in that early tube?

A. No, sir.

XQ. 244. It was the plate of tungsten that you heated to incandescence?

A. Yes, sir.

XQ. 245. That is right. If at the time of that experiment you had had a filament in place of the hot tungsten plate, it is my understanding that there would have been still enough gas to produce some ions and that this hitting such a hypothetical filament maintained hot might have caused it to have a short life unless the filament was quite large, but I say without considering that phase of the matter, I want you to tell me whether or not in such a hypothetical tube the action would have been harmfully influenced by the small positive ionization that would have been present?

A. I do not think, Mr. Darby, that at that time the amount of ionization present would have been small. I had at that time a very massive tungsten target.

XQ. 246. Then, as I understand it, it is your belief that the amount of ionization present would have been harmful, is that it?

THE COURT: Won't you read that question again.

(XQ. 245 was repeated by the stenographer.)

A. (Continued.) I think, Mr. Darby, that the amount of positive ionization would have been very great because——

XQ. 247. Would it have been harmful?

A. Yes, Mr. Darby, harmful, if I may finish, harmful in this way, certainly, that the tube would have been very unstable indeed, that is, the filament would certainly have been heated by that positive ion bombardment in the vacuum which I would have had at that time in that tube and that would have made the tube very unstable as an X-ray tube.

XQ. 248. Now, in connection with your direct examination on the claims that were in your application as they were originally filed, have you any independent recollection today of the interpretation that you gave to those claims at the time you executed this application?

A. None whatever, Mr. Darby.

XQ. 249. Will you just very briefly tell me the difference in principles of operation of the so-called Coolidge X-ray tube and the old X-ray tube?

A. In the old X-ray tube the electrons were liberated from the cathode by positive ion bombardment. To get these positive ions it was then necessary to have an appreciable amount of gas in the tube. The presence of this gas and of these positive ions brought with them certain complicating circumstances——

MR. DARBY: Pardon me if I interrupt one minute. I find that we are getting more or less into repetition and unless there is any question in your Honor's mind as to the difference between them I think I can shorten the examination.

The Court: I think counsel or witnesses have made that reasonably clear to me before so that if you want to——

Mr. Darby: I can shorten it materially.

The Court: If you want to state it and ask if Dr. Coolidge agrees with you, very well. That may shorten it a lot.

XQ. 250. See if you will agree with me on this, that the difference in operation of the new Coolidge X-ray tubes is that it operates on the pure electron flow theory, whereas the old X-ray tubes operated on gas ionization theory, is that generally stated correct?

A. In a broad way, yes.

XQ. 251. And the operating characteristics, can you give me just a broad statement of the difference in operating characteristics in the same way?

A. I will not be able to make it quite as brief, but I will do the best I can. In the gas tube, the old X-ray tube, there were certain influences tending to increase the gas pressure in the tube as the tube was operated. There were some other influences at work which tended to diminish the gas pressure as the tube was operated. As a result of these various influences to which I have alluded, the tube was in general unstable. By adapting oneself to the condition of the particular tube at the time, he could get along with it, meaning by that that he could get a certain current to pass through it at a certain voltage for a certain length of time.

He had to adapt himself, however, as I have said to the state of the tube at the time. With the hot cathode high vacuum tube, such as we have here, the situation is entirely different. It becomes possible with this tube to get within limits any desired current at any desired voltage, and again within limits for any desired time. In other words, flexibility of the device is very much greater.

XQ. 252. Maybe I can expedite this answer, too, by stating I notice in your patent No. 1,203,495, that you outline eight characteristics of the gassy tubes. Before you begin the description of the new Coolidge X-ray tube—and may I sum it up in this broad statement, that the difference in the operating characteristics between the new tube and the old type X-ray tubes inherently flow from the utilization of the pure electron flow principle; is that correct?

A. I think that is correct, Mr. Darby.

XQ. 253. Now, as a matter of fact, as I understand your testimony, Dr. Langmuir pointed out to you this difference in principle between the new tube and the old tube; is that correct?

A. I do not remember Dr. Langmuir's telling me about the old tube, no.

XQ. 254. He pointed out to you the advantages to be obtained by using the new tube, the pure electron flow theory, did he not?

A. I do not think so, Mr. Darby.

XQ. 255. You do not?

A. Except in so far as he pointed out to me that by the pure electron discharge method, one could have reproducibility, perfect reproducibility of results. That is, up to that time we had had one method of getting the electrons out of the cathode, only one method, which was useful in X-ray work. Here was a new and very much better method revealed for the first time for getting electrons out of the cathode.

XQ. 256. Do you intend that last statement of yours as a modification of your answer to my question, or as an explanation of it, or is it just volunteered?

A. I should say it was in explanation.

XQ. 257. You do not intend it as a modification of your answer?

A. No, sir.

XQ. 258. Very well. Now, your patent recites after outlining all of these disadvantages, eight in number, the old X-ray tube:

> "In order to overcome these troubles met with in the X-ray tubes of the prior art, I remove the cause of the trouble, namely, the gas in the tube, and produce the electrons from the cathode necessary to the production of the X-rays, not by a bombardment of the cathode by positive ions due to ionization of the gas by the voltage impressed upon the tube, but by heating the cathode to incandescence by energy from a suitable source."

Dr. Langmuir told you that, did he not?

A. Yes. He suggested to me that I use a pure electron discharge in the X-ray tube as a source.

XQ. 259. Then your patent goes on:

> "In tubes made according to my invention I eliminate the action of positive ions as far as it is possible to do so by evacuating the tube to the highest vacuum which can possibly be attained and by thoroughly freeing the electrodes from gas."

Now, Dr. Langmuir told that to you; that was his idea, not yours?

A. He did not tell me how to make an X-ray tube embodying the pure electron discharge.

XQ. 260. Did he tell you to eliminate the action of positive ions as far as it was possible to do so by evacuating the tube to the highest vacuum which could possibly be obtained, and by thoroughly freeing the electrodes from gas; did he tell you that?

A. I do not remember whether he told me that or not.

XQ. 261. You knew?

A. I knew from my own knowledge.

XQ. 262. Do you deny that he did?

A. No. But I knew of my own knowledge about the harmful effect of positive ions in X-ray tubes of the prior art, but I think it unlikely that he told me that.

Mr. Darby: Read the previous question. (Previous part of the record repeated as recorded.)

XQ. 263. He did not tell you how to do it, but he told you to do it; is that correct?

A. He suggested that I do it, that is correct.

XQ. 264. And in doing it, he told you to eliminate the action of the positive ions, did he not?

A. Well, I do not remember his saying that to me, Mr. Darby.

XQ. 265. Did he tell you to "evacuate the tube to the highest vacuum which could possibly be obtained"?

A. I do not think so, Mr. Darby. I think Dr. Langmuir told me about his own experiments.

XQ. 266. That answers my question, Doctor. Did he tell you to thoroughly free the electrodes from gas?

A. I do not think so, Mr. Darby.

XQ. 267. Now, he told you that he had done all those things, did he not?

A. Not——

XQ. 268. In an electron discharge device?

A. But not in an X-ray tube.

Mr. Davis: The X-ray Coolidge patent is not in suit, and again I dislike in the slightest degree to interrupt cross-examination that has a value, but if it is directed to the validity of the Coolidge patent, I object. That is to save time. The patent is already in the record.

Mr. Darby: I am not trying the Coolidge patent here.

THE COURT: I think this cross-examination is within the field of reason, Mr. Davis.

By MR. DARBY:

XQ. 269. You say you told me just a minute ago, Dr. Coolidge, that an X-ray tube is an electron discharge device; that is correct, is it not?

A. That is correct.

XQ. 270. Then your patent states:

> "as a cathode I ordinarily use a tungsten filament."

Dr. Langmuir told you to use a tungsten filament, did he not?

A. It is only the form of that question that troubles me at all, Mr. Darby; I do not know that Dr. Langmuir said to "Coolidge, use a tungsten filament in this X-ray tube," but he did tell me about his experiments in which he had used tungsten filaments.

XQ. 271. Did Dr. Langmuir suggest to you that you use a tungsten filament?

A. I do not remember, Mr. Darby.

XQ. 272. Do you deny that he did?

A. No, sir.

XQ. 273. You do remember that the idea of using a tungsten filament was not your original idea, don't you?

A. You have called attention already to one case in which I did have the idea of using a tungsten filament as a source of electrons in an X-ray tube.

XQ. 274. I see. Then that was your original idea that you carried right with you up to this day of December 10, 1912; I understood from that you had abandoned the idea?

A. I did abandon the idea.

THE COURT: I did not get that.

(Answer repeated by the stenographer as follows:

"A. I did abandon the idea.")

XQ. 275. And the ultimate result of the present tube employing a tungsten filament was Dr. Langmuir's suggestion to you of December 10, 1912?

A. It was the result of Dr. Langmuir's communications to me of December 10th.

XQ. 276. And that communication explicitly contained a suggestion to use a tungsten filament, did it not?

A. I think so.

XQ. 277. All right. Then your patent states:

> "I have found that electrons will be emitted from such a cathode."

Tungsten filament cathode——

> "which electrons will traverse the space between the cathode and the target under the influence of the electromotive force impressed upon the tube, and by bombardment of the target, will give rise to X-rays."

That was part of what Dr. Langmuir suggested to you, was it not?

A. Well, Dr. Langmuir certainly did not——

XQ. 278. Can you answer that?

Mr. Davis: Let him answer it.

XQ. 279. Will you answer the question, please, and explain it later?

A. Well, I guess the answer is yes and no. If I may explain, I should say that the experiment which Dr. Langmuir described to me, the work which he told me about, was a small tube with two metal filaments, tungsten filaments in it. It certainly was not an X-ray tube, and I did not feel then, and do not feel now that Dr. Langmuir told me how to make an X-ray tube. He suggested to me that I make an X-ray tube employing the pure electron discharge. I had a great deal to learn, Mr. Darby, in doing that work. I have told you about that point.

XQ. 280. You have said several times, Doctor, and I am confining my entire cross-examination to expressed suggestions to you on express things. Now, I understand fundamentally that you say that Dr. Langmuir suggested that you construct an X-ray tube, having a hot filament of tungsten, employing pure electron flow; is that correct?

A. That is correct.

XQ. 281. Dr. Langmuir suggested that to you?

A. That is correct.

XQ. 282. And I also am assuming in my questions, that Dr. Langmuir knew what an X-ray tube was, or that he would not?

A. I am sure he did.

XQ. 283. That he would have to have another electrode to which the electrons would have to travel?

A. Certainly.

XQ. 284. Then we are not at disagreement?

A. No, sir.

XQ. 285. Now, my question is, did Dr. Langmuir suggest to you any such arrangement that

> "electrons will be emitted from such a cathode, which electrons will traverse the space between the cathode and the target under the influence of the electromotive force impressed upon the tube, and by bombardment of the target, will give rise to X-rays."

A. I do not think so, Mr. Darby.

XQ. 286. You do not think he suggested that to you at all?

A. I think that Dr. Langmuir was sure that I knew that.

XQ. 287. I see. Was he sure that you knew that electrons would be emitted from the tungsten cathode?

A. I do not know, Mr. Darby, just how sure he was of the effect of his communication to me, but he might very safely have assumed that, because I had the greatest faith in what Dr. Langmuir told me about his work.

XQ. 288. The next statement of the patent is:

> "In this new type of tube positive ions appear to play no role whatsoever."

Dr. Langmuir told you that, did he not, that in a tube constructed in accordance with his suggestions, that positive ions would play no part whatever in the operation of the tube?

A. I do not say that, Mr. Darby.

XQ. 289. You do not think so?

A. I do not believe Dr. Langmuir could have known what the effect would be of using, let us say, one-hundred thousand volts on that tube.

XQ. 290. You do not think he told you that?

A. I do not think so.

XQ. 291. Then the next statement in your patent is:

> "Gas pressure in the tube being thus eliminated to the highest possible degree, those features of instability in the tubes of the prior art which it can now be seen were due to the presence of the gas in the tube are likewise eliminated."

Did not Dr. Langmuir tell you that with a pure electron-flow in the X-ray tube, that the "features of instability of the tubes of the prior art would be eliminated"?

A. I do not remember, Mr. Darby.

XQ. 292. Do you deny that he did?

A. No, sir.

XQ. 293. Then you state:

> "In the preparation of the tube the glass is first freed from moisture and gas by heating and other approved methods and the electrodes preferably are freed from gas as by heating them to a high temperature in a vacuum."

Dr. Langmuir told you that in connection with the work that he had been doing, did he not?

A. He told me that he had used such methods in his exhaust work.

XQ. 294. Then the patent continues:

> "Exhaustion of the tube is preferably carried on by means of a pump which will remove vapors as well as gases."

And he did tell you that in connection with his prior work, did he not?

A. I do not think that Dr. Langmuir had had such a pump at that time.

XQ. 295. He told you that in his exhaust that he removed vapors, as well as gases, did he not?

A. Yes, sir.

XQ. 296. And he suggested that is what you should do in obtaining gas from the X-ray tube?

A. The form of those questions is very troublesome to me, Mr. Darby, because the answer always seems to be the same, that Dr. Langmuir told me about his own experiments, and then suggested that I try the pure electron discharge in an X-ray tube. I do not think he went into details as to how that X-ray tube could be made embodying that pure electron discharge.

XQ. 297. He went into details of telling how to get a pure electron discharge, that is, with regard to the degree of evacuation and how to get the evacuation?

A. He told me how it was obtained.

XQ. 298. That is exactly what I mean.

A. There is quite a difference, because in one case we are dealing with little tungsten filaments and in another case we are dealing with large tungsten masses which Dr. Langmuir did not have to deal with and which I had to learn how to deal with.

XQ. 299. In other words, Dr. Langmuir told you how he had freed what he was handling of gas and water vapor in order to get the high vacuum?

A. Yes, sir.

XQ. 300. And he suggested to you to obtain a high vacuum in an X-ray tube to produce a new X-ray tube operating on a new principle, on pure electron flow?

A. That is right.

XQ. 301. His principle of pure electron flow?

A. That is right.

XQ. 302. The next statement of your patent is:

> "The electrodes should be made of refractory metal such as tungsten so that they will withstand the very high temperatures attainable by operating the tube while connected to the pump, whereby gas may be effectively driven out."

Dr. Langmuir had told you that you had to drive the gas out of the tungsten filament, did he not, in your X-ray tube?

A. He told me that he had driven the gas out of tungsten filament.

XQ. 303. He suggested to you that you should do the same thing, did he not?

A. I do not know how to take that question. He suggested that I use pure electron discharge in an X-ray tube.

XQ. 304. Did he specifically suggest to you that you use tungsten filament from which you should or somebody else should expel all of the gas?

A. I do not think so, Mr. Darby.

XQ. 305. Did he suggest to you the use of tungsten filament—did he not?

A. I think so.

XQ. 306. So as I understand your last answer, he did not suggest to you that the tungsten filament had to be gas freed?

A. Certainly by implication.

XQ. 307. But not in so many words?

A. Insofar as I can remember.

XQ. 308. Then it was only by implication that you stated what Dr. Langmuir told you in answer to Q. 103 in your direct examination in the following language, and in answer to the question: "What did Dr. Langmuir tell you at that interview?

A. That when filaments had been carefully freed from gas in a high vacuum he had found it possible to maintain a discharge" and so forth. You did not intend that answer to imply that Dr. Langmuir had suggested to you to use that in X-ray work, did you?

A. I am getting a little bit confused by your language, Mr. Darby, but it seems to me that I stated over and over again what did take place, and Dr. Langmuir told me about his experiments and told me how he got tungsten filaments free from gas and operated them in a very high vacuum and got pure electron discharge which was reproducible and suggested that I use such a discharge in an X-ray tube.

Mr. Darby: I move to strike out the answer as not responsive.

Mr. Davis: May I have the last question read.

(The stenographer repeated the last question.)

Mr. Davis: I have not this part of the record, and I do not know how my brother got it, but the question is "What did Dr. Langmuir tell you at that interview? A. That when these filaments had been carefully freed from gas he had found it possible,'' and so on, nothing about his telling Dr. Coolidge to do anything, exactly what the witness has been saying right along. He is saying exactly what he said before in almost the same language. I move to strike out the question.

Mr. Haight: May we have the question read.

(The question was repeated by the stenographer.)

Mr. Haight: We think it is argument and we consent to striking it out.

The Court: In the absence of agreement I shall grant both motions. The answer and the question both go out.

Mr. Darby: That is entirely agreeable to me.

By Mr. Darby:

XQ. 309. Now, your patent states: ''My novel apparatus, therefore, has the following valuable and striking characteristics. First, the resistance of the tube, and, hence the penetrating power of the Roentgen rays produced in the tube, may be controlled with certainty, and may be instantly increased or decreased at will, by raising or lowering of the temperature of the cathode.'' Did Dr. Langmuir suggest to you or tell you that that would inevitably follow from employing his pure electron discharge?

A. I do not remember, Mr. Darby, but I doubt it.

XQ. 310. Then the second point follows: ''Second, a much more homogeneous bundle of X-rays can be produced even though a several-fold increase, or decrease of gas pressure takes place in the tube, providing the pressure remains within the limits above indicated.'' Had Dr. Langmuir told you that the operation would be independent of the degree of vacuum below a certain minimum value?

A. To this extent, Mr. Darby, he had told me that in his own experience the electron emission was independent of the vacuum beyond a certain point of evacuation.

XQ. 311. Then am I to understand that he did not tell you specifically that the X-ray tube that you would construct would not depend upon the degree of vacuum?

A. I think that is correct, Mr. Darby.

XQ. 312. And then the patent continues: "Third, as the discharge can pass through the tube only when the heated electrode is made the cathode, the tube may be operated on alternating current almost equally as well as on direct current."

Did Dr. Langmuir tell you that in the X-ray tube that you would construct that that would be the case?

A. I doubt very much his having hazarded such a statement as that. Dr. Langmuir's work as I have told you was done with relatively low voltages, a couple of hundred volts as I remember it——

Mr. Darby: I move to strike it out.

The Court: Beginning with "Dr. Langmuir's work as I have told you," goes out.

XQ. 313. The next is "Fourth, if desired, a tube may be proportioned to give over a predetermined range of impressed voltage X-rays of substantially uniform penetration."

Now, did Dr. Langmuir tell you that in the X-ray tube which would result from his suggestion if followed by you that the voltage would be determined by the voltage delivered by the transformer that you used to obtain the potential for the anode?

A. I doubt his having made that specific statement.

The Court: I interrupt now only because Mr. Davis made a former objection. So far as you have been cross-examining as to the disclosure made by Dr. Langmuir to Dr. Coolidge in December of 1912——

Mr. Darby: And I still am.

The Court: —for the purposes of this case, of course,——

Mr. Darby: Yes, sir.

The Court: But with the last question I begin to wonder whether you were not going beyond that field.

Mr. Darby: No, sir. I am sticking strictly to the testimony already in the case.

The Court: My difficulty is this: I can see how that question would be very pertinent to the patent for the X-ray tube, but I miss its relation to the case at bar, and I raise the question simply because Mr. Davis had earlier objected and I thought it was a continuing objection.

Mr. Darby: The validity or invalidity of the Coolidge patent is something that I am not the least bit concerned with.

The Court: Of course, it has nothing to do with this case, but I thought the last question was possibly near if not over the border line in pertinence to the Langmuir disclosure.

Mr. Davis: Perhaps Mr. Darby will be willing to state what the connection is.

Mr. Darby: I would not like to do so to the witness.

The Court: I am not going to ask you to do that.

Mr. Darby: I will be glad to show your Honor.

The Court: You may proceed. I wanted you to understand that my prior ruling was based on the fact that I thought the objection was not valid then, but I was beginning to think that the point would be arrived at where it might be valid.

By **Mr. Darby:**

XQ. 314. The patent then says:

"One of the main causes for the uniformity of the penetrability of the X-rays is to be ascribed

> to the fact that the operation of the tube is not dependent upon positive ion bombardment of the cathode."

I think you stated once before that Dr. Langmuir told you that in an X-ray tube constructed embodying what he disclosed to you, that the operation would not be dependent upon positive ion bombardment; that is correct?

A. I do not remember having made such a statement.

XQ. 315. Is it correct then? Did Dr. Langmuir tell you that an X-ray tube constructed in accordance with his suggestion to you, that the operation would not be dependent upon positive ion bombardment of the cathode?

A. I do not remember whether he said that or not, Mr. Darby.

XQ. 316. My difficulty, Dr. Coolidge, is that you do not remember whether he said it or not. Would you deny that he did say so?

A. No.

XQ. 317. Then the patent continues:

> "Another cause is its complete independence of vacuum changes within the permissible range of pressure."

Did Dr. Langmuir tell you that the X-ray tube constructed in accordance with his suggestion to you would operate independently of vacuum changes within the permissible ranges of pressure below a certain minimum?

A. I do not remember his having made any such statement to me, Mr. Darby.

XQ. 318. And the next statement of the patent is:

> "It will also be noted that with the high vacuum existing in the tube, the mean free path be-

tween gas molecules is much greater than the distance between anode and cathode, and, therefore, very few electrons can collide with gas molecules in passing from cathode to anode, practically all of the electrons reach the target with uniform velocity."

Did Dr. Langmuir suggest to you in the X-ray tubes that you were to construct that you should place the cathode close to the anode?

A. I do not remember, Mr. Darby.

XQ. 319. And the patent continues:

"Because of the low gas pressure the number of positive ions is so small that the filament is not heated at all by bombardment."

Did Dr. Langmuir tell you in the X-ray tube that you would construct that the filament would not be heated by bombardment?

A. I do not think so.

XQ. 320. You do not think so?

A. No.

XQ. 321. The patent states:

"The wall of the tube exposed to the anode is not heated by secondary cathode rays from the anode, thereby removing the limitation formerly imposed by local tube heating."

Did Dr. Langmuir tell you that that would be the fact with respect to the X-ray tube that you might construct in accordance with his suggestion?

A. I doubt it.

XQ. 322. You doubt it?

A. Yes.

XQ. 323. Then, follow me closely on this, Doctor, please. As I understand it, to sum this up very briefly, Dr. Langmuir suggested to you that if you would build an X-ray tube, that is, an electron discharge device, designed for the purpose of producing X-rays with the usual electrodes, that is, with the usual target, or a target—put it that way—and an incandescent cathode made of tungsten in a vacuum, the vacuum being attentuated so as to practically eliminate the production of positive ions, and heat your incandescent cathode independently of the voltage applied between the two electrodes, that you would get a good X-ray tube?

A. I do not think he used just that language, Mr. Darby, but I think that that is what the suggestion amounted to.

XQ. 324. In the operation of the Coolidge X-ray tube, space charge is not a factor, is it?

A. It is not a factor limiting the discharge current.

XQ. 325. That is what I mean.

A. That is right.

XQ. 326. And the voltage that you employed is far higher than what is necessary to draw all of the electrons emitted from the hot cathode to the anode?

A. That is not exactly right, Mr. Darby.

XQ. 327. Straighten it out for me, will you please?

A. With the focusing device there, the voltage used on the tube does not draw to the anode all of the electrons that are emitted by the filament. Some of them fall back again into the cathode.

XQ. 328. True, but if the focusing device was eliminated my question would be correct?

A. Yes.

XQ. 329. That is, the voltage is far higher than what would be sufficient to draw all of the electrons emitted from the cathode over to the anode?

A. Yes, sir.

XQ. 330. The current is determined by the cathode temperature at the operating voltages; that is correct, is it not?

A. That is correct.

XQ. 331. In all of these respects the case is just the opposite to that of a three-electrode audion, for example, in which space charge is a factor, the voltage is not high enough to draw to the anode all of the electrons emitted by the cathode, and the current is determined by the voltage and not by the cathode temperature; that is correct, is it not?

A. There is that difference, yes.

XQ. 332. It was of course part of Dr. Langmuir's suggestion to you that in the tube to be constructed embodying his idea of pure electron flow, by reason of the existence of a high vacuum, or the absence of pressure, it was part of his idea that he suggested to you that the vacuum had to be maintained, was it not?

A. I think so, Mr. Darby.

Mr. Haight: Possibly I could save time by asking the witness two or three questions instead of suggesting them to Mr. Darby.

The Court: Any objection?

Mr. Davis: No objection.

Cross-examination (Continued).

By Mr. Haight:

XQ. 333. Did Dr. Langmuir suggest to you that the hot wire cathode be placed close to the anode so that the charges on the glass would have little effect?

A. I do not remember his having made such a suggestion as that.

XQ. 334. Did he suggest that the focusing of the rays might be accomplished by deflecting them magnetically, while close to the anode and while moving with low velocity, and that they would then acquire velocity in moving towards the anode?

A. I do not remember, Judge Haight. I might say that I was familiar with the method of magnetic focusing, otherwise I might remember that better, but

I had done a lot of work with that method myself in times past.

XQ. 335. Let me ask you this question. Possibly you have answered it a number of times in the course of your cross-examination. As I understand it, the improved X-ray tube, of which it is said that you are the inventor, and which is covered by a patent that has been referred to, the improvement was that you used instead of a gas tube a high vacuum tube. Is that in general the improvement that was made, the change that was made over the prior tube?

Mr. Davis: It seems to me that this is entirely outside of any question raised in this case.

Mr. Haight: I will lead right up.

The Court: Will you not read the question?

Mr. Haight: I will strike it out.

XQ. 336. I understand that the X-ray tubes of the prior art before you made some changes worked on the principle of gas; that is right?

A. That is right.

XQ. 337. You changed that principle completely and worked on the principle of a high vacuum?

A. Yes.

XQ. 338. And the idea that the pure electron discharge in a high vacuum should be used in an X-ray tube was suggested to you by Dr. Langmuir?

A. That is correct.

XQ. 339. So that the backbone of your invention was Langmuir's suggestion?

Mr. Davis: That I object to. The last thing the witness can do is to qualify in that way.

Mr. Haight: I should think that the witness would know what the backbone—if I may use that crude but rather expressive expression—is.

The Court: Do you press your question?

Mr. Haight: Yes, sir.

The Court: Then I will hear you.

Mr. Haight: I have already stated my reason.

The Court: You do not care to be heard further?

Mr. Haight: No, sir.

The Court: Then I sustain the objection.

By Mr. Haight:

XQ. 340. I am wondering this, whether what you wrote in your notebook on December 10, 1912, namely, "I will try this out at once in an X-ray tube in which I can heat the cathode to any desired temperature," is not a more accurate statement as to how you came to apply the principle which Dr. Langmuir had advised you of on that day to an X-ray tube than your present recollection that Dr. Langmuir suggested to you that you so apply it?

A. I do not think so, Judge Haight.

XQ. 341. You had already in the preceding May yourself sensed exactly the same principle, hadn't you?

A. Sensed it perhaps, but failed with it.

XQ. 342. Failed with it in practice. I understand that. But you said on May 8th that you believed that the ideal X-ray tube would be a high vacuum tube, didn't you?

A. Yes, sir.

XQ. 343. And then you had conceived this kind of an X-ray tube, I mean the kind that you eventually did produce?

A. I certainly thought of it. I do not know about that word "conception of an idea" as applied here.

XQ. 344. You said, "I believe that the above points the way to the ideal X-ray tube." That is true, is it not?

A. Yes, that was my opinion.

XQ. 345. And that was the result of your own experiments and observations?

A. Yes, sir.

XQ. 346. Now then came December 10th, and Dr. Langmuir and you working in the same laboratory, he knew you were working on X-ray tubes, I suppose?

A. Yes, sir.

XQ. 347. And you knew that he was working with some of the phenomena in vacuum tubes?

A. Yes, sir.

XQ. 348. And he then told you of what he had found in respect to the electron discharge in a high vacuum, is that right?

A. Yes, sir.

XQ. 349. Then you wrote down in your notebook that day: "I will try this out at once in an X-ray tube," didn't you?

A. Yes, sir.

XQ. 350. Don't you think that in view of what you had conceived in May but which you had not been able to work out definitely, and in view of the fact that he had told you what he had accomplished in electron discharge, and in view of the statement contained in your notebook, which I have just read to you, don't you think that the idea of applying that principle to an X-ray tube was your own rather than one suggested by Dr. Langmuir?

Mr. Davis: Just a moment.

Mr. Haight: It is the same question over again.

Mr. Davis: That is one of the disadvantages of having two counsel cross-examining the witness.

Mr. Haight: It is the same question I asked.

(Discussion.)

Mr. Davis: In this case, I have no objection whatever to that question, if it is merely as to who it was in this interview between these two scientists that really made the suggestion, that is all.

Mr. Haight: That is all I am trying to find out.

Mr. Davis: I have no objection to that.

The Witness: It was Dr. Langmuir's, Judge Haight.

By Mr. Haight:

XQ. 351. Then, the opinion I have referred to, having induced you to change your mind, as expressed when Mr. Darby cross-examined you a while ago——

A. No, Judge Haight, there is this thing I would like to correct. You say that I have had an idea once upon a time of using a hot filament, hot cathode, in an X-ray tube, but that I had not fully worked it out. Now, as a matter of fact——

XQ. 352. That is what you said, Doctor; I did not. You said you had not worked it out?

A. I thought that I made it stronger than that; I meant to. My feeling was then that I had failed flatly——

XQ. 353. All right.

A. —and stopped.

XQ. 354. Now then, Dr. Langmuir came along, and told you that working with hot cathode filaments, he had been able to get a pure electron discharge in a high vacuum; is that right?

A. That is right.

XQ. 355. Now then, did not that immediately awaken in your mind:—Why, here the reason why I failed on this same thought before, was because I was working on a large piece of tungsten. Now, if I can just take this piece of filament and put it in an X-ray tube, I can get what I have been looking for for so long?

A. That idea certainly came to my head, but I am very positive——

XQ. 356. Did not that originate with you rather than with Dr. Langmuir?

Mr. Davis: Let him finish his answer.

A. I am very positive that Dr. Langmuir made the definite suggestion to me at that time immediately after telling me about his own experiments, and before I had had time to think the thing over in its bearings on the X-ray tube problem, in which I was so much interested.

XQ. 357. And do you suggest why you did not write that down in your notebook?

A. Well, I am rather surprised that I did as well as I did, Judge Haight. I did not keep notes very consistently, and they usually are briefer than they ought to be.

XQ. 358. They seem to be fairly full there, along this time, they run along every day, don't they (handing book)?

A. I hope so. I am afraid not every day.

XQ. 359. Look before you get up. I say every day. I mean practically every day.

A. I think it depends on what part of that notebook you strike.

XQ. 360. I am referring to this particular part right along here, where the going is good.

A. Here, I see a certain attempt—18/19/20.

XQ. 361. And before that the 5th?

A. You will find them oftener after this, Judge Haight, because we soon became very much interested indeed in that type of X-ray tube.

XQ. 362. You have no other suggestion to make as to why you did not write down in your notebook that Dr. Langmuir suggested to you the application of this principle to X-ray tubes, than the fact that you sometimes did not keep full notes?

A. No, sir.

MR. DARBY: That is all.

MR. DAVIS: That is all.

(Witness excused.)

MR. RICHMOND: Your Honor, at the close of the cross-examination of the witness Kelly, requests were made for some data, and I now wish to have marked for identification "Kelly Data for Defendant's Exhibit No. 56," E for Identification. This data we submitted to our opponents the day before yesterday.

(Received and marked "Defendant's Exhibit N for Identification.")

JOHN V. L. HOGAN.

JOHN V. L. HOGAN, was recalled in rebuttal, on behalf of the plaintiffs, and having been previously duly sworn, testified further as follows:

DIRECT EXAMINATION.

By MR. EDMONDS:

Q. 194. Mr. Hogan, I take it that you are familiar with the defense's material in this case, including the prior patents and publication as referred to by Professor Chaffee, and the prior knowledge and use and the deposition as taken in San Francisco?

A. That is correct.

Q. 195. Will you say if you find in any of this material the disclosure of a cathode for electron discharge apparatus consisting largely of a highly refractory metal and a surface layer of material having an electron emissivity at a given temperature materially greater for unit surface than said refractory metal independently of and in the presence of positive ionization?

A. I do not.

Q. 196. Do you find in that material a device operating by pure electron discharge independent of positive ionization having a conductor comprising a refractory metal and a surface film of thorium metal vaporizable at a temperature above about 2300 degrees K., and having a greater electron emission when at incandescence, in a non-striking vacuum than said refractory metal?

A. No, I do not.

Q. 197. Do you find there an electrical discharge device, having an electrode comprising in part at least oxidizable thorium material, said electrode having at a temperature of about 1300 to 1380 degrees absolute an electron emission substantially equal to that of tungsten at about 2000 degrees absolute?

A. No, I do not.

Q. 198. And finally, an electrical discharge device having an electrode comprising metallic tungsten and thoria, said electrode being subjected to a temperature of about 2200 to 2350 degrees K., and having an electron emission a thousand times as great per unit of surface as tungsten in a vacuum too high to permit of positive ionization?

A. No.

Q. 199. Do you find in that material considered apart from any reference to the Wehnelt cathode any means for increasing the electron emissivity of the cathode other than increasing its temperature?

A. No.

Q. 200. Will you assume that someone put a thoriated tungsten lamp filament in a vacuum tube in 1911 or 1912, and that the vacuum was the ordinary X-ray vacuum? Would the film of thorium be formed under those conditions?

A. No. Even with proper temperature treatment, the film would not form because thorium is so sensitive to oxidation that the partial pressure of oxygen in even the best X-ray vacuum of the old days would be enough to destroy (by oxidation) the thorium as fast as it appeared.

Q. 201. I think you might explain that a little more fully at this point if you will.

A. I have made an additional assumption and that is to say that in addition to putting in a lamp filament one gave it a temperature treatment corresponding to activation treatment that is described in the second patent, and I have said that even though that were done so that thorium would distill outward through the filament to the surface, as it appeared on the surface of the filament the oxygen which would necessarily be in the tube at a pressure of three microns or more, that is to say an X-ray tube pressure, it would instantaneously, practically instantaneously oxidize and destroy the thorium on the surface of the filament and so prevent its contributing to emission.

Q. 202. So that what emission you got from such a tube would be tungsten emission and not thorium emission?

A. It would be practically the emission of pure tungsten, and, of course, if you do not give it the temperature treatment the thorium would not even come out of the filament so that then the emission would be simply that of pure tungsten.

Q. 203. Now, will you assume a very high vacuum, the highest possible vacuum, were given a tube and the tube was operated at the normal filament temperature for tungsten cathodes, would the film be formed under those conditions?

A. I will have to define highest possible vacuum in that connection and for the assumption of your question I will take that as being not merely a very high vacuum such as would be required for space charge operation in accordance with the first patent in suit, but also the character of vacuum, the quality of vacuum, which has a partial pressure of oxygen far below that which is necessary for the 3/2 power operation and sufficiently low to prevent rapid or in fact any oxidation of substantial amount of thorium.

If the vacuum were as good as that, that is to say, as good in the vacuum in the modern tubes using all four of the patents in suit, and the filament were operated at normal cathode temperatures for tungsten, that is to say temperatures above 2400 degrees K., the bright white temperature so to speak of the ordinary tungsten lamp, (which were exceeded if anything in the tungsten filament vacuum tubes used in 1913, or thereabouts, 1912, perhaps) then the thorium if there was thorium in the filament would diffuse to the surface of the filament but would immediately evaporate from the filament. The rate of evaporation is so high at those temperatures that it would not remain as an active monatomic layer on the surface of the tungsten. Consequently at those temperatures first whatever thorium might be in the filament would rapidly be exhausted and secondly, the emission would be little if any higher, probably no higher than that of pure tungsten. Certainly after the exhaust it would be no higher and even during the evaporation I doubt if it would be substantially higher.

Q. 204. So that under the conditions stated you would be getting no useful result whatever from the thorium?

A. That is correct.

Q. 205. Do you find in the defense material any disclosure of an electrical discharge device comprising electrodes, one of which contains thorium, an inclosing envelop the space within which is evacuated to a pressure so low that positive ionization is substantially absent, and a quantity of a vaporizable reagent capable of preventing the oxidation of thorium in communication with the space within said envelop?

A. No, I do not.

Q. 206. Or a disclosure of an electrical discharge device comprising electrodes, one of which consists of metallic tungsten and a thorium material in an oxidizable state, an inclosing envelop, and a quantity of a vaporizable reagent within said envelop capable of preventing the oxidation of thorium at an elevated temperature?

A. No, that combination does not appear.

Q. 207. Or an electrical discharge device comprising a sealed envelop, electrodes therein one of which is of the thoriated type and a film of magnesium deposited on the inner surface of said envelop?

A. No.

Q. 208. Or an electrical discharge device comprising a container, electrodes therein one of which consists largely of refractory metal and contains an oxide of a metal of high electron emissivity which when rendered active is sensitive to ion bombardment together with a reducing agent, and a quantity of alkaline earth metal, the latter being deposited as a film on the inner wall of said container?

Mr. Darby: I do not know how far——

Mr. Edmonds: I am through.

A. No, I do not find that either.

Mr. Darby: I think those were all questions for the Court to be answered.

Q. 209. In his answer to Q. 34, Professor Chaffee referred to the following prior patents and publications, the patents of Malignani, Dwyer, Von Recklinghausen, Merritt, Soddy, Clark, Clough, Marshall and MacKay, and the publications of Soddy, Doane, Hupka, Kunz and Kemp and Whitney. You are familiar with those, are you not?

A. Yes, I have read all of them.

Q. 210. I wish you would take up those patents in the order in which Professor Chaffee discussed them, if you find that convenient, and say what if anything you find in them bearing upon the second, third and fourth patents in this suit?

A. If it is equally satisfactory I think it might be more convenient to take these up in the order of the exhibit numbers, that is to say in the order in which they were introduced. I think that agrees in general with the order that Dr. Chaffee used, but it makes it more or less chronological.

The first patent is that issued to Malignani, No. 537,693, April 16, 1895. This is a lamp evacuating patent and has to do with the so-called chemical evacuation of lamps. Malignani in the process described first evacuates the lamp to about two millimeters gas pressure, page 1, line 36 of the patent. That corresponds to 2000 microns pressure.

He then lights the filament, driving off, or as he calls it generating, gases in the filament, the reference being page 1, line 40, and then he vaporizes arsenic, what he calls "sulphuric," or iodine, which as vapors are intended to combine with gas within the lamp and to precipitate.

The Malignani process as it is referred to in the lamp industry used phosphorus instead of arsenic or iodine or "sulphuric," which I believe means sulphur, and in any event the whole exhaustion effected depends upon ionization of the vapors or gases and is not a simple absorption; that is to say, in the lamp process when the phosphorus was vaporized in the lamp with the filament lighted, the lamp would glow as a result of the ionization of the gases under the potential applied across the filament terminals and in that period of glow or of extremely intense ionization the improvement of the vacuum would take place.

The process was not used so far as I have been able to learn on low voltage lamps, for the simple reason that without high voltage across the filament terminals, the necessary ionization would not take place.

Of course, the disclosure and the practical use of the process involved lamps, not thermionic tubes, not tubes containing any metals or electrodes other than the filament. Of course, there was no highly oxidizable thorium filament.

The initial pressure was very high and while it was reduced by the vaporizing and ionization clean-up to a fair lamp vacuum as of that time, even the final pressure was too high to be tolerated in a good electronic device.

As to any indication of the amount of reagent, if one may call the phosphorus a reagent for the clean-up, it is perfectly clear and it is stated in a number of patents which I may call Malignani improvement patents, that the amount of phosphorus to be used must be minimized. The reason for that is also simple. The reason is that the device is a lamp and the walls must not be clouded if it is to be a satisfactory commercial article.

As to the specific materials suggested by Malignani, it has been found impossible to activate a thoriated filament by temperature treatment in the presence of vapors of arsenic, sulphur, or phosphorus. As to iodine, while I know of no tests having been made of it, is clearly of such a high vapor pressure as to be of no utility in a thermionic device.

We all remember bottles of iodine in the chemical laboratories in which the blue vapor even at room temperature is perfectly visible, and that of course means a very high pressure in terms of lamp pressures.

Certainly, there is no suggestion in the Malignani patent of any keeping action as a result of any of the materials used. The clean-up is a simple lamp clean-up going from a very high pressure of thousands of microns to a lamp pressure of the order of ten microns or less, not below one or two microns in any event, and once that is done the reagent is through, its function has been performed and there is no suggestion that it has any further utility.

One other point might be mentioned in connection with this Malignani patent, and that is, that in the customary use of mercury pumps with lamps, the phosphorus that was used in the Malignani process, that is, phosphorus in general, and I am not referring to any particular kind of phosphorus, but phosphorus as used in the Malignani process, does not take up the mercury vapor so far as I have been able to find, and consequently the partial pressure of mercury amounting to a micron and a half at room temperature would remain within any tube in which one used a mercury pump without special means of removing mercury vapor.

I think that covers the Malignani patent and I will take up next Defendant's Exhibit 7, which is U. S. Patent 596,694, issued to Dwyer on January 4, 1898.

This again is a lamp evacuating patent and in the process described Dwyer pumps his lamp, as for example by a mechanical or mercury pump, page 1, line 21, to what was probably a lamp vacuum of a few microns. He then lights his filament to expand the gases and to drive off gas particularly from the joints as illustrated in Figs. 2 and 3 of the patent, the joints where the filament is fastened to the lead-in wires.

Q. 211. May I interrupt, Mr. Hogan? This vacuum that you have referred to in connection with this patent corresponds to what he speaks of as a partial or incomplete vacuum at line 26 of the first page of the specification?

A. Yes. He says that that is readily obtained by a good mechanical or mercurial pump, and in saying two or three microns, I have given him the benefit of the doubt. The partial vacuum which is insufficient might be as high as fifteen or twenty microns, because the range of carbon lamp vacua, so far as I have been able to determine may begin as high as ten microns.

After heating the filament he vaporizes a condensible gas (and he suggests phosphorus for that purpose) to displace the residual gas. The description is based upon the idea that you shall pump out to a fair vacuum, a partial vacuum, as stated, and then, displace the remaining gases by means of some condensible gas and thereafter condense that condensible gas so leaving presumably a high vacuum.

The practice with phosphorus is more likely to correspond with what is understood to be the Malignani effect rather than any displacement of molecules which are widely separated in a partially evacuated vessel, by putting in another gas whose molecules are also widely separated, which does not occur. One can displace gases at atmospheric pressures or thereabouts with other gases, because of the collisions which will force out the displaced gas, but when one is working in an approximately or even fairly good vacuum, this displacement does not occur in the same way.

He specifies that in any event the minimum amount of material must be used, because of the possible coloring of the globe. He refers also as prior practice to the use of mercury, iodine, sodium, potassium and arsenic by introduction and cooling, and Dwyer's improvement seems to be the use of phosphorus and of electrical heat to vaporize the phosphorus.

The complete emphasis is, as I think I indicated, on the displacement of all the gases in the tube and the subsequent condensation of the replacing vapor.

Somewhat the same comments apply to this patent as to the Malignani patent and the practical Malignani process which I also discussed in connection with the Malignani patent.

It is not a thermionic tube; there are no electrodes other than the simple lamp filament; the filament itself is not an oxidizable thoriated filament, that not even being known at the time. There is no initial low pressure, the pressure when the chemical and heating treatment are applied being high in comparison with vacuum tube pressures. The same impossibility of forming a thick film exists on account of the device being a lamp.

Tests have shown that the phosphorus which is shown as the best displacing means will prevent the activation of the thorium filament when used to get the vacuum according to the Malignani process, and there is no hint of keeping a vacuum in a lamp of this kind by Dwyer.

With reference to the prior art materials referred to at page 1, line 70, mercury, of course, has too high a pressure for use in vacuum tubes. It ionizes at room temperature under a small voltage. Iodine I have mentioned before has the same disadvantage or the same characteristic which would prevent it from being used. Sodium and potassium, two materials mentioned here, will work to attack oxygen and water vapor and clean a vacuum of those gases if it is used as described in the third patent in suit here, but it cannot be used that way in a lamp. No coating could be tolerated in a lamp. There is no suggestion that those materials be used in that way.

There is no oxidizable filament to protect and at the pressures that Dwyer used, the sodium and potassium would, I believe, be completely exhausted in any quantity that could be used in an incandescent lamp before they had carried the partial pressure of oxygen down to the extremely minute values that can exist in a thoriated filament vacuum tube without killing the emission of the filament in a very short time. Of course, there is no suggestion of any cold action, any action in the absence of heat on any of these materials in the Dwyer patent.

Q. 212. Before leaving that patent, Mr. Hogan, will you note that in the last paragraph on the second page there is a reference to the use with greater or less success, as Dwyer says, of ammonium cuprous chlorate? What have you to say as to that?

A. I have never used ammonium cuprous chlorate in connection with a vacuum tube, but I have no idea that it could be used with any effect. It would break up and give off chlorine, probably hydrogen and nitrogen, and while it might conceivably be partially useful for such a purpose as Dwyer's, I am confident that it would not protect a sensitive thorium activated filament.

Q. 213. In any event, the patentee clearly expresses a preference for phosphorus over all of the other materials mentioned in this patent?

A. Yes, there is no doubt about that. At page 2, line 131 he says: "I prefer phosphorus to other materials."

The next exhibit to which I have a reference here is a paper by Doane which is Defendant's Exhibit 11, and which appeared in the *Electrical World and Engineer* for May 21, 1904, beginning at page 963. The title is "A Resume of Incandescent Electric Lamp Exhausting." And it is an interesting running description of lamp exhaust processes as used up to that time.

It has mainly to do with mercury and phosphorus lamp exhausts as they were used in the practice. Comments on this article would add practically very little to those that I have already made as to Dwyer, since the type of exhaust treated is practically the same.

I might point out that on page 965 there is a warning that the operator has to be careful not to vaporize too much phosphorus for the reasons that I have indicated. The decrease of vacuum securable in the carbon lamps that were made with these exhausts, mercury and phosphorus exhausts, were very high compared to thermionic tube vacuums.

As I have said, ten microns pressure was ordinarily satisfactory and might be reduced to a matter of two microns in a carbon lamp.

On page 964 the Doane article refers to a preliminary mechanical exhaust prior to a chemical exhaust which brings the vacuum down to .125 millimeters which is 125 microns. The further evacuation to a satisfactory lamp vacuum being the chemical evacuation of the sort that I have described.

As to the mercury exhaust referred to, of course, we recognize that mercury in a thermionic tube is intolerable from the ionization viewpoint, both with respect to operation without disturbance by ionization as to the tube characteristic, and particularly with respect to the bombardment of the sensitive thoriated filament or mercury ions as soon as ionization voltage is exceeded.

The next citation is Defendant's Exhibit 12, which is U. S. Patent No. 946,068, issued on January 11, 1910, to Von Recklinghausen. Von Recklinghausen's proposal is to clean a mercury vapor lamp or converter referred to at page 1, line 10 to 12, by exposing heated or melted magnesium within the mercury bulb.

He puts the magnesium in a little insulating boat so as to prevent it from touching the glass walls while heated, page 1, line 39. He points out that the magnesium must be kept from coming in contact with the glass walls.

The purpose of the magnesium is given at page 1, line 77, to absorb injurious nitrogen and oxygen remaining within the container.

The pressures in a device of this sort are of course high. He refers to a very high degree of exhaustion in an iron chamber at page 1, line 80, the thought being that if iron is used the attack of magnesium on glass can be avoided. We all know from our experience with mercury vapor converters in steel casings, that it is impossible to keep even the pressures that are necessary for successful operation in the practical cases without having a pump going all the time, that is to say, a vacuum pump. Iron or steel casings will not permit a high vacuum to be held and yet such a casing is suggested for what Von Recklinghausen calls a very high degree of exhaustion at page 1, line 81.

Q. 214. The plain indication being what?

A. The plain indication being that his pressures were really high, and what he called a high vacuum would be what we would call in thermionic work or even in lamp-work a very poor vacuum.

This converter or mercury lamp is not a thermionic device, it has no filament, certainly no highly oxidizable filament; if there were such a filament as a thoriated cathode put into a chamber of this kind the mercury ionization would at once strip the thorium surface from the cathode. There is no low pressure of gases in the chamber at any time, either in its construction or operation. There is no hint in the specification or disclosure of any keeping action on the part of the magnesium. Whatever action the magnesium may have toward getting out the water vapor, nitrogen and oxygen in accordance with the desires of Von Recklinghausen is had while it is heated or melted in accordance with page 1, line 75.

There is no suggestion that a magnesium film could form in a device of this kind and the probability, in fact I think I can say the certainty is that the mercury vapor, the hot mercury vapor in a tube of this sort would attack and wash off any film of magnesium that might tend to deposit if the magnesium in the boat were vaporized rather than merely warmed or heated.

So far as I know, there is no vapor combination of magnesium and mercury. Mercury may amalgamate with cold magnesium, but any action of that sort would be slow and in any event could never do more than saturate the magnesium in a structure of this kind because of the large amount of mercury present.

Of course, the tube does operate like all mercury converters or lamps in a high pressure of hot mercury vapor and that is an impossible condition of affairs for the operation of a thermionic tube under either the first or second patents here in suit.

The next reference is Defendant's Exhibit 13, U. S. Patent 909,811, issued on January 12, 1909, to Merritt. This is a lamp exhaust patent an improvement on the Malignani patent, Exhibit 6, that I have already discussed. Merritt proposes to put his reagent on the inside of the bulb, as indicated at E in the drawing of the patent, instead of the tubular connection or tube through which the exhaust is made, the latter being the arrangement indicated in the Malignani drawing.

The only material that Merritt suggests is red phosphorus which is referred to at page 2, line 66. His purpose in putting the reagent on the inside of the wall of the lamp itself instead of the tubular tube is to avoid a blocking or sealing action which he describes. He applies heat to the phosphorus while the tube is on the pump and again after it is sealed off and he uses a minimum amount of phosphorus as referred to on page 2, line 63, and following, and at page 2, line 74, where he says that the amount shown in the drawing is greatly exaggerated.

The general effect of a little getter of this kind is that the red phosphorus, which has extremely low, practically zero, vapor pressure, is painted on, a small amount put on the lamp bulb, and when that is heated and evaporated it takes the active yellow phosphorus form and when ionized by the voltage cleans up a certain amount of gas, the ionization being accompanied by the characteristic glow of the lamp exhaust.

In that process the phosphorus returns to the low vapor pressure red form. The glow characteristic of the use of this phosphorus is referred to at page 2, line 127, and page 1, line 53. The comments which I may make on the Merritt patent are similar to those on Malignani and Dwyer and very briefly are that it is not a thermionic tube, it has no oxidizable filament, it has no low pressure, because it is a lamp only very little material can be used, phosphorus has been found to be poisonous to a thoriated tungsten filament, there is no suggestion of any keeping action in the disclosure here, and phosphorus is not useful to clean up mercury vapor of the sort that would be given off from a pump or gauge in the old exhaust process.

The next reference is U. S. Patent 859,021 issued to Soddy on July 2, 1907, and is Defendant's Exhibit 17. This patent describes a chemical pump shown in Fig. 1 at B, which utilizes the gas-absorbing capacity of very hot calcium or magnesium. References to the materials and the heating are at page 1, line 33, page 1, line 55, page 1, line 73, and specifically to electrically heating the material at page 2, line 89.

This pump is a side chamber distinct from the bulb to be evacuated and connected to that bulb through a tube with the usual constriction for sealing off. This arrangement is shown very clearly in Fig. 1 which illustrates the chemical pump in operation for the exhaustion of an X-ray tube. It is such a chemical evacuating means as that which Langmuir stated in his first patent at page 2, line 69, might be used for general pumping.

This type of calcium or magnesium pump using the vapor action, the hot vapor action, of calcium or magnesium is satisfactory for securing an X-ray vacuum or a lamp vacuum, when preceded by rough pumping. The range of pressures that lamps and X-ray tubes use at the start, are certainly not less than one micron, and in the case of the old X-ray tubes, and carbon lamps, often as high as 10 microns.

The action of a pump of this kind depends on collisions between the gas and the vap[illegible] molecules, and of course the number of these collisions is reduced rapidly as the pressure is lowered, and the spacing between the molecules that are expected to collide, increases, so that its efficiency falls off as the pressure is reduced.

It should be noted that no magnesuim or calcium will get into the tube or the lamp being exhausted, because of the construction used. The hot vapors are confined to the Soddy pump itself and would condense on the cool walls or on connecting the tube at the constriction before they get into the tube being exhausted; and of course, that is a perfectly proper and logical thing for Soddy to do, because one would not want any calcium or magnesium vapor to get into a tube that was to give off light or X-rays, that is to say, a lamp.

Now, Soddy emphasizes the heating of his magnesium and calcium and makes no suggestion of any cold action by those materials, and of course there is no suggestion of keeping action. This is a pumping process.

The pressures do not reach the low values at which the cold film keeping action of the fourth patent in suit become useful and of course there is no suggestion of any use for the protection of a highly oxidizable filament.

The next publication is Defendant's Exhibit No. 18, which is a short article signed by Frederick Soddy, and published in *Nature*, for November 21, 1907, beginning at page 53. This describes a test to determine whether the high emission from a Wehnelt cathode is independent of the perfection of the vacuum as is stated at the end of the first paragraph. Soddy used in the tube he was testing a calcium anode, and takes advantage of the hot vapor action of the pump described in his patent, to which I have already referred, as a vacuum producing means. He says that the tube was:

> "prepared in the usual way by preliminary exhaustion and washing out with oxygen to remove argon, and then subjected to the action of calcium heated in a furnace attached to the apparatus."

That phrase is descriptive of the use of his electrically heated calcium pump described in the patent, Defendant's Exhibit No. 17:

There is no reference to baking the tube and it should be noted that the tube was washed out with oxygen, in order to remove argon. I think that Soddy has stated that the calcium pump would not take out argon, and he apparently wished to get rid of it in this experiment. He does not suggest heating the lamps in connection with the patent on the pump either. He does suggest lighting the filament, but not heating the tube; and so I think that the reference to the use of the pump in the article conveys the same idea that one would get from the patent.

He then ran the tube at 1.2 amperes. Near the bottom of the first page of the article he says that:

> "The gases evolved from the anode and tube under this treatment were absorbed by the calcium in the furnace"——

And then he says that:

> "When the gases had been for the most part removed the current was passed continuously, heating the calcium anode up to its volatilizing point."

He continues:

> "Quite suddenly and completely the current through the tube stopped, and at the same moment a copious mirror of calcium was volatilized from the anode. In a little while a very feeble glow started and passed intermittently from time to time, but it was not enough to move the ammeter needle."

I might point out that he was using an ampere meter, not a very sensitive instrument—

> "and was most likely due to a further slow evolution of gas from the still heated surfaces. A current could be passed by a coil from the hot cathode to a third electrode as anode without causing any appreciable resumption of the flow in the 250-volt circuit. More gas was then generated within the apparatus by heating the third electrode with the coil discharge."

Then he goes on to speak of a repetition of the same experiment.

By Mr. Edmonds:

Q. 215. That is the cessation of the current?

A. Yes, and says that it may be—I think the implication at least is that the experiment may be repeated time and time again. He concludes that

> "in a sufficiently high vacuum, the Wehnelt electrode ceases to be effective,"

and that the electronic emission can account for no more than a negligible fraction of the total current

And he warns, at the end of his article, that it is very hard to get a good vacuum.

Under the conditions of his test, the tube glowed, and immediately after the hot calcium was released in the tube, so that the current dropped, the tube commenced to flicker again, showing, of course, visible ionization effects in both cases.

Now, I think that this article is a demonstration of the pumping action of vaporized hot calcium, both in the pump as in the case of the patent and in the tube itself; but there is no suggestion at all in the article of any cold action of calcium nor of any possible keeping action. In fact, when the mirror formed, as he describes it, the vacuum was not kept at all, but the intermittent glow started immediately afterwards. The initial pressures were high, the sort of pressure that the calcium pump itself could produce, and could not have been reduced with that construction, so far as I can see, to an extent that would be necessary to protect a thoriated cathode; and it is clear that neither the walls nor the third electrode were freed from gas, so that whatever the vacuum might have attained instantaneously it would not have remained there.

Also Soddy points out how he got the gas which made the tube glow by slightly heating his third electrode.

The oxygen wash which was used to displace the argon and other gases in the tube, that is to say, a high pressure wash at atmospheric pressure or thereabouts, would probably have left in the unbaked tube, much more than enough oxygen to destroy a thoriated filament surface, in spite of the hot calcium vapor action, and vaporization; but perhaps even a discussion on that point is gratuitous on my part, because Soddy had no oxidizable filament to be protected.

There is no more in this article than the magnesium flash clean-up or the so-called gettering action.

That is to say, the action of the hot vapor at the instant of flash, which is what Soddy utilized in his 1907 pump.

By Mr. Edmonds:

Q. 216. You do not mean magnesium, do you?

A. Did I say calcium?

Q. 217. I think you meant calcium.

A. Either calcium or magnesium or both were suggested, and I think he used calcium in this article; in fact, I am sure of it. There is no suggestion that the material had any later value, so to speak. It might as well have taken place, (that is, the vaporizing action) in the side tube, as in the case of the patent, in so far as the instantaneous flash absorption of gas is concerned, and the mirror that Soddy refers to in the article, was a secondary result, which is of no utility, either recognized or suggested by him.

In this connection, that is, in connection with the Soddy work, both as to the pump described in the patent, and the experiment described in the article, I would like to point out that Hupka, who wrote an article in the *Annalen der Physik* for 1909, which is Exhibit 21, and which I will discuss next, referred to an attempt to use the Soddy hot vapor method of evacuation, and he said that he could attain a hard X-ray vacuum by the use of calcium, but that it was not adequate for his purposes. A hard X-ray vacuum would be at the lower end of the old X-ray vacuum; range from ten down to about three microns. I think that marks about the limit of what could be done with this hot calcium process, because of course, it is convenient, and Hupka would have been glad to have used it if it had been satisfactory to go to lower pressure.

In this same connection, perhaps I should point out that pressures of the sort we have been considering, if related to oxygen, are extremely high for the action of a thoriated filament.

With respect to a comparison of lamp vacua and of non-ionization vacua, vacua in which positive ionization is substantially absent and does not interfere with the operation of the device, either by changing its characteristic, or in the case of thoriated tubes by bombarding the thorium cathode, and stripping the thorium off by that mechanical action so to speak, we have one set of conditions. But when we get to oxygen and its effects, and water vapor and its effects, its chemical effects on the filament surface, we have to adopt a new idea of pressures.

A pressure of even one one-thousandth of a micron of oxygen in a thoriated tube will oxidize the sensitive activated molecular surface so rapidly as to cause the emission to drop to one per cent. in the initial emission, in such a short time as five seconds; and if the pressure is reduced, the partial pressure of oxygen is reduced to one one-millionth of a micron, the emission will drop down to one per cent. in only about half an hour of running.

So that the amount by which the oxygen in a thoriated device, a device having an active thoriated filament, has got to be reduced, is really an astounding thing. The pressures, to get long life, are of the order of a millionth of a millionth of a micron. That is to say, the partial pressure of oxygen. One does not care, of course, to have all other gases taken down to that extent, (and probably that could not be done) because the other gases are not harmful to the sensitive surface; but the oxygen-carrying gases, oxygen itself, carbon monoxide, carbon dioxide, water, all must be excluded to a degree that is totally impossible with anything operating in the range of lamp or X-ray vacua.

Incidentally, the gases that are given out in the operation of a tube by an untreated anode, are largely oxygen and carbon monoxide, either of which would hurt the thoriated filament.

The magnesium film of the fourth patent in suit, will take up those gases, if the tube starts at a low pressure, and well below one micron, and will take them up faster than they can damage the filament; but above a micron, the space collisions become the important thing, rather than the film action, and so the keeper action of the film would seem to be applicable only to the low pressures of that general order.

Coming now to Exhibit No. 21, which is the Hupka article appearing in Volume 31, of the *Annalen der Physik* for 1909, beginning on page 169, I find the only part referred to by Dr. Chaffee, has to do with a trial of the Soddy evacuation by use of vaporized calcium in the tube.

This portion is on pages 179 and 180 of the original article, and on page 13 of the translation that we have been using, it reads:

> "I have also made experiments with the process of calcium vaporization suggested by Soddy. In one case a calcium rod connected in the circuit by a loose contact was vaporized by direct short-circuiting and formation of an arc. Another time, pieces of calcium, the size of peas, were put into a porcelain tube cemented to the vessel to be evacuated and closed at the end; this was carefully heated to a red heat by the flame of a blower. The degrees of evacuation obtained in this manner were not inconsiderable; for instance, a vessel of about one-half liters capacity was reduced from a water jet vacuum to a hard X-ray vacuum at the moment of vaporization. For the present purpose, however, this method was not adequate."

He then goes on to discuss charcoal and liquid air, but that is all there is with reference to Soddy, and Dr. Chaffee quoted only the first part of that. The point which seems significant to me is that he would not be able to go below an X-ray vacuum, and even that was attained only at the moment of vaporization.

We know that the cut-off, so to speak, of the old X-ray tube, will come in somewhere in the neighborhood of three microns of gas. That is not a hard and fast figure, because as I think has been explained, the rate of gas clean-up and of gas evolution from the electrodes in the old X-ray tube, is a differential one. There is gas coming out of electrodes and gas being cleaned up by the discharge. If we had an electrode which would not give off any more gas, then so far as the best determinations seem to go, the discharge would stop, as soon as the vacuum passed below three microns; but I say I do not want that to be taken as a hard and fast figure. It might be in one tube that it would be a two microns, and in another one, ten microns. In any event, such pressures are far too high for any purposes we are considering in this case.

I have been through the whole translation of this Hupka article, and I find no other references to a vaporizable reagent, if we can use that general term, even for getting a vacuum, much less for keeping one, and Hupka seems to have had gassy electrodes and gassy tube walls, as far as I can make out from the article. He spoke of a few sparks having been passed to one of the electrodes for cleaning it up, but of course we all recognize that that would be totally inadequate for a real clean-up of the gas operated in any metal electrode, and even when he did spark into his electrodes, the gas that he got off, whatever it may have been, was released right into the sealed tube.

He had two cemented joints in his tube, a screen, and a quartz window; and altogether the article is descriptive of an experiment that could have no bearing on any of the present inventions.

The next reference I have is the Marshall patent, No. 1,205,002, which is Defendant's Exhibit No. 28. Here again we have a variation of the Malignani process of exhausting lamps, Mr. Marshall's plan being to regulate exactly the amount of phosphorus that is to be used in each lamp. He explains that in page 1, line 40. He exhausts his lamp heated, but without lighting the filament (page 1, line 38), he seals it off, and then he lights the filament and that vaporizes the phosphorus that has been put on the end of the filament supporting stem, gives the blue glow, and then the lamp is finished. He says in the specification, page 1, line 90, that in the drawing, the showing of the amount of phosphorus used, is much exaggerated, and at page 2, line 69, he refers to the amount as a "barely discernible deposit."

On this application date of 1911, Marshall was apparently not even certain that the improvement produced in a lamp by the use of phosphorus was due to a better vacuum. He makes some rather hesitating comments as to the importance of improving vacuum by phosphorus, though I think that it is generally recognized that this phosphorus does act when ionized, as I have described, in bringing down a rough pump vacuum to a lamp vacuum.

Now, the comments that I would make, outside of the description of the invention, would be much the same as in the case of the Merritt patent, which was Defendant's Exhibit No. 13. There is no thermionic tube involved; no structure having anodes or electrodes other than the filament. There is no highly oxidizable filament. The initial pressure is very high. The same impossibility of using enough reagent to form an active film on the globe is here.

We know that phosphorus poisons a thoriated tungsten filament, and there is no suggestion of any cold action or keeping action on the part of the reagent, and it would be useless for the clean-up of mercury vapor.

Exhibit No. 32 is the next to which I come, and is an article by Kunz & Kemp in the *Phys. Zeit.* for 1912, July 1, pages 594 and 595.

This describes a spectroscopic experiment on sodium vapor, on potassium vapor, and on hydrogen gas; and the best vacuum that is suggested is as of the X-ray order, that is to say, from three to ten microns.

I have read the translation of the entire article very carefully and I can not find any justification for Dr. Chaffee's suggestion that the cathode was hot, or even partially heated, when X-rays were produced in this vacuum.

The translation reads:

> "A complete vacuum was produced so that Roentgen rays were created without heating the Wehnelt cathode."

And that particular sentence occurs in the description of the device before there is any mention of heat. So that I think it is perfectly clear that the initial investigation of the vacuum before the cathode was heated, resulted in the production of X-rays, and therefore that the vacuum was of the X-ray order.

This is confirmed by the statement which immediately follows, and which is:

> "As soon, however, as the calcium oxide electrode had been sufficiently heated, then there appeared the blue rays of electrons which spread from the cathode to the anode, however, without producing any other light."

I do not see how X-rays could have been produced with the hot cathode if as soon as the cathode was heated the glow of the cathode rays passing through the partial vacuum became visible.

Apparently Kunz and Kemp introduced sodium and calcium vapors by heating a side tube which is shown in the drawing at page 595 of the original article, but there is no evidence of any vacuum improvement as a result of that and no evidence of any higher vacuum than the X-ray values that Soddy and Hupka got using calcium. This experiment mentions sodium and potassium, but there is no evidence of any keeping action of these two materials.

Kunz and Kemp's tube was not baked and the electrodes were not heated so far as I can tell from the article and gas was apparently evolved from the walls when the tube was later slightly heated, so that I can not find anything in this Kunz and Kemp article that remotely suggests the use of the materials sodium and potassium (which are specifically named in the exhibit) for any such purpose as that of the third patent in suit.

Perhaps that sentence is not clear because it has a double clause in it. What I want to say is that although Kunz and Kemp specifically refer to sodium and potassium, and although they used those materials to determine the spectroscopic effects following the investigation of the vapors, there is no suggestion that they are improving the vacuum even on the Soddy basis of obtaining X-ray value and much less no suggestion of any keeping or cold action on their part.

The next reference in order is Defendant's Exhibit 33, which is the American Institute of Electrical Engineers' paper of June 25, 1912, by Dr. Whitney. This is entitled "Vacua," and describes the Malignani process as practically used, and as I have discussed it in connection with Defendant's Exhibit 6 and Defendant's Exhibit 13. It states the recognition of the blue glow and the high filament heat that are necessary to get the Malignani reaction.

Page 1208 of the article points out that when the vacuum had been pumped down to 30 microns and then the pump closed off, a trace of phosphorus distilled into the bulb, while the filament was very hot, a blue glow appeared, brought the vacuum down as quickly as the gauge could be read to one or two microns. That is the same order of the effects I have described in connection with the Malignani and the Malignani improvement patents. It checks with Soddy's and Hupka's and Kunz and Kemp's general order of result, although they used other hot vapors.

The Whitney article describes further the clean-up of high voltage lamps, lamps of operating voltages of 50 to 110, which is not experienced in low voltage lamps in the same way.

The article is quite a detailed discussion of lamp practice in producing vacua, but there is no suggestion in it of any cold action of a vaporizable material of any kind nor of any film action, action in film form as in the case of the third and fourth patents in suit here, nor of any keeping action.

There are some new materials mentioned, that is, new from the point of view of this case, at page 1215. About the middle of the page Dr. Whitney says:

> "X-ray tubes are usually made with a salt such as potassium chlorate or potassium hydrate, mica, asbestos, etc., in an attached side tube. This may be heated when the tube in use attains a high degree of evacuation and in this way gas is liberated into the bulb."

That of course is descriptive of the use of the so-called regulator on the old-fashioned X-ray tube, by the use of which, when the pressure in the tube had become too small for successful or regular operation, more gas could be put into the bulb by heating such material as potassium chlorate or potassium hydrate.

I mention that in connection with this Whitney paper, because potassium is a part of the name of each of those two materials, and potassium metal is one of the materials suggested in the third patent here in suit. I think it is perfectly clear that potassium chlorate and potassium hydrate are both very different things from potassium metal, and that the suggestion that gas may be evolved by heating either of those materials is a very different thing from the patented invention of using the metal films for the absorption of a harmful gas.

Potassium chlorate gives up oxygen when heated and melts at a relatively low temperature, about the same temperature at which glass softens, and potassium hydrate is used as a drier and it will give up water when it is heated after it is absorbed. It melts also at about the same general range of temperature.

That is all I have been able to find of interest in the Whitney paper, that is to say from the point of view in this suit. Perhaps I should note that the pages which I have given are the pages on the photostat I have here of a reprint of the paper, and I am not certain that the paging is the same in the transactions that are published once a year and form the collected papers of the American Institute of Electrical Engineers. Therefore, I might say that the two pages I have referred to specifically 1208, is the second page, and 1215 is the ninth page, respectively, of the article.

The next exhibit is Defendant's Exhibit No. 34, U. S. Patent 1,121,802, issued to Clark on December 22, 1914. This is hardly an electrical patent. It suggests placing a potassium or sodium coating on the interior of a lamp wall and to that extent it is of electrical importance. It puts the sodium into the tube by distillation from a side chamber as in Figure 1 or Figure 3, the side chamber being marked 2, and the vapor condenses on the wall of the lamp so that there it will act as a reflecting mirror. That is set out at page 2, line 41 of the patent and the fact that such a mirror has a high reflection coefficient is pointed out at line 100, page 1.

Clark indicates that the calcium or sodium which he proposes to use will oxidize and that therefore he must apply the coating without letting them oxidize. Reference to that is at page 2, line 5. And he does that,—he puts the alkaline metal into the tube without allowing it to oxidize by distilling it in the vacuum instead of by doing it in the open air where moisture or oxygen would spoil the brightness of the surface.

His statement is that when the alkaline metal is distilled in this way the oxygen free result that is desired, that is, the bright mirror, is had, and there is no suggestion so far as I can find in the patent of the removal of the lamp's oxygen, that is the oxygen of the air that originally filled the lamp at atmospheric pressure, except by the evacuation prior to the distillation.

Of course, there is no recognition of any keeping action on the part of the sodium or potassium mirror which forms on the inside of the wall. In fact, so far as that might occur it would dull the mirror and destroy Clark's result and his purpose. I think that this is not even remotely allied to the present case except that it does describe a mirror of one of the metals suggested, on the inside of a vacuum tube, but it could have no such effect as is necessary for the protection of a thoriated filament, which is perfectly clear from the fact that at page 2, line 114, of the Clark specification, that oil or mercury or some other liquid within the bulb is used in order to keep an open window through which the light may emerge after reflecting on the inside mirror, if anything more were needed to show that there can be no vapor free or oxygen free or mercury free vacuum within a chamber made in this way.

The next exhibit is Defendant's Exhibit No. 36, Patent No. 1,246,054, to John Clough, issued on November 13, 1917. This is a tube containing a rare gas and having an anode of calcium, magnesium, titanium, or the like, as stated in the specification. It operates at a high gas pressure. The specification page 1, line 65, points out that it should be above a pressure of several milliamperes of mercury and will more usually approach the order of magnitude of atmospheric pressure; and a specific pressure desired in the case of argon filling is given at page 2, line 11, as from five to twelve centimeters. That would be from 50 to 120 millimeters of mercury pressure.

That of course is a condition that is utterly impossible for a thermionic tube of either the first patent or the second patent in case voltages above ionizing voltages are used, because the ionization would kill the 3/2 power operation in the space charge range and would also destroy the sensitive thoriated filament.

The device of Clough is called an enclosed arc device and is that in fact. He says that it has a cathode consisting of a highly refractory material and operating at incandescence in a gaseous atmosphere, the pressures of which I have already indicated. He proposes the use of a highly chemically reactive metal such as calcium, magnesium, or titanium (this is on page 1, line 18), with a gaseous atmosphere of argon or one of the monatomic gases so as to reduce the voltage drop in the arc to what he calls a hitherto unattainable low value.

The purpose of that is to reduce the voltage that is consumed, so to speak, in the rectifier device itself; and of course in low voltage high current devices of this enclosed arc type, which is of the group that is generally characterized by the name Tungar, it is important to reduce the voltage drop and therefore the losses within the rectifier itself as far as possible.

For instance, if one is charging a six-volt storage battery with a rectifier that has a voltage drop of twelve volts, obviously the greater part of the effective total voltage of eighteen is across the rectifier instead of across the battery and consequently one endeavors to reduce voltage drop on the rectifier as far as that may be done.

The specific examples that Mr. Clough gives as to current and voltage are on page 2, line 12 and the following. The currents passed are in one instance eight amperes, in another twenty amperes, and in another ten amperes.

Those of course are high space currents characteristic of large ionization produced in gases of these high pressures. He points out that long running, forty minutes to three hours, again in this same section on page 2, will reduce the voltage drop in the way he desires and he attributes that to the action of this calcium, magnesium or titanium anode in getting rid of impurities in the atmosphere of inert gas. He says that the voltage reducing effect is entirely new and he describes the drop in arc voltage as a chemical effect of the calcium anode in the case of one of his experiments.

That reduction occurs in a high pressure tube of this kind under conditions of violent ionization and of course vapor from the calcium or magnesium anode under the heat developed at that anode will contribute to the ionization in the gas path, in the arc path, the ionized path between the two electrodes. There is consequently a possibility of the hot vapor removal of water vapor or of oxygen in much the same way as in the case of the Soddy pump where the hot vapor acted on these gases and that may have contributed as much or perhaps not so much or perhaps more, I think not so much, to the reduction in arc drop as does easy ionization of calcium or magnesium vapor.

In any event, the reduction would be to no more than the pressure of a few microns as in the case of the X-ray tubes, and that is particularly well indicated by the fact that the initial exhaust before rare gas is put into the tube, need not be done carefully. Clough says on page 1, line 61:

> "The action of the anode material makes it unnecessary to use such great care in exhaust as has been necessary formerly."

I take it from that that he would give these tubes an exhaust characteristic of the Tungar before introducing the rare gas, and that would be that they would be brought down to a matter of ten or fifty microns, so that clearly the vapor from the anode could not take up enough of the pressure of oxygen or of water vapor, beginning at even ten microns, to reduce the partial pressure to a point that would be sufficiently well cleared of oxidizing gas to protect a thoriated cathode. More would have to be done than indicated here in order to get any such result as that. Without regard to that as a matter of discussion, however, this structure has no oxidizable filament to protect. The cathode is not of a thoriated type. There is, as I said, no low initial pressure, nor any careful exhaust, and consequently there is no possibility, and of course, no suggestion of any keeper action in a tube built in this way. Yes, that finishes that part.

THE COURT: Ten o'clock tomorrow morning.

(Whereupon at 6 P. M., an adjournment was taken until Friday, November 5, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del.,
Friday, 5th November, 1926,
10 o'clock A. M.

SEVENTEENTH DAY.

Before:
Hon. Hugh M. Morris,
U. S. District Judge.

Appearances as before.

Mr. Davis: I wish to state that it is not the intention of the plaintiff to recall Dr. Arnold for further cross-examination with reference to the notebooks, and so forth, provided that defendants will agree to keep these various notebooks available to us; and we understand, of course, that they will be returned, and that we may take such extracts or photostat copies of specific pages as we may need, and that when our witness desires to testify about what he finds in these notebooks the defendants will stipulate that these are the books that they purport to be.

Mr. Haight: Our position regarding these books, if your Honor please, is this: The books have not been proved and cannot be used in evidence without proof, or without our consent. We have no disposition, however, to prevent the use of such part of the books as the plaintiffs may want to use, provided we are notified now, or before we depart for the week-end, of the parts that they want to use, and the reasons why they think that they are relevant and material to the issue in this case.

Mr. Davis: I am sorry that I shall be unable to give that notice today in detail. It will be physically impossible to do it.

Mr. Haight: Well, I suppose if we have notice on Monday, it will be time enough.

Mr. Richmond: I cannot answer that, because I do not know how big the proposition will be, but we will do the best we can.

Mr. Haight: I do not want to ask Mr. Davis to do an impossible thing. I thought probably they had the thing lined up if he was going to be in Court today.

Mr. Richmond: There is a stack of these books that high (indicating), and our opponents know a lot better than we do what is in them. They have had them from an hour to a week, as we have been able to get them here for them, so that it is hard for me to answer more definitely than that.

(Further Discussion.)

Mr. Haight: I do not want your Honor to be under a misunderstanding. Both sides have furnished each other with documents and papers as requested, and we have done that as a matter of decent practice of law.

The Court: Surely. That is the reason I hope you ignore——

Mr. Haight: And the only question now is whether these notebooks are admissible in evidence. Now, we say that they are not admissible, but we have not any objection to the other side using them, provided they tell us what parts they want to use, and point out the relevancy or materiality of those parts, so that we will be in a position to explain or rebut them, if we deem it advisable to do so.

Mr. Davis: I think perhaps under the circumstances it is proper that I should withdraw the statement that I am not going to cross-examine Dr. Arnold because I propose to get what I want out of those notebooks, if I have to subpoena people from New York to testify about them.

Mr. Haight: You see if that is done, that will give us the very thing that we feel that might be given to us the other way. All that we want is not to bludgeon in the dark, that is rather——

The Court: I had no thought that counsel will not be able to continue as they have begun.

Mr. Davis: We will do all we can, if your Honor please, but we have been under great pressure for a long time.

Mr. Davis: I ask that defendant's counsel stipulate that the Coolidge patent No. 1,211,091, issued January 2, 1917, and referred to in the history of the Arnold patent, which I offered in evidence yesterday, that the stipulation be that the application for that patent was filed in the United States Patent Office, October 28, 1915.

Mr. Darby: You ask us to stipulate. Very well, subject to correction.

Mr. Davis: And in the same manner, and subject to the same correction, stipulate that the application for the Coolidge patent, No. 1,211,092, January 2, 1917, was filed June 5, 1915.

Mr. Darby: It is so stipulated, subject to correction if error appears.

Mr. Davis: If your Honor please, Dr. Coolidge is here and my friends on the other side——

Mr. Haight: What about Mr. White?

Mr. Davis: We have now two witnesses on the stand, but I would like to have Dr. Coolidge go home today. I think defendants would like a little time after his direct, to look at the notebooks, and perhaps get ready his cross-examination, and I thought they would prefer I put on Dr. Coolidge first, that is all—anything they like.

Mr. Haight: That is agreeable.

The Court: Then very well; let Dr. Coolidge be sworn.*

John V. L. Hogan, resumes the stand.

Direct Examination (Continued).

By Mr. Edmonds:

Q. 218. Mr. Hogan, will you continue your answer to the last question? You have reached, I think, the patent of MacKay?

A. That is correct. The next reference to be considered is, I believe, the last one on the list contained in the question, and is Defendant's Exhibit No. 37, which is a patent No. 1,208,597, issued to MacKay on December 12, 1916. This has to do with enclosed arc rectifying devices of the sort referred to in the Clough patent discussed at the end of the session yesterday. The drawing is much the same, the difference being that the anode in MacKay is made of tungsten or carbon, as explained at page 1, line 54, and that on the heavy wire lead supporting the filament, there is placed, as shown in the drawing by reference number 9 on Figure 1, a wrapping, so to speak, of magnesium or calcium. Another way of putting the material into the tube is suggested in Figure 2, where a capsule is shown at the top of the tube. This invention of MacKay's has to do with the operation of a high pressure gaseous atmosphere rectifier, specific reference to the pressures occurring on page 1, line 78, and the following, for instance, where it is stated that argon at a pressure of about 5 to 12 centimeters of mercury is found suitable.

---

*For examination of Dr. Coolidge, see page 1495.

Q. 219. That is what, in microns?

A. 50,000 for 5 centimeters. This patent is, like the Clough patent, directed toward decreasing the arc voltage drop in a device of this kind, so as to improve its efficiency. The conditions of operation, are, of course, impossible for a thermionic tube, because there is so much ionization that space charge would be destroyed. In fact, it is only by the destruction of space charge that the extremely high current flows through such a device. Also, the filament, if it were of thoriated tungsten, would be destroyed by ionization, as soon as a voltage above ionization values was applied. The preparation of the tube involves evacuation and the filling with a suitable gas at a considerable pressure. I think the comments I made as to the Clough patent in this same connection, would apply here.

Now, MacKay says on page 1, line 63; that:

> "Removal of water vapor from the bulb by heating the bulb during evacuation is desirable, but not so necessary as when no chemical addition is used."

He suggests at page 1, line 23, the use of non-metallic absorbents, such as phosphorus pentoxide instead of the alkali earth metal, calcium or magnesium, and evidently considers them equivalents, and says that they have no affinity for the gaseous filling, but are chemically active with respect to impurities in the gaseous filling.

That is stated at page 1, lines 24 to 26 in connection with the discussion of the desire to produce a markedly lowered voltage drop or loss in the arc, as stated at the beginning of the first paragraph. The end of that paragraph points out that where argon is used, the most deleterious gaseous impurities tending to increase the drop of potential, appeared to be water vapor, hydrogen and nitrogen. The only one of those three that affects the thoriated filament, which we are considering, is water vapor, by reason of its oxygen, although of course above ionization potentials, bombardment by either of the other two gases might make trouble.

The MacKay specification on page 2, line 20, points out that the arc apparently activates the gaseous impurities, so that they combine more readily with the chemical agents within the bulb; and it is perfectly clear from the disclosure, that he relies upon or considers necessary this arc heat or the highly active state of his contained materials which result from the high temperature at which this sort of device operates in the discharge path, the ionized path.

I suppose that even starting with a rough exhaust of the sort that would be used here or in the Clough case, the partial pressures of oxygen or water vapor might as the result of the process described here, go as low as a few microns, or perhaps even lower than that; but I see no possibility of those pressures going down to anything like the order that we have to have with a thoriated tungsten filament, in order to prevent oxidation of its highly sensitive surface, and consequent destruction of this high emission. Of course there is no suggestion in the MacKay patent of any cold action on the part of any of the materials contained, whether calcium or magnesium, which are specifically used in the fourth patent in suit, or of phosphorus pentoxide, MacKay's alternative that is of no value in connection with thorium emission at all, and there is no suggestion in MacKay of any film keeping action as the result of his use of any of the three materials that he proposes.

I do not believe that any such film-keeping action or cold action can be expected at pressures of the order used by the MacKay. Such pressures and temperatures as are used by him, that if a film should occur on cooling, for example, when the arc is started positive ion bombardment from the arc would sputter the film or vestiges of the film to a vapor, and we would be back where we were before to that hot vapor clearing out impurities for the purpose of reducing the arc drop. The emphasis on page 1, line 93, is on the heating in MacKay, and page 1, line 88 on the vapor, and he gives as his examples a six-ampere arc in argon with phosphorus pentoxide, giving a drop of thirty to forty volts ordinarily reduced to about ten volts, when a small quantity of phosphorus pentoxide is used in the tube.

That example occurs on page 2, beginning at line 37, and continuing to line 44.

A second example of a neon-filled tube is given, in which the arc drop is reduced from about fifty volts down to about twenty volts, by supplying metallic calcium in the tube. Since the stated purpose and the practical value of the MacKay invention is the reduction of the arc drop, it is clear that the phosphorus pentoxide which brought the voltage drop down to ten volts, on a six-ampere tube, would be preferred to calcium which brought it down to twenty volts only in a similar six-ampere tube, one being used with argon, and the other with neon.

I believe, now, Mr. Edmonds, that I have covered all of the citations given in your question.

By Mr. Edmonds:

Q. 210a. Before you leave the MacKay patent, will you explain the statements appearing on the second page at line 20, with respect to the function performed by the arc in developing the activity of the gaseous impurities?

A. The sentence is:

> "Apparently the arc activities the gaseous impurities, so that they combine more readily with the chemical agents within the bulb."

That is the sort of reference I spoke of as to the necessity of heating from the arc, or perhaps positive ions from the arc, but in any event the creation of an active state in which these desired combinations proceed in such a way as to reduce the arc drop.

Of course, there is another possibility there. I think I referred to that in connection with the Clough patent, and the emphasis on the action of the arc itself, rather strengthens that.

The point is that the reduction in arc drop may be very largely due, and perhaps almost entirely due to the relatively easy ionization of the vapors from the materials put in. Of course, that is a function, which, while useful in a device of the Clough or MacKay type, would be exactly the sort of thing one would not want in a pure electron thermionic device, or a device operating with a thoriated cathode.

Q. 211a. Will you next consider the White patent, No. 1,159,307, Defendant's Exhibit No. 42, in this case, and state what bearing you find that patent to have upon the third and fourth of the patents in suit, if any?

> MR. EDMONDS: I do not know whether your Honor will recall this patent or not (handing paper to Court).
>
> THE COURT: No, I do not.

A. The White patent, No. 1,159,307, describes an electrical discharge device which is, as stated at page 1, line 14: "My Improved Detector." That is to say, a device utilized for the conversion of radio waves into a form that will operate a normal indicator, and so give a response, for instance, in a telephone receiver.

The improved detector is stated in the same paragraph to be similar to the DeForest audion, and also similar to the vacuum tube device of the Langmuir patent, or of the Langmuir application, No. 795,610, which I believe resulted in the first patent in suit here.

The first long paragraph in the specification, constituting practically the whole first column of page 1, describes the common features of both devices. They are treated as the three-electrode type of device from the point of view of this patent and are rather completely described here. White points out in the second column that the detection sensitiveness of a Langmuir tube may not be sufficiently high to give the best possible response.

He states that, as based upon "asymetry of current flow," beginning at page 1, line 58, and he says beginning at line 65, that the device, that is to say, the Langmuir device, "is more especially valuable as a relay or amplifier of such oscillations." Then he states that if a certain amount of residual gas be present in the tube the operation of the device becomes quite different, and he goes on to describe the audion, pointing out at line 79, that there is a limit to the voltage which may be used in the circuit of the audion, because as the voltage increases ionization of the gas in the tube increases, a blue glow appears followed by deterioration of the electrodes, disengagement of more gas therefrom and finally the destruction of the operative qualities of the tube.

He explains thereafter that the voltage is made as high as possible consistent with avoidance of those limitations, and explains the principle of operation of the audion in that a decrease of potential on the grid causes a decrease of current in the plate circuit and *vice versa*, and your Honor may recall that that fundamental explanation of the way in which the audion operates was that which was put out by Armstrong and adopted thereafter by most of the people including White.

He says that the result is that when high frequency oscillations are impressed upon the grid their presence is made known by a decrease of current in local or plate circuit, and that is the normal operation of the audion detector.

Then he continues on page 1, line 104, stating that he has found that by maintaining within the evacuated container of a device of the general nature already described, that is to say, a three-electrode tube, a certain definite pressure of gas which in amount is very much less than that which is necessary to make the so-called audion operative, and not greatly more than would be tolerated in a device such as disclosed in the Langmuir application, very remarkable results are secured in the relations which then exist between the current in the plate circuit and the voltage on the grid.

That is to say, he proposes the use of a definite and small amount of gas or vapor in a tube which has previously been cleaned and made a perfect Langmuir tube so to speak. He says, beginning at page 2, line 6, that, with this definite pressure of gas or vapor in the device, he has found that the variation of current in the plate current with variation of potential circuit on the grid follows the law of a pure electron discharge tube such as that of the Langmuir application, except within a small range of voltage the plate circuit. Page 2, line, 13, reads:

> "Within this small range there appears to be a condition of instability such that when high frequency oscillations are impressed upon the grid there always follows a sudden decrease of current in the local circuit."

That is later described with reference to a sudden drop or kink in a characteristic curve, which kink is at a definitely restricted point of the characteristic. As one increases the voltage it results, because of the steepness of current change at that point, in a much greater detector sensitiveness than would be secured in a Langmuir tube.

Beginning at page 2, line 35, White says that while his improved detector is dependent upon the presence of a small but definite gas pressure in the space including the electrodes, its operation is not accompanied by blue glow or any other well-recognized evidences of positive gas ionization, and

> "The amount of gas or vapor present is perhaps not more than one-tenth of that which characterizes the so-called audion."

The next paragraph, beginning at line 44, describes the sudden change in plate current to which I have already referred, and then beginning at line 55 of page 2, White says:

> "In producing and maintaining the desired gas pressure in my improved device it is not sufficient to leave in the tube a certain amount of residual gas during exhaustion, since this gas does not remain constant in amount but generally will decrease upon operation of the device by the well-known cleanup action, though in some cases the amount of gas present increases rather than decreases, due to other causes."

That of course refers to a possible attempt to clean the tube and the electrodes and then to leave within the tube a certain amount of gas during exhaustion and White warns against that, since he says it will not be steady and the clean-up will reduce the gas and he says in some cases the gas pressure will increase to an unwanted extent due to other causes.

Those causes are necessarily incomplete bake-out or incomplete preparation of the electrodes within the tube.

Then he continues at line 64 of page 2:

> "To secure the necessary definite gas or vapor pressure in the tube, I therefore provide a substance with the desired vapor pressure and place this in the tube. Among other things I have found that amalgam is suitable for the purpose. Mercury alone appears to be unsuitable, as it has too high a vapor pressure at ordinary temperatures though by lowering the temperature of the mercury the desired vapor pressure may be obtained."

In other words, White wants a certain amount of gas in his tube, gas or vapor, it makes no difference from the ionization point of view which it is. He wants to get a certain definite and controlled amount of ionization, which will produce a certain irregularity at some part of the characteristic curve and this increases the sensitiveness of the device as a detector when operated at that point.

Of course, such a discontinuity or irregularity would work against the use of the device as a quantitative amplifying apparatus, for instance, but it is desirable for increasing the sensitiveness in the detector condition.

White says that he cannot rely upon residual gas, not completely exhausted, and so he proposes cleaning the tube completely and then putting in a substance with the desired vapor pressure such as amalgam.

An amalgam is simply a piece of metal which alloys with mercury or which mercury will wet and which has as a result of the alloying action a somewhat lower vapor pressure than liquid mercury alone would have at any given temperature.

I am not sure what the range of pressures attainable by the use of amalgams may be, although I can look that up, but I think it is easily possible to produce metal amalgams of mercury which have pressures of the order of one-tenth of that of mercury itself for the same temperature.

The remainder of the second page of the specification is a detailed description of the structure and at the beginning at the top of page 3, more information about this introduced substance is given at line 5 and the following:

> "Before the envelop is sealed off there is placed in it (in a manner hereinafter described) a small amount of vaporizable material 17, for example, an amalgam, sulphur, phosphorus pentoxide, tungsten hexachloride, and in general substances having a suitable vapor pressure at the operating temperature of the device."

He then goes on to warn against substances having too high a vapor pressure such as mercury, but to indicate that they may be used if a low temperature is maintained as in a side chamber. That is of course a practical thing to do although inconvenient.

He says at line 16 that gases at the proper pressure will give the desired effect, but the effective pressure and possibly also the character of the gas are changed by some chemical or electro-chemical action in the tube, so that gases act only temporarily. That is another reference to the change of pressure of which I spoke.

Again referring to the material 17, either loosely placed in the main envelope, page 3, line 21, or placed in the side chamber, he states, at page 3, line 23:

> "The character of this material depends upon the temperature and voltages at which the device is operated, as will be hereinafter explained, its purpose being to maintain in the space, vapor at a definite low pressure."

Following that is a description of the evacuation of the device and the formation of the amalgam within it by the introduction of mercury vapor and its subsequent condensation before the seal-off and after evacuation.

Then occurs the statement on page 3, line 79, that a device thus prepared will operate at ordinary room temperatures with a substantially pure electron discharge between anode and cathode without positive ionization, even when the impressed voltage is as high as three to four hundred volts or even higher.

However, when the voltage between cathode and anode is within a certain range an irregularity is observed in the electron discharge current as already described.

That portion ends at line 88 and is a more detailed description of the kink in the characteristic to which I referred.

The circuits are described in the next two columns and then beginning at page 4, line 51, White says:

> "On either side of the region of greatest sensitiveness indicated by the off-set of the curve 18 of grid potential, the characteristic of my device, is substantially that of a pure electron discharge. The vapor pressure necessary to produce this peculiar effect varies with the character of the material used."

He then states the sort of pressures which he wishes to obtain in his tube by the introduction of these amalgams or the other materials.

> "For mercury vapor in the type of apparatus illustrated the pressure should be between the limits of .00006 and .00040 millimeters of mercury."

This corresponds from six one-hundredths to four-tenths of a micron of mercury. Continuing at line 61 for the case of sulphur he says that it operates best at a pressure of from two-tenths to three microns of mercury. He then goes on to describe the operation of additional circuits.

THE COURT: You come now to the conclusions?

THE WITNESS: Yes.

THE COURT: We will defer that until the next session.

MR. HAIGHT: It is stipulated that the original of such of defendant's Exhibits Nos. 100 to 278, inclusive, offered in evidence in this case and listed on pages 935 to 947, inclusive, of the record, as are reproduced in the Interference record, need not be produced and filed with the clerk, but that in lieu thereof, the copies of such exhibits embodied in the Interference record may be considered as the original exhibits in this case and marked by the clerk accordingly.

And it is further stipulated that the original of such of Plaintiff's Exhibits Nos. 20 to 161, inclusive, offered in evidence in this case and listed on pages 928 to 934, inclusive, of the typewritten record, as are reproduced in the Interference record, need not be produced and filed with the clerk, but in lieu thereof, the copies of such exhibits embodied in the Interference record may be considered as the original exhibits in this case and marked by the clerk accordingly.

(Whereupon at 5 P. M. an adjournment was taken to Tuesday, November 9, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del,
Tuesday, November 9, 1926,
at 10 o'clock A. M

EIGHTEENTH DAY.

Before:
Hon. Hugh M. Morris,
U. S. District Judge.

Appearances: As before.

Mr. Edmonds: Now, Mr. Hogan.

John V. L. Hogan, resumes the stand.

Direct Examination (Continued).

By Mr. Edmonds:

Q. 212a. Mr. Hogan, will you complete your answer to the last question, concerning the White patent?

A. I think I had already pointed out at the end of the specification that Mr. White said, page 4, line 51, that his tube operated like the Langmuir tube of the first patent, except at the kink in the characteristic curve which was produced by the additional gas, and also that at page 4, line 60, he points out that when mercury is used, he desires a pressure of from six one-hundredths of a micron up to four-tenths of a micron, of the specially added vapor, and that when sulphur is used, he may desire from two-tenths of a micron to three microns.

This White tube is then a detector tube which is produced by introducing into the tube a definite pressure of gas or of vapor. Before the gas is introduced, the tube is prepared as would be a Langmuir tube of the first patent here in suit.

The introduction of the gas or vapor at the definite pressure destroys the smooth and regular operation of the tube at one part of the voltage range. The vapor may be introduced by a vaporizing material, such as sulphur, mercury, amalgam, of which White spoke, and that particular material or the alternative materials to which he referred, gives off a definite amount of gas.

Putting in that material then instead of improving the vacuum of the Langmuir tube of the first patent, as is the case with the magnesium or the alkali metal of the third and fourth patents, that is to say, instead of taking out or reducing the partial pressure of oxygen, or water vapor, or carbon monoxide or carbon dioxide, here White increases the pressure and prevents a clean-up.

If this device should be used with a sensitive thoriated tungsten filament, the bombardment of positive ions, even if not the vapors themselves, would shorten the emission by knocking the thorium off the filament, even if they were operated considerably below the blue glow point, because the kink or irregularity in the characteristic is based upon the presence of a definite amount of ionization which is produced by the introduction of gas-giving materials.

In that connection I have a curve that gives the vapor pressures of mercury, sodium, potassium, and magnesium in a range of temperatures from zero degrees Centigrade to 300 degrees Centigrade. That shows in the upper left-hand corner a high pressure corresponding to a micron of mercury at about room temperature. The ranges chosen by White are indicated on this sheet. Then at considerably lower vapor pressures come the potassium and sodium curves and finally the magnesium curve with a very much lower vapor pressure at considerably higher temperatures.

I have also made a tabulation of the temperatures in degrees Centigrade that are necessary to attain specific vapor pressures for these five materials, mercury, potassium, sodium, magnesium and calcium. Four pressures have been chosen, one one-thousandth of a micron, one one-hundredth, one-tenth and one micron and perhaps the quickest way to handle this would be to give the tabulation to the reporter and put it into the record at this point. I want to comment that the amalgams will come a little below the mercury but are above the potassium with respect to the scale.

(The tabulation referred to by the witness is as follows):

Temperatures in Degrees Centigrade to Attain Specific Vapor Pressures.

Pressure	Mercury	Potassium	Sodium	Magnesium	Calcium
0.001 micron	—43°	64°	83°	260°	416°
0.01 "	—27°	83°	112°	300°	468°
0.1 "	—7°	118°	150°	346°	524°
1.0 "	18°	153°	192°	398°	592°

Mr. Edmonds: Curve produced by the witness is offered in evidence.

(Received in evidence and marked "Plaintiff's Exhibit No. 176." *See Volume IV, Plaintiff's Exhibits, page 129.*)

By Mr. Edmonds:

Q. 213a. Referring now to the Defendant's Exhibits, Nos. 39, 40 and 41, these being the patents of New Zealand, Australia, and Great Britain, I find referring for example to the New Zealand patent the following passage:

> "The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used."

This last sentence, and I think the next one as well, is common to all three of the patents. Will you explain to the Court the meaning of that last sentence?

Mr. Darby: I object to that. The patent speaks for itself.

The Court: Will you read the question?

(Q. 213a was repeated by the stenographer.)

The Court: I see no word or phrase or sentence there that needs interpretation. I may be mistaken about that and consequently I will overrule the objection. Unless there is, I think it goes beyond the expert's testimony.

Mr. Edmonds: I did not think your Honor would know whether this is an additional step or a substitutional step.

The Court: It is on that basis that I overrule the objection.

Mr. Darby: As I understand from Mr. Edmonds' last statement, the witness will draw his own conclusions and advance them. As I understand, Mr. Edmonds admits that the question is not directed to explain any word, phrase or technical expression.

The Court: If it is a construction of the patent, whether it is in the record or not, I cannot tell what it is until he gives it. While expert testimony in its proper field is exceedingly helpful and indispensable, when it goes into the judicial field it is of no help.

A. The reference to chemical evacuating means such as electrically vaporized calcium or magnesium, which may also be used, is a reference to such a calcium or magnesium furnace, electrically heated——

Mr. Darby: I object to that. There he is going outside of an expression in the patent. He refers to some other kind of means not described in the patent.

The Court: That is on the border line, I think, Mr. Darby, and I will not strike it out.

A. (Continued.) Such an electrically heated calcium or magnesium furnace as we discussed in connection with the Soddy patent last week. The use of that may be in addition, and as Soddy proposed it, it was in addition to another pump. That is to say, the use of electrically vaporized calcium and magnesium is an additional evacuating means over and above the rough pump.

By The Court:

Q. 214a. The patent says that?

A. It says "may also be used." I think the natural way to read it in view of Soddy is that a rough pump would be used first and calcium and magnesium additional.

Q. 215a. I gather from the reading of the words of the patent, it was an alternative and not an addition.

A. It may be taken either way and I am not positive as to which. I think that the use of calcium and magnesium furnace was always in connection with a preliminary pumping.

Q. 216a. But the patent is not clear as it is there?

A. That is correct.

By Mr. Edmonds:

Q. 217a. I call your attention to the two photographs, Defendant's Exhibits No. 70 and 71, of the Lamont pumps and the testimony of the California witnesses concerning them, and particularly the matter of technique of using them in evacuating tubes. Using these pumps and that technique, will you say what would be the character of the vacuum of a tube exhausted by means thereof?

A. This pump with its use of mercury, without any means of excluding it, without any effective exclusion of water vapor, without adequate baking of the bulb, and without any heating of the plate or grid of the tube, other than that incidentally secured by the gas-heating of the bulb, would necessarily result in producing a tube of the typical DeForest audion type characterized by a low-power limit and irregularity of operation. If sulphuric acid were used in the bulb E of the pump, oxygen-bearing vapors would get into the tube and affect both the ionization and a filament there, and if phosphorus pentoxide were used while it is a useful drying agent, it gives off oxygen gas, and that would be present in the tube.

Q. 218a. If an attempt were made to use a thoriated tungsten filament in a tube evacuated by means of these pumps, and this technique, would thorium emission be realized?

A. No, I am quite certain it could not, because of oxygen-bearing gas and oxygen itself, in addition to the bombardment that would follow in such a tube.

Q. 219a. Would you say in a word, Mr. Hogan, whether there would be any essential difference as between such a tube as Lamont is said to have evacuated by means of this apparatus and technique, and on the other hand, the regulation DeForest audion of 1912?

A. No. I think there would not. I think Lamont simply made audions which were of fair performance.

Q. 220. Referring to a vacuum tube said to have been operated upon by Lamont, defendant's witness Hewlett testified that it was customary to put in his station, a variable B-battery ranging from forty to seventy volts. His testimony continued:

> "The voltage depended upon the degree of exhaustion of the particular tube I had in use, and I would say it ranged around about 60 volts but I had a glass beaker with a thermometer and the tube in the oil of this beaker, and by lighting a small alcohol lamp under this beaker, I could some-

> what control the amount of B-battery used for best results . . . heating the tube lowered, the amount of B-battery used on the tube . . . the filament of the vacuum tube was lit to a brilliant incandescence, and the filament was controlled by a small rheostat from a suitable battery."

Will you say what effect upon the tube or its vacuum, the heat in the oil bath had, Mr. Hogan?

A. That is exactly like the tube heating that was commonly used by radio operators in the early years of the audion. The heat applied to the glass walls results in disengaging gas within the tube and therefore increasing the gas pressure in the tube and reducing the voltage at which a blue glow can be had, and also the operating voltage of the tube. A blue glow at sixty to seventy-five volts shows in the ordinary audion construction with a gas pressure of something like four to six microns.

Q. 221. The defendant's witness Beck testified that when filaments were replaced in Lamont's shop, the replacement filaments were of tungsten, and that "they acted just like wire," that she "could handle the tungsten just like the wire, and could bend it in shape," that she "actually did bend it," and that she knew the replacement filament was tungsten wire "because it was not carbon." Will you state if, in your opinion, this testimony points to the use of tungsten wire at all?

A. Well, from the fact that tungsten filament taken from a lamp is extremely brittle, I think that that could not have been tungsten. Tungsten filament from the spool, before it goes into a lamp, is bendable, but once it has been heated in the vacuum, even for the aging run at the factory, and after the use of the lamp in normal service, the filament becomes brittle so that it would not bend like wire. Tantalum, on the other hand, will bend in that way.

Q. 222. Then you agree with defendant's witness Lamont in the statement that "it is next to impossible to re-shape the tungsten filament"?

A. Yes, if the filament is taken out of a lamp.

Q. 223. Witness Hyde testified to the practice of exhausting a vessel by means of a pump, and the use of manganese dioxide in a side tube connected with the vessel. I call your attention to his answers to XQs. 2 to 11, and ask you to state what would be the degree and quality of the vacuum resulting from this practice.

A. This was a side tube chemical pump used in addition to the mechanical pump, and I think not always used, as I remember Hyde's testimony. With manganese dioxide heated in such a side tube, he might be able to get a useful X-ray vacuum of from three microns up to ten microns, but there would be no chance at all of his getting a low pressure and particularly a partial pressure of oxygen-bearing gases corresponding to what is necessary for the last three patents in suit here. Tests of manganese dioxide as a pumping agent used in this way have shown the impossibility of activating a thorium filament in the vacuum thus produced.

That probably is due because managnese dioxide when it is heated apparently gives off enough oxygen from the compound to poison the thoriated filament and then does not reabsorb in cooling enough to prevent that poisoning. It is a relatively poor chemical pump.

Q. 224. The witness Hyde also testified XQ. 59, that he "made changes on the pump that made it possible to obtain a vacuum, without use of any chemical agent, equal to rotary oil pumps used at the present time and roughly to a vacuum of four to six microns."

Say in a word whether a thoriated filament could be operated to realize thorium emission in such a vacuum.

A. No, it could not. That is an X-ray vacuum.

Q. 225. Defendant's witness Beale testified to the use of DeForest audions at Q. 11 that according to his recollection, "There was a defined distinction between detector tubes and amplifier tubes in the fall of 1912." Have you any knowledge on that point?

Mr. Darby: I object to that. The testimony refers to a distinction in the Federal Telegraph Company out in California.

The Court: The statement as made by Mr. Edmonds is too general?

Mr. Darby: Yes, sir.

By Mr. Edmonds:

Q. 226. Just limit the answer to the question to your own knowledge of the conditions existing in that year entirely apart and outside of the affairs of the DeForest Company in California.

Mr. Darby: I object to that as immaterial.

The Court: I will hear you, Mr. Edmonds, because as I understand the status of the evidence from Mr. Darby, it would not meet the evidence put in by Mr. Darby.

Mr. Edmonds: I think that quite apart from meeting that evidence specifically as to what was the practice in the Federal Company's place, it would be proper for us to show that in the general use of these audions, that there was no distinction recognized at all or if there was a distinction to show what it was.

The Court: That would be evidence meeting defendant's case generally and not meeting the evidence specifically.

Mr. Edmonds: Yes, sir.

The Court: Let me hear the question.

(Q. 226 was repeated by the stenographer.)

The Court: Do you want to reframe that question?

By Mr. Edmonds:

Q. 227. Entirely without reference to Beale, will you state whether there was any such thing as a recognized distinction between detector tubes and amplifier tubes of the DeForest type in and about 1912?

Mr. Darby: I object to the form of the question, because by inference it has some bearing on Beale and the Federal Telegraph Company.

The Court: I think your objection is well taken. Do you want to still reframe it?

Mr. Edmonds: Yes, sir.

Q. 228. In 1912, was it so far as you are aware, the practice in the use of the DeForest audions to distinguish between some of them and others of them with respect to their use as detectors or amplifiers?

A. I do not know what the custom was in 1912, since we had no DeForest amplifiers in the East at that time. I do know that when DeForest came East in 1913, the distinction— —

Mr. Darby: I object to that.

The Court: Sustained. This part of the answer is not responsive to your question.

By Mr. Edmonds:

Q. 229. Let me ask you if it was common to use DeForest audions of different types with respect to their vacua for detection or amplification?

Mr. Darby: When?

Mr. Edmonds: In and about 1912.

A. I cannot answer that as of 1912, though I can, as of the few years following.

Q. 230. Please do so.

A. The amplifier tubes so-called were tubes of the double plate type and the detector tubes were tubes of the single plate type. The pressures in both types were substantially the same, that is to say, the variation from tube to tube of either type was greater than the variation from one type to the other. I base that statement on measurements of pressure that I have made on DeForest tubes which I purchased in 1914 and 1915.

By **The Court**:

Q. 231. Which has the double plate?

A. The amplifier.

By **Mr. Edmonds**:

Q. 232. You said that there was no essential difference between the DeForest tubes treated by Lamont and the DeForest tubes as made by McCandless; placing them together in one category, will you say how they compared in operation, behavior, and characteristics with, for example, the plaintiff's UV or UX-201-A tube such as Plaintiff's Exhibit 17?

Mr. Darby: I do not know how far afield we are getting. I understand that the witness has testified as to his opinion as to the Lamont tube built on the Lamont pump, but I do not believe that he has testified as of his own knowledge of any Lamont tubes that he himself has used, and I do not see how he can answer this question unless he has had experience with the Lamont tubes.

Mr. Edmonds: The witness has said that the Lamont re-exhausted tubes were essentially the same as the regulation DeForest audion of 1912, and I am grouping those two tubes and asked the witness to compare that with the tube before your Honor in this suit.

The Court: I do not think it is helpful at all. But should there be anything that may be helpful you can be protected by your cross-examination.

Mr. Darby: I do not know whether to move to strike out in view of your ruling or not, but the witness proceeds to state that this is matter that has already been covered in the testimony and then he proceeds to state that the DeForest tube, by inference at least, carried back to the Lamont tubes, was not reproducible and what-not, and this witness is in no more position to testify to that than I am. I will not move to strike it out.

Mr. Edmonds: I think he is.

Q. 233. Will you please make the comparison with respect to the matter of the economy of use, assuming that use to be in connection with radio?

Mr. Darby: I renew my objection.

(Discussion.)

The Court: I will overrule the objection.

A. The old DeForest audion amplifiers which I bought and used had a filament power consumption under normal conditions of about 5½ watts, that is to say, with a voltage of 3½ applied to the filament, the current was about 1.6 amperes which represents a heating power for the DeForest amplifier tube of 5.6 watts. The 201 type filament, which is the pure tungsten filament tube, put out by the plaintiff here, from something like 1920 and before the thoriated filament tubes were put on the market, had a power consumption at normal adjustment of five watts, that is to say, one ampere flowed through the filament at five volts. Although the power consumption was approximately the same as of the DeForest amplifier tubes that I bought from DeForest, and which I have measured myself. The performance of the 201 tube was considerably better, because of its improved design.

Now, the 201-A tube in which the thoriated filament of the second patent here in suit was incorporated, and similarly in the defendant's D V-5 tube, which followed it on the market, the filament power consumption was reduced to one and one-quarter watts, that is to say, only one-quarter of an ampere at five volts. Therefore, one could run four of the new thoriated filament tubes at the same filament cost as he could run one of the old 201-A tubes or old DeForest amplifier tubes.

Q. 234. You do not mean the old 201-A tubes?

A. The old 201 pure tungsten filament tubes or the old DeForest tubes, and at the same time get a better performance. Now, that saving in filament power, while it is small per tube, is tremendous when considered in the aggregate, as covering, for instance, the number of sets used in the United States. It represents a saving to the radio users of the United States, those who are now using 201-A tubes with thoriated filaments instead of 201 tubes, for instance, with pure tungsten filaments, a saving of certainly millions of dollars per year, and I think well over ten million dollars per year. That follows from the thoriated filament construction, and of course is in addition to the longer filament life and the possibility of reactivation and also ruggedness and freedom from burn-out, which are characteristic of the thoriated filament. I might say also that while that has to do specifically with the second patent, the low pressure necessary to get the activated thorium filament could not have been attained if we had not at first gotten as far down as necessary for the ionization free operation of the first patent in suit.

Q. 235. You have referred, Mr. Hogan, to having made purchases of DeForest tubes in 1914. Did you keep abreast of the development of the DeForest tube thereafter, and have you down to date, and can you express that evolution as briefly as possible? I mean now, down to the time of the advent of the D V-5 tube which is complained of in this case?

A. Yes. I have kept in touch with the development of the DeForest tubes. In 1912, the structure as shown by Exhibit 7-A here, is of the same type as McCandless continued to make in 1913 and 1914.

Mr. Haight: May I interrupt you just a minute, Mr. Hogan? I do not know whether I was listening to the objection and to your Honor's ruling a minute ago, and maybe my objection has already been covered by some ruling, but it does not seem to me to be proper for this witness to testify as to his knowledge of the development of the DeForest audion. He can not at the best have more than second-hand knowledge. We have in the evidence the first-hand knowledge.

The Court: I think he had primary evidence of it.

Mr. Haight: He can not know what Dr. Arnold did, or Langmuir did.

The Court: Not at that time.

Mr. Edmonds: We will cure that in a moment, sir. Of course, you understand, Mr. Hogan, I am talking about DeForest audions as put out by DeForest's various companies——

Mr. Haight: I understand then this is limited to the audions put out by the DeForest Company?

Mr. Edmonds: Including this defendant, the DeForest Radio Company, is it? The same corporation under its earlier name, the DeForest Radio Telephone & Telegraph Company.

Mr. Haight: That is the same company.

Q. 236. That is the same company, generally speaking, the companies with which DeForest was identified regardless of the name?

A. Yes, sir, that was my understanding of your question.

Q. 237-38. Yes.

A. The tubes in 1914 which I bought were of the same general type as those which I now know were put out in 1912 and 1913. The two specific kinds were the detector which had the single filament and plate and used about three and a half volts on the filament, with a current of about one-half ampere, and the amplifiers which had the double filament and plate and used about 3½ volts, and 1.6 amperes. I have a copy of the DeForest 1914 bulletin, B-14, entitled: "DeForest Audion Detector," which refers to both the detector and the amplifier bulbs and contains some instructions and comments on their use. Do you want me to quote from this circular, Mr. Edmonds?

Mr. Darby: The only objection I have is to its relevancy and materiality.

The Court: Where is it pertinent, Mr. Edmonds?

Mr. Edmonds: I think it is very pertinent to show, if the Court please, in view particularly of the assertion which the defendant makes on the California evidence, just what it was that DeForest and his companies had subsequently to the time when they say, he made something pertinent to the patents in suit. Your Honor was not advised during my brother Darby's argument that there is a defense of prior knowledge and use by DeForest in California, and throughout this California testimony, DeForest's name appears, as in the correspondence in evidence, so that he is linked up with this testimony.

The Court: You may finish your answer.

The Witness: On page 2, second paragraph, under heading "DeForest Detector Type R. J.-5" has as its second sentence:

> "The battery switch at the left of the lamp, and the rheostat lever are then moved to a position where signals are at their best."

This refers to the double adjustment, both of filament current and of the B-battery potential, which was necessary with the gassy audions of that time.

The last paragraph on the page headed "Audion Bulbs for Renewals," reads:

> "The sensitiveness of audion bulbs has been still further improved of late. We make two grades, the 'S' or Standard, and the 'X' or extra sensitive. Audion bulbs are sold only as renewals or to those who have purchased our audion receiving sets, and then only on the return of the old bulbs."

And then follows a price list for the two bulbs. At page 3, the last paragraph, under "Instructions," it says:

> "If too much 'Battery B' voltage be applied a blue glow will appear in the bulb, or may be seen merely around the edges of the 'plate' or wing. When this blue glow fills the bulb it is usually not very sensitive. The glow can be removed by simply reducing the B voltage by the 3-point switch on the RJ-4 and the 6-point switch on the RJ-5. The sensitiveness can be instantly restored by merely switching off and on the lighting current. Only one filament should be burned at one time. This doubles the life of the bulb."

And on the fourth page, the third item from the end towards the last:

> "Audion Bulbs, double grid and double plate, for renewals only."

Following the listing of amplifiers, those are the amplifier bulbs to which I refer, and those instructions are characteristic of the use of the bulbs which I bought and used in 1914 and 1915.

Q. 239. I think you are going to refer to some subsequent bulletins, Mr. Hogan. Will you do so briefly?

A. I have now Bulletin B-15 of DeForest audion detectors, variometers and the time receiver, which is a 1915 Bulletin and shows the same types of tube. Page 2 in the second paragraph says:

> "When once the proper voltage and heating currents are determined, no further adjustment is required."

This refers to the double adjustment, both of filament current and plate voltage as before. The third paragraph from the last on page 2, says:

> "The battery 'B' is located inside the case and is composed of a number (from 10 to 12) of three-cell flashlight dry batteries."

On page 4, the fourth paragraph as to the DeForest audion detector R. J.-5, reads:

> "If too much battery 'B' voltage is applied in any Audion Detector, a blue glow will appear in the bulb, or may be seen around the edges of the plate or wing, and a roaring sound will generally be heard in the telephone receivers. When this blue glow fills the bulb it is usually not very sensitive, and if this discharge is allowed to persist for a time, the bulb will become 'hard,' and will require a higher battery 'B' voltage."

And further:

> "A 'hard' bulb can be 'softened' by heating very carefully and evenly over a flame for a few minutes."

Page 7 in the directions for the DeForest audion time-receiver, the fourth paragraph reads:

> "Now start the switch B at the lowest point 12, and turn to the right until a blue discharge occurs in the audion bulb, or a hissing noise occurs in receivers. Bring the switch back one point at once, as the blue discharge, if prolonged, is detrimental to the bulb."

A photograph on page 10, showing the combined audion detector and single step amplifier, shows the filament rheostat controls and the Battery B switches separately for each of the two tubes. That is to say, the contact points forming a semi-circle at the right of each bulb adjust the B-battery for the particular bulb and the rheostat knobs are between the bulbs and the battery switches and a little above a separate rheostat being provided for each bulb. This is referred to on page 11 at the end of the third paragraph from the bottom, which says:

> "Each bulb has its individual control switches, B 1 and B 2 control each battery 'B,' and each bulb has its own rheostat lettered OUT and IN."

The very last sentence on page 11 is:

> "Two separate 'A' batteries are required for this instrument."

Showing the necessity of individual and careful adjustment for each of the two bulbs. On page 14, the third paragraph:

> "Audion bulbs are furnished in two styles—those of standard degree of sensitiveness (Style 'S') and those of especial sensitiveness (Style 'X'). Every bulb is given two tests before leaving our factory, against a standard. Amplifier bulbs are supplied only in 'X' grade, in tantalum filament and Hudson or tungsten filament types. The latter types have from two to three times the operating life of tantalum filament bulbs."

Q. 240. May I interrupt you there, Mr. Hogan? By Hudson type filament, you were familiar with that, were you?

A. Yes.

Q. 240a. And that was a filament of pure tungsten, with a spiral wire of tantalum around the loop; is that correct?

A. Yes. Page 15, the second part of the price-list is headed:

"Renewal audion bulbs," and gives prices for the two types of detector bulbs, Type "S" and Type "X," and the two types of amplifier bulb with tantalum and Hudson filament. This is the 1915 Bulletin.

In 1916, the same line of round audion bulbs was continued, and in addition a tubular audion bulb type "T" was put out. This is referred to in Bulletin C-16, page 3, as to the directions for using, under the subheading "Caution." Paragraph 4 says:

> "4. Adjust rheostat to give normal filament brilliancy and adjust Battery B switch to best point. Then try reversing current from the lighting battery to find out which direction is better.
>
> "5. The bulb is most sensitive at a point just below that at which the hissing sound is heard in the telephones."

This tubular bulb requires the characteristic adjustment of the gassy tubes.

Q. 241. Is this type "T" DeForest audion a tube of the character described and listed in the C-16 catalog?

A. Yes, that is stamped D.F. on the plate and has the DeForest label. There were several similar types put out by other manufacturers. Your Honor can see the grid through the opening in the plate, and the straight filament there.

THE COURT: Yes.

A. (Continued.) In 1917 and 1918, the war years, the DeForest Company made the V. T.-21 receiving tube, using about 3.6 volts on the filament, with a current of about 1.1 amperes.

In 1919 and 1920, they put out the so-called VT which had the standard Navy base, the four-prong base which was adopted during the war, and which used a filament current of about 8/10 amperes and about four volts filament potential. I believe they also sold to the public during 1919 and 1920, some surplus VT-21 tubes. Their catalog B headed "Post-War Models," of September, 1919, shows the new DeForest VT audion on page 19, and this is described as follows:

> "This tube is identical with the latest forms of tubes manufactured by the DeForest Radio Tel. & Tel. Co. for war work and is similar in shape to the V. T.-21 tube of which the DeForest Company made thousands for the Signal Corps during the war. In the United States its sale is restricted to amateurs and experimenters for reception only.
>
> "The tube consists of a highly evacuated vessel cylindrieal, rather, than bulbular, in shape enclosing the three elements, grid, plate and filament, in the form of the old type T tubular DeForest tube with which amateurs are familiar. The plate is of nickle, cylindrical in shape and surrounds a helical grid also of nickle. The filament is a crimped tungsten wire passing through the center of the grid exactly as it did in the old style T type DeForest tube. The chief difference between this tube and the type T tube of similar mechanical construction is in its evacuation. The old style type T was an ionic or gaseous tube, very unstable in operation and requiring a variable 'B' battery. It had the decided disadvantage that after continued use the tube would get 'hard' and require more 'B' battery until it reached such a state as to be inoperative. The new 'VT' tube, like the DeForest standard tubes today, is purely an electronic tube exhausted to a very high vacuum, so that it is nongaseous and will stand very high plate potentials. When used as a detector, however, a battery of 20 to 40 volts is sufficient to give the proper plate current although voltages of 80

> to 100 may be used without detrimental effect upon the tube. The 'B' battery, moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work."
>
> "The filament takes from .75 to .8 amps. only, whereas the old type T tube required about double this amount. This is a decided advantage in that it saves charging of the storage battery at short intervals. A 4-volt storage battery will light the filament, but a 6-volt battery with a control rheostat will give better results. The filament is of crimped tungsten and tests show that the majority of these tubes will burn from 1000 to 2000 hours."

Then under the instructions on page 21:

> "These instructions apply to the new type high vacuum tube such as was used by the U. S. Army and Navy and is at present being manufactured by the Moorehead Company exclusively for the DeForest Company under the latter's patents. The Marconi Company are sole distributors for us. The old type gaseous tube with the candleabra base can be used similarly, except that a variable 'B' battery of from 20 to 50 volts is required The gaseous type tubes are, however, no longer being maufactured."

And the third and the last paragraph:

> "Connect a fixed battery of from 20 to 60 volts into the plate circuit."

Your Honor will recognize the type T tube as that which I spoke of in connection with the 1916 circular, and also the change in operation occasioned by elimination of the variable B-battery that was necessary for the gaseous tube, and is not necessary for the hard tube of this 1919 type.

The sale of these VT's was continued into 1920 and I believe into 1921. About December, 1922, DeForest brought out a new DV-6 tube which had a cylindrical bulb and a 4-prong base, but had its grid plate and filament elements horizontal. This used a tungsten filament with a rating of three to five volts and of one-half to .7 ampere. In January, 1923——

Q. 242. May I interrupt a moment? Do you happen to know at what time the plaintiff's UV-201-A and 199 were produced?

A. Yes. Those got on the market about January, 1923.

Q. 243. Will you now proceed with your answer?

A. Yes. They were the thoriated filament tubes.

Q. 244. Such as the plaintiff's tube in evidence in this case?

A. Yes, that is correct. The DeForest Company, about April, 1923, put out the DV-6-A tube which had filament characteristics similar to those of the 201-A, except I think the filament current was rated somewhat higher. That tube had also a thoriated filament and the magnesium keeper. It had the horizontal elements similar to the DV-6.

It is shown in a DeForest circular, marked catalogue L in the lower left-hand corner of the cover, beginning at page 21, and carrying over to page 22. The second paragraph on page 21 points out that these tubes are of the so-called hard or gas free type, and that because of this they are stable in their operation. The small filament consumption is emphasized and here the filament rating is given as five-tenths of an ampere, which is at five volts and is higher, twice as high, as that used in the 201-A.

In September, 1923, the DeForest Company put out the DV-1 tube or at least it was available on the market in September, it may have come out shortly before, and that had a thoriated tungsten filament and a magnesium keeper and was like the Radio Corporation UV-199 as to filament consumption, three volts and six one-hundredths ampere, though it had a standard size base instead of the small base characteristic of the 199.

They also put out about that same time the DV-2 which was like the 201-A tube, with filament rating five volts and one-quarter ampere. It had a standard base, tubular bulb, thoriated tungsten filament, magnesium keeper and a plate voltage rating of 90. The plate and grid filaments were boxed like as in the case of the 201-A.

Sometime in 1924, the DV-3 tube with the same filament ratings as the UV-199 was available and then in 1925 came the DV-5 tube, which is like the 201-A and has a filament rating of five volts and one-quarter ampere, a normal filament temperature of 1925 degrees K. and a plate voltage rating of 125 volts.

Q. 245. Have you stated the normal filament operating temperature of the 201-A?

A. The 201-A is rated I think at 135 volts for amplification. I have forgotten that.

Q. 246. The normal operating filament temperature?

A. The normal operating filament temperature is 1925 K.

Mr. Edmonds: With the consent of the opposing counsel, instead of introducing these original circulars, I wish to introduce photostat copies of them, they being first the DeForest Bulletin of 1914 as Plaintiff's Exhibit 177.

(Received in evidence and marked "Plaintiff's Exhibit No. 177." *See Volume IV, Plaintiff's Exhibits, page 130.)*

Mr. Edmonds: DeForest Bulletin of 1915 as Plaintiff's Exhibit 178.

(Received in evidence and marked "Plaintiff's Exhibit No. 178." *See Volume IV, Plaintiff's Exhibits, page 134.)*

Mr. Edmonds: The DeForest Bulletin of 1916, as Plaintiff's Exhibit 179.

(Received in evidence and marked "Plaintiff's Exhibit No. 179." *See Volume IV, Plaintiff's Exhibits, page 149.)*

Mr. Edmonds: And the DeForest Company Catalogue L of 1922——

The Witness: I do not know the date of that, but it refers to the DV-6-A tube.

By **Mr. Edmonds:**

Q. 247. Which would bring it about April, 1923?

A. Yes, I think this was a 1923 catalogue. It is not dated.

(Received in evidence and marked "Plaintiff's Exhibit No. 180." *See Volume IV, Plaintiff's Exhibits, page 153.)*

Mr. Edmonds: The DeForest Catalogue of 1919, as Plaintiff's Exhibit 181.

(Received in evidence and marked "Plaintiff's Exhibit No. 181." *See Volume IV, Plaintiff's Exhibits, page 156.)*

Mr. Edmonds: And finally the DeForest tube T audion referred to by the witness as Plaintiff's Exhibit 182.

(Received in evidence and marked "Plaintiff's Exhibit No. 182.")

Mr. Edmonds: You will agree, Mr. Darby, that these catalogues and bulletins which have just been offered in evidence were put out by the defendant company at or about the dates referred to by the witness.

Mr. Darby: I agree to that subject to correction if error be made to appear. I know they are all catalogues put out by the DeForest Company, but as to the dates, I do not like to stipulate, because I do not know whether it is a fact myself.

Mr. Edmonds: And there is no dispute between us as to the type T audion which I have just introduced, being a production of the DeForest Company.

Mr. Darby: I do not know that that is made by the DeForest Company, but I believe it was. The reason I make that reservation is because at the time these tubes were put out there were a number of counterfeit tubes manufactured which opposing counsel have been aware of and as far as I can go is that this type audion is a type of the DeForest type T.

Mr. Edmonds: And that it represents in every respect the DeForest type T audion.

Mr. Darby: Yes.

Mr. Edmonds: I would like to mention to your Honor one fact, and that was referred to by my brother Darby in opening for the defense. He was explaining how it was that testimony was taken in San Francisco, that is now being used in this case, and explained to your Honor that it was taken in other cases brought in the Eastern District of New York under the three patents before your Honor. I want to add to that that the Brooklyn case against the DeForest Company under the second and third patents here in suit was brought in May, 1924, and under the fourth patent here in suit in April, 1925, that is correct, Mr. Darby?

Mr. Darby: Yes, sir.

By Mr. Edmonds:

Q. 248. The Wehnelt cathode has been several times referred to in this testimony. I will ask you to explain briefly and generally the construction and operation of that cathode and compare it with a thoriated tungsten cathode operating in the environment in which that cathode is used as for instance in the plaintiff's tubes?

A. The Wehnelt or oxide coated cathode dates from about 1904, when Wehnelt proposed to coat a platinum strip with calcium or barium or strontium oxide and he used that as a cathode. One method of preparation was to paint on a paste of the oxide, and another was to dip the platinum wire into a nitrate solution and oxidize the calcium on the wire itself.

There was a good deal of difficulty in getting uniform oxide coatings on the strips, and the cathodes made and used in the old experimental devices showed a decrease in emission with time in addition to the nonuniformity. A good deal of work was necessary to make a practical oxide cathode from the types that were in experimental use up to 1912 and 1913. Even today with the best oxide cathodes, a great deal of care is necessary in their handling as compared to the thoriated tungsten filament, for instance.

One part of the evacuating process that I believe has been mentioned in Dr. Arnold's testimony has to do with the "opening up" of the Wehnelt cathode. That is to say, as put into the tube it does not show high electron emission and it has been found necessary to bombard the cathode itself with positive ions while the tube is on the pump, watching it very carefully, because as soon as the filament starts to emit its emission gains very rapidly and unless the current is taken off or reduced almost immediately the filament burns up. It is a very tricky step in the preparation of a Wehnelt cathode, this "opening up" proposition.

In general, the Wehnelt cathode both as to the filament and as to the tube containing it costs more than a similar tube using the thoriated tungsten. That is largely because of the better exhaust required in order to get satisfactory operation from the Wehnelt cathode. More time is required on the pump and more care in the exhausting process and there are more rejected tubes, I believe.

The matter of cost is also affected by the matter of convenience of manufacture. The Wehnelt cathode wire must be kept away from the air until it is used. The thoriated tungsten wire is used right from spools. There is more breakage I believe, in the case of the Wehnelt cathode, because bending breaks off the coating unless it is very carefully done.

The thoriated wire is considerably more rugged and stands higher cleaning temperatures and Wehnelt oxide covered wire as used today, I think, has a melting limit or at least a dissociation limit at about something one and a half times above the rated voltage; that one cannot go above a low voltage across the filament without making it so hot as to almost if not quite destroy it, whereas thoriated wire may be overloaded something like four times without burning it out; that is to say, 400 per cent.

In operation the coated wire (following that same thought of cleaning) will burn out at a voltage where thoriated filament will not. That is a definite practical advantage to the user who may accidentally put a high voltage across the filament and does do so quite frequently.

At the same filament efficiency I think the lower current and higher voltage that are characteristic of the thorium filament give greater freedom from battery troubles and contact resistance troubles in series with the filament circuit. The amplifying power of the tube using thoriated tungsten filament is more nearly uniform throughout its life. The low current limit that you can get with a thoriated tungsten filament you cannot get with the Wehnelt cathode and that makes possible the power socket operation with reasonably cheap rectifying apparatus, that is, in connection with present-day receiving sets operated from the wall outlets.

On life, the reactivation possible in the thoriated tungsten filament I believe gives it an even longer life than can be had from the Wehnelt cathode. The Wehnelt cathode well made, will last longer (and considerably longer, often) than the first activation of the thoriated filament, but with the successive reactivations in good vacuum I believe that the total thoriated filament life can be extended considerably longer. In any event, there is no marked difference except possibly in favor of the thoriated cathode, as to life. I think that generally summarizes the differences between the two types of filament.

Q. 249. Will you tell us to what extent the practice of reactivating the thoriated tungsten filament of the plaintiff's tube obtains today and has in the recent past?

A. Since the thoriated tungsten filaments came on the market and the reactivating process became understood there has been a quite wide growth of the sale and use of so-called rejuvenators, and reactivators and reconditioners. Those are usually little transformers arranged for alternating current operation from the light socket and fitted with a control switch and a tube socket, sometimes also fitted with a meter, and so arranged that a tube which has either had thorium removed by excessive heating, for instance, by putting the B-battery current accidentally through the filament, or which has attained a low emission in normal use, may be put into the reactivator and given both the flashing or cleaning treatment which is accompanied by reduction of thoria to thorium at a high temperature, and then (by throwing a switch the other way) the activating heat treatment that brings out the thorium from the inside to the surface of the cathode.

There are something like a dozen or more makes of reactivators advertised and a number of radio stores make a practice of reactivating tubes for the customers and making a charge for that.

I have used two types of reactivators, one the Sterling and one the Hemco. The Sterling is an alternating current instrument and the Hemco is good for either one (A. C. or D. C.). The calibration of the Sterling, shows that the cleaning and reducing temperature corresponded with 16.3 volts across the 201 A. C. filament and that represents a temperature of 2775 degrees K. The activating voltage gave 2170 degrees K. and in this same device a checking position or voltage corresponding to the operating voltage of five volts is also provided so that the emission can be read on a small meter under the operating condition and that corresponds to a temperature of 1925 degrees K.

The directions with the activator were to operate at the high voltage, which corresponds to 2775 degrees for thirty seconds and then to activate at the medium voltage 7½, or 2170 degrees K. for from two to ten minutes or until the test voltage shows good emission.

Q. 250. Does this circular which I show you, purporting to have been published by the Sterling Company, illustrate the Sterling reactivator to which you refer?

A. Yes, sir. That is the instrument. This type of device, all these devices, are useful only with the thoriated cathode tubes, because that is the only type of tube which can be reactivated.

Mr. Edmonds: I offer the Sterling catalogue in evidence as Plaintiff's Exhibit 183.

The Court: In the absence of objection it is admitted.

(Received in evidence and marked "Plaintiff's Exhibit No. 183." *See Volume IV, Plaintiff's Exhibits, page 161.*)

Mr. Edmonds: I offer in evidence Exhibit 1, being a sketch made by the witness Hewlett as Plaintiff's Exhibit 184.

(Received in evidence and marked "Plaintiff's Exhibit No. 184." *See Volume IV, Plaintiff's Exhibits, page 165.*)

Mr. Edmonds: That is all of the direct, for the second case, and I understand, if the Court please, that Mr. Darby is ready to cross-examine the witness on the testimony as thus far given relating to the last three patents.

Mr. Darby: I do not know whether that is exactly the case. Your statement is perfectly right but the thought occurred to me that inasmuch as this witness's testimony up to the present time has been confined largely, if not entirely, to the last three patents in suit, if it would be of assistance or advantage to your Honor to have the cross-examination of this witness on the last three patents appear at this part of the record.

The Court: Any way.

Mr. Darby: Both Mr. Edmonds and Mr. Davis and myself have agreed that for our purposes it would be better, if it is entirely satisfactory to your Honor.

The Court: All right. We will take our short recess.

(After a short recess.)

Cross-Examination.

By Mr. Darby:

XQ. 251. In connection with these DeForest bulletins, Mr. Hogan, what type of tubes was it that you bought from the DeForest Company or DeForest tubes which you bought in 1914?

A. The round bulbs, both of the detector and amplifying type. I cannot say as to 1914, that I got double-plate tubes, but I got both types in 1914 and 1915.

XQ. 252. What were the type numbers of the tubes that you got?

A. I do not believe there was any type numbers.

XQ. 253. Were there any type letters?

A. No, I do not believe there were type letters. There was the S-grade and the X-grade detector which was the single plate tube, and I had both of those, though I think I bought X grades mostly; and then on the amplifier tubes there were no types other than the designation tantalum filament, or Hudson filament and I had both of those.

XQ. 254. And separate B-batteries were recommended for use in connection with the different uses of the tube, that is, when they were used as a detector and amplifier in the same equipment, separate B-batteries were employed?

A. I do not remember as to 1914 and 1915, but I do remember as to 1913, that the DeForest Company put out a three-stage amplifier in which each of the three tubes had separate B-batteries.

XQ. 255. I am not referring to the amplifier, but to the detector as distinguished from the amplifier and call your attention to catalogue B-15, page 10?

A. There is one detector and one amplifier shown and each has a separate battery.

XQ. 256. And in this catalogue B-15 there is one paragraph at the bottom of page 2, reading as follows:

> "All our audion detectors are regularly furnished with standard 'S' grade audion bulbs. The 'X' grade will be supplied at the additional prices as given in the price list in this bulletin."

That is correct?

A. Yes, the X-grade was a more sensitive bulb.

XQ. 257. And the bulletins did not state in what respect the X-grade and the S-grade differ from each other?

A. No. Except as to sensitiveness. They state that clearly.

XQ. 258. Then, in catalogue B at page 21——

A. I have not got that, Mr. Darby.

XQ. 259. You read from it?

A. Yes, I gave Mr. Edmonds my copy to put in evidence.

XQ. 260. On page 21 you read: "Connect a fixed battery of from 20 to 60 volts into the plate circuit and in series with the telephone receivers." And from the context of what you had read theretofore it appears that that was contained as part of the instructions for using the DeForest audion of the new type high vacuum tube; is that correct?

A. That is correct, except that later in the paragraph it speaks of a similar use of the old type.

XQ. 261. What was the significance of that statement "Connect a fixed battery of from 20 to 60 volts into the plate circuit and in series with the telephone receivers," which caused you to read it into the record?

A. That is a reference to a fixed battery.

XQ. 262. From twenty to sixty volts?

A. Yes, depending on the use.

XQ. 263. And it is your understanding that those instructions were with reference to a hard or high vacuum tube as distinguished from the gaseous tube?

A. I think it makes it clear that the B-battery need not be adjusted with respect to the hard tube. It must be chosen as to the use.

XQ. 264. My question was, it is clear in your mind that those instructions to connect a fixed battery of from twenty to sixty volts were part of the instructions in connection with the use of the hard vacuum tube as distinguished from the gaseous tube?

A. Yes, I think that is correct.

XQ. 265. And on the same page reference is made that the tubes were being manufactured by the Moorehead Company exclusively for the DeForest Company under the latter's patent and the Marconi Company are sole distributors for us. What Marconi Company did you understand that to be?

A. I think that was the Marconi Wireless Telegraph Company of America.

XQ. 266. The same company who were then within the limitations contained in the statement of Mr. Davis, were the predecessors of the Radio Corporation?

A. I do not know what those limitations were, but I do know that the Marconi Company turned over part of its business to the Radio Corporation.

XQ. 267. In other words, we are talking about the same Marconi Company?

A. I think so.

XQ. 268. Are you familiar with the methods now employed in manufacturing vacuum tubes?

A. I am familiar with some of the methods.

XQ. 269. Are you familiar with the automatic exhaust machines?

A. I have seen some of them in operation, although there is a good deal of variation there.

XQ. 270. Very briefly, see if we can agree on this, that the way the vacuum tubes today are generally made where the automatic exhaust machines are employed, is to first initially or partially exhaust the vacuum tube on the exhaust machine and then seal it off; is that correct?

A. I think you have to go further than that to give a good picture of the process. Before seal-off the tubes are quite well exhausted in the process I have seen.

XQ. 271. What do you mean quite well? To what degree of vacuum?

A. Probably——

XQ. 272. A micron?

A. Or less.

XQ. 273. A micron or less?

A. Yes.

XQ. 274. But in that process they are using thoriated tungsten filament, are they not?

A. Yes.

XQ. 275. Then will you tell me, as I understood your testimony that a micron of gas contained in a vacuum tube would be far too high a pressure for use of the thoriated tungsten filament, is that correct?

A. That is correct, if that was an oxygen bearing gas.

XQ. 276. After they seal off the tube from the exhaustion machine, say with roughly one micron of gas in it, they thereafter flash the magnesium, do they not?

A. I think that the magnesium in some processes——

XQ. 277. The point I am trying to make——

A. Just a moment, Mr. Darby. The manufacture of the 201-A tube with which I am familiar vaporizes the magnesium and degases the plate before the tube is sealed off.

XQ. 278. Before the tube is sealed off?

A. Yes. Therefore——

XQ. 279. You are not familiar then with any process where they seal off before they vaporize the vaporizable reagent?

A. No, I have not seen that in a factory.

XQ. 280. Do you know that that is being used?

A. No, not of my own knowledge. I have heard so.

XQ. 281. As I understood you a minute ago you stated that you were familiar with the process where the pump produced a vacuum equal to about one micron——

A. I said one micron or better.

XQ. 282. All right. Before it was sealed off. And with the thoriated tungsten filament. In the process that you are familiar with, what means if any were taken thereafter to decrease the gas pressure in the tube?

A. None with respect to the oxidizing gases, that is to say, the partial pressure of the oxidizing gases including water would be as far down as it was necessary to go before the tube was sealed off; that is to say, below a one one-millionth of a micron. As to the non-oxidizing gases a so-called filament or gas clean-up was used and that probably reduced the pressure from something of the order of one one-hundredth of a micron or something better. It is hard to say.

XQ. 283. My information is that the plaintiff company in manufacturing some of its tubes here in evidence uses an automatic exhaust machine, exhausting the interior of the tube down to one micron or thereabouts, in some instances even higher, and after the tube is sealed off from the machine, flash the vaporizable reagents to thereby obtain the necessary degree of vacuum. Are you from your own knowledge in a position to tell me whether that is correct or not?

A. No, I am not, but I think it is very unlikely.

XQ. 284. You do not know of your own knowledge?

A. No.

XQ. 285. Do you see any reason why it could not be done?

A. I think that the vaporizing of the calcium or magnesium would give off a good deal of gas that should be taken out in the pump and I do not think it would be as good a process as to flash, so to speak, while on the pump.

XQ. 286. Do you think that that process employed would obtain a high enough degree of vacuum required by Patents Nos. 2, 3, and 4 in suit?

A. I do not know. Perhaps if you will let me say that the degree of vacuum of 2, 3 and 4 is a matter of the purity in general, I could add that probably the magnesium flash would clean up the oxygen bearing gases even though the tubes were off the pump, but it may at the same time release other gases which would give ionization trouble but I cannot be sure.

XQ. 287. They certainly would be sufficient—the process I outlined to you certainly would be sufficient to take care of any oxygen containing gas?

A. I said I thought that likely.

XQ. 288. You know the affinity between thorium and oxygen is very high, do you not?

A. Yes. That is to say, thorium is easily oxidized.

XQ. 289. And I also believe you stated that tungsten, even thoriated tungsten, after it has once been heated thereafter becomes very brittle; is that correct?

A. The heated filament in a lamp is stronger from some points of view than the unheated filament, but it is not so ductile. It is brittle. It will break off short.

XQ. 290. When it is heated again, however, it is ductile in part at least while it is still hot, that is, it can be bent without fracture; that is a fact, is it not?

A. I have not tried that, but I know if you heat a filament in vacuum you can bend it.

XQ. 291. And you do not know that the same is not true in open air?

A. I do not know at what temperature you have to heat the filament.

XQ. 292. I am not asking you about the temperatures. If you heat it like you heat a tungsten filament so that you can bend it?

A. The point is that——

XQ. 293. Can you answer that question first?

A. No, I cannot.

XQ. 294. You do not know?

A. No, except as I have already stated.

XQ. 295. Did you consider in the reasons that you advanced to the Court in considering the testimony of Mrs. Beck whether or not Mrs. Beck when she bent the filament had heated it?

A. No, I think the statement read to me was that it could be handled like wire.

XQ. 296. And you based your testimony on that statement which was read to you?

A. That and the other portions read to me.

XQ. 297. You did not look through the testimony yourself to ascertain whether or not she stated anywhere that when she bent it it was hot?

A. Yes, I read the testimony but I do not remember any statement of that sort.

XQ. 298. And therefore your testimony is based on that?

A. Yes.

XQ. 299. Would your testimony have been different if you found in there that Mrs. Beck stated that she had heated the filament while she was bending it?

A. No, I think not, because——

XQ. 300. All right, that is all I want. As I understand it, without knowing whether or not heating it would permit it to be bent, you came to the conclusion that it was not tungsten that Mrs. Beck employed, merely because she said she could bend the filament?

A. No, that is not quite a fair statement. I do know that you can bend tungsten under proper conditions and at a high enough temperature even though it has been heated before. What the conditions were for Mrs. Beck I do not know except as she stated she could handle it like wire and she knew that it was tungsten or thought that it was tungsten because she knew it was not carbon. I thought that all of that was insufficient to show that it was tungsten and the description was much more likely to indicate the use of tantalum by her, tantalum lamps being available on the market until early 1914.

XQ. 301. My point is, as I understood you, your conclusions would not have been modified or altered in any respect if you had taken into consideration the fact that she had heated the tungsten while she was handling it?

A. Not by the simple statement that the tungsten was heated, that is correct.

XQ. 302. We all know that incandescent lamps, which I believe you had pointed out, have very poor vacuum, some of them, when they are in their unlighted condition, it is very easy to break the filament if it is made of tungsten by a slight jar, that is correct?

A. Your introductory statement was not correct, that is to say, tungsten filament lamps may have a very good vacuum after they have been used for some time.

XQ. 303. Let us take an incandescent lamp in use less than 100 hours.

A. Even then the vacuum may be good. It is very difficult to tell what the vacuum is after a lamp has been sealed off.

XQ. 304. Then you disagree with Mr. Langmuir in his 1915 article that after 100 hours you can get a very good degree of vacuum. You believe you can get it sooner than that?

A. You have two variables there. There is no sharp cut-off at 100 hours and there is no statement in your question as to what is a good vacuum. What I am trying to say is that a lamp grows harder in use and does not decrease in pressure all at once. That is all.

XQ. 305. Now, having made that statement will you answer my question as to whether or not we all know that a tungsten lamp, after it has once been heated, can thereafter have its filament broken by a relatively slight jar to the lamp while the filament is in an unlighted condition?

A. Yes, I think your point is that it takes ordinarily a harder blow to break the filament when the filament is lighted than when it is not.

XQ. 306. Yes.

A. I think that is general experience.

XQ. 307. And do you attribute that to the fact that the filament is more elastic when it is hot?

A. I would say that it was stronger. It would not break so easily.

XQ. 308. Would you not say that it is more elastic?

A. I do not know. "Elastic" is much misused as a word.

XQ. 309. In discussing the Merritt Patent 909,811, you stated that the only material Merritt suggests is red phosphorus, Merritt referring to a vaporizable reagent. I notice that the Merritt patent says, line 61:

> "Upon the inner walls of the bulb itself, as at *e*, there is deposited a small and preferably definite amount of some one of the well-known agents suitable for chemical exhaustion, such, for example, as red amorphous phosphorus."

Can you tell me what were some of the other well-known agents suitable for chemical exhaustion as of the date of that patent?

A. Merritt was 1909 and refers to a Malignani improvement, so to speak, and so I suppose we should go back to the Malignani patent which specifies in 1895—

XQ. 310. It is all right for you to make the——

A. I do not know of anything outside of phosphorus that was used.

XQ. 311. At 1909?

A. At 1909.

XQ. 312. You do not know that magnesium was used?

A. Not in lamp practice.

XQ. 313. Or calcium?

A. No.

XQ. 314. Did not Soddy prior to 1909 mention both magnesium and calcium?

A. Yes, for his pump.

XQ. 315. But you did not consider that to be a chemical evacuation?

A. Yes, it is, Mr. Darby.

XQ. 316. That is just what I asked you.

A. Then I missed your question.

XQ. 317. Very well, I will repeat it. My question was this: The Merritt patent states that some one of the well known agents suitable for chemical exhaustion could be used. Now, my question is, what chemical agents were known? That is, what agents suitable for chemical exhaustion besides red phosphorus were known at the date of the Merritt patent?

A. Well, I have answered with respect to lamp practice that I think red phosphorus—

XQ. 318. My question is not confined to lamp practice.

A. And to answer that with respect to what chemical exhaustion materials had been proposed to be to 1909, I would have to go through the publications chronologically, which I have not done.

XQ. 318a. Can not you do it from recollection?

A. I can agree with you that Soddy proposes both calcium and magnesium before 1909.

XQ. 319. And potassium and sodium?

A. They were referred to in one of these patents as having produced displacing gases, as I recall it.

XQ. 320. All right. Now, will you please refer to the Clough patent No. 1,246,054?

A. I might add that the Dwyer patent is the one which I am speaking of. Yes, I have the Clough patent.

XQ. 321. It is a fact, is it not, that the magnesium calcium or this material that is employed in that patent, is employed for the purpose of getting out all oxygen-containing gases, or oxygen out of the oxygen-containing gases?

A. I was under the impression that that was not stated, but that the purpose was given as to reduce the voltage drop by using a metal highly reactive chemically to gases other than the so-called rare or monatomic gases. For instance, page 1, lines 48 to 50. Perhaps you can find a reference to a direct effect on oxygen. I do not remember it.

XQ. 322. In other words, the patent is even broader than my statement, is that correct?

A. Yes. It makes no specific reference to the oxygen-bearing gases, so far as I find.

XQ. 323. And the purpose of employing magnesium calcium or the like, so as to get out all gases other than the so-called rare or monatomic gases, is that correct?

A. It does not say that. It says that the purpose is to reduce the arc drop, and he uses an anode of a metal highly reactive to the others.

XQ. 324. What was the purpose of using that?

A. I think it was to attack the gases and to reduce the arc drop.

XQ. 325. Attack the gases in what way, chemically combining with them?

A. I think it would do that, whether it was recognized by Clough or not, yes.

XQ. 326. And you know that calcium magnesium of course would take up any oxygen?

A. Yes, in a hot state.

XQ. 327. Now, I think this is clear, but I want to make sure that it is. As I understand your testimony, the magnesium of patent No. 4, not only acts as a getter, but it also acts as a keeper, is that correct?

A. Yes. If you mean what I do. That is, that the flash of magnesium in the tube, whether it be the electrical flash of the heated coil type shown in the patent, or the heating produced electrically by the induction furnace, that is used in practice, gives a hot, highly active vapor which operates as Soddy pointed out, to improve the vacuum, to get a higher vacuum or a lower pressure. Then after that, which is a factory process, the film on the wall acts in accordance with this Langmuir patent to keep the partial pressure of oxygen down to the desired low value.

XQ. 328. And it does that by the film of magnesium on the wall, as it combines with any gas that is liberated, and takes out so to speak, any oxygen therein contained; is that correct?

A. It may not be a direct chemical combination, but we do know that oxygen and water vapor are held to the surface of the magnesium film, and that the large area of the film exposed by the tube, as compared with the smaller area of the tungsten filament is such that the probability of collision of the oxidizing gas with the wall is very much greater than its probability of collision with the filament. Therefore, that even though the magnesium is not so active chemically as thorium, it acts to protect the filament surface.

XQ. 329. I think you had stated all that in your direct examination. I was trying to boil it down into a very brief statement, if I can get you to agree with me, that the magnesium on the inner surface of the tube performs the function of taking up any oxygen or gas evolved after the tube is put in use; is that correct?

A. It is not correct. It does as to the first part of your statement prevent the oxidation of a filament. The first part is correct.

XQ. 330. Prevent the oxidation of the filament?

A. Yes.

XQ. 331. It likewise takes up any water vapor that is present in the tube afterwards, is that correct?

A. Yes. Of course, it also seals on anything that there might be in the glass that is another feature.

XQ. 332. Seals on?

A. Yes, it covers and pastes over any molecules that might be left on the inside of the wall.

XQ. 332a. That is inherent to flashing the magnesium, is it not?

A. Yes, and to the deposition. It would also be done by the tungsten of the second patent.

XQ. 333. Now you understand that the magnesium is employed in patent No. 4 in suit after the initial pumping on the pump; is that correct? In other words, its function is not to take out all the gases or obtain the initial vacuum, but it is to take out the last traces of the gases after the pump has performed its function?

A. Yes. Its real purpose is to take out the oxygen bearing gas to the extent necessary to protect the thoria, and it is flashed after a good deal of pumping has been done.

XQ. 334. And patents No. 2, 3 and 4, all describe the degree of evacuation, if not in words, but in the sense that the degree of evacuation is desired—the degree of evacuation that is desired is so high that there is practically no ionizable gas remaining; is that right?

A. Well, that is a different feature, of course, from what we have been speaking of.

XQ. 335. I understand it is different.

A. It is true that first the oxidizing partial gas pressure must be exceedingly low, and second, that the other gas pressures which may give rise to bombardment, must be below a pressure at which substantial ionization takes place.

XQ. 336. In other words, maybe we can find a common ground in this expression—the operation of all of the patents in suit depends upon pure electron flow as distinguished from gas ionization; that is correct, is it not?

A. That is generally correct except that I hope you are not using "pure" in the sense of 100 per cent. because——

XQ. 337. I do not think anybody has in this trial, Mr. Hogan?

A. All right. As long as you are not doing that, I am satisfied.

XQ. 338. Then all four patents operate on pure electron flow, and I think you will likewise agree with me that you could not get pure electron flow if there is substantial amounts of gas left in the tube?

A. Yes, and if you operate above ionization.

XQ. 339. Yes. Now, with respect to the magnesium method, the magnesium pump, I think you called it, or a calcium pump, can you by means of a calcium pump alone get a sufficiently high vacuum to enable the operation of the three-electrode tube, let us say, or a two-electrode tube, by pure electron flow, with voltages substantially above ionization?

A. No, I think not.

XQ. 340. Then you would have to use something in addition to that. You referred to the practice that is at the present time being employed by flashing the magnesium while it is still on the pump. The fact that the pump is still connected to the tube when the magnesium is flashed, does not, of course, prevent the magnesium from hitting the surface of the tube so as to form that film?

A. That is correct.

XQ. 341. And in the practice that you are familiar with is the pump still in operation while the magnesium is flashed?

A. I think so.

XQ. 342. Then let us refer to the White patent, and I call your attention to page 3 of the White patent, line 40. Before I ask you that question, let me ask you this: You understand, do you not, that the White patent describes a tube which is initially evacuated to such a degree that current conduction can take place from cathode to anode by means of specially pure electron discharge as distinguished from gas ionization?

A. Yes.

XQ. 343. All right. Let me call your attention to page 3, line 40, where the statement is contained:

> "The evacuation of the tube is carried out by the most approved methods of incandescent lamp exhaust, and the last traces of gas are removed by either a Gaede molecular pump or by some chemical evacuating means, such as the use of vaporized calcium or magnesium."

You do not understand from that statement, do you, that White meant in his patent that he could use a molecular pump?

A. Why not?

XQ. 343a. You do mean that?

A. I think it is perfectly possible, yes.

XQ. 344. And I understood you to say a minute ago that you could not obtain a sufficient high degree vacuum with a magnesium pump so that you could get the flow?

A. Your question said magnesium pump alone.

XQ. 345. Yes.

A. That is correct.

XQ. 346. Then you consider this as being in addition to the Gaede molecular pump, that is the mechanism used in addition to the Gaede molecular pump?

A. No, I think the last traces are removed by either a Gaede molecular pump or by some chemical evacuation means following the pre-treatment described in the first part of that paragraph, and the best and most approved method of incandescent lamp exhaust referred to.

XQ. 347. And what pumps do you know of that will perform that function other than the Gaede molecular pump?

A. Perform what function?

XQ. 348. Perform the function of enabling one to get a sufficient high degree of vacuum so that you can operate these devices by reason of the pure electron flow as distinguished from gas ionization?

A. Why, even for the ordinary tube, a Toepler pump, and I think a Sprengel pump, if the mercury is kept out with solid carbon dioxide or liquid air, it will give you amply low enough pressure for the ordinary purpose.

XQ. 349. Do you know Mr. Saul Dushman?

A. Yes.

XQ. 349a. He is one of the Research Engineers of the General Electric Company, is he not?

A. Yes, that is correct.

XQ. 350. He attended part at least of this trial?

A. I think so.

XQ. 351. And he is also an author of the book entitled "High Vacuum," is he not?

A. That is correct.

XQ. 352. You have read that book?

A. No. I have used it as a reference book but I have never read it from cover to cover.

XQ. 353. Mr. Dushman states in this book on page 134:

> "In considering absorption of charcoal at low temperature, immediately below a table:—
>
> "That is, at a pressure of 0.01 bar (which is a maximum pressure for the efficient operation of hot cathode high vacuum devices) one gram of charcoal (such as used by Claude) would clean up about 130 centimeters of hydrogen or 18,000 centimeters of nitrogen from a pressure of one bar down to 0.01 bar."

First, let me ask you this: 0.01 bar is equal to .0075 microns, is that correct?

A. Approximately.

XQ. 354. About seven and a half thousandths of a micron. Now, do you agree with Mr. Dushman's statement that seven and a half thousandths micron is a maximum pressure for the effiecient operation of a hot cathode high vacuum device?

A. It may have been perfectly correct——

XQ. 355. Do you agree with that?

A. Not in general, no.

XQ. 356. You do not agree with that in general? What did you start to say?

A. I started to say that it might be correct for a device which he had in mind, but I do not know of any limiting pressure which will define the point at which the substantial ionization occurs in a wide class of devices.

XQ. 357. Then it is your opinion that Mr. Dushman must have had some particular device in mind when he made that statement?

A. I think that is likely. I know the effect is that the pressure at which harmful ionization begins, depends very largely on the geometry of the device, that is, on the actual design.

XQ. 358. Can you tell me what is the material? What do you mean when you say that the material can be "sublimed"?

A. Can be "sublimed," I think that means that it gives a vapor off about apparent boiling, that one can see in the case of water.

XQ. 359. In other words, magnesium is a vapor which can be sublimed, is it not?

A. I do not know. It was a vapor pressure.

XQ. 360. Has calcium?

A. Yes, they all have vapor pressures, without seeing them boil, if that is what you mean by "sublimed."

XQ. 361. Yes, magnesium, potassium and sodium are all metals which can be sublimed?

A. They are all metals which have vapor pressure from a solid state.

XQ. 362-63. And do not have to be boiled, according to your definition; do you mean that that statement found on page 204 of Dushman, and I may explain that this appears in a shape relating to "chemical and electro-chemical clean-up of gas at low pressure."

> "As mentioned by Dr. Whitney, arsenic, sulphur and iodine act in a similar manner to phosphorus in cleaning up gas in incandescent lamps. In fact any substance that can be readily sublimed acts in the same manner."

Do you agree with that statement?

A. No, I do not know the boundary conditions well enough to accept that.

XQ. 364. Then in consideration of this clean-up Mr. Dushman states on page 201:

> "In general, over 90 per cent. of the residual gas is cleaned up in a lamp during the blue glow period."

Do you agree with that?

A. That agrees with my understanding, if you mean the clean-up of lamp manufacture, where the use of phosphorus, for instance, is accompanied by blue glow?

XQ. 365-66. And then the statement continues:

> "and the rate of clean-up during this time is much more rapid than that obtained subsequently. The final pressure attained on flashing varies from 0.01 to 0.001 × 10 = 3 mm. of mercury."

That means from—just translate that to microns, will you?

A. If I heard you, it is .01 to .001 microns.

XQ. 367. In other words, from one-hundredth to one-thousandths of a micron, is that correct?

A. Yes. That is, those are the figures you have given me. I have forgotten the context.

XQ. 368. "This final pressure obtained by flashing varies from .01 to .001"?

A. I do not know as to the fact, but I do know that these pressures correspond to these number of microns.

XQ. 369. Do you agree with that statement?

A. I say I do not know. I do not know what is attained on the flash. My impression was that it was not as low as that.

XQ. 370. Was not as low as that? You mean that you would not get as low as one-thousandths of a micron by flashing?

A. Not as the result of a phosphorus flash with blue glow in the ordinary lamp.

Mr. Darby: That is all.

The Court: Mr. Richmond, have you some cross-examination?

Mr. Richmond: Not at this stage.

The Court: Very well.

Mr. Davis: With your Honor's permission, I will continue the direct examination of the witness on other aspects of the case than those touched by Mr. Edmonds.

The Court: Very well.

Direct Examination (Continued).

By Mr. Davis:

Q. 371. Mr. Hogan, what are the practical devices or tubes of the prior art which have been referred to in this record? I merely want a list or enumeration of them.

A. It includes the Fleming valve——

Mr. Richmond: I object to the question. It seems to me it calls for a summary.

The Court: You can embody that in your question, if you want to, to the witness, to go on from that, and I think it would be very nearly proper, as I understand it, if you ask the witness to summarize for you.

Mr. Davis: If your Honor please, what I am trying to get at is to separate and for separate consideration, an actual working device from the devices described.

The Court: I still am under the impression that Mr. Richmond's objection is good and that you may make that assumption in your question, and deal with it on that basis, rather than ask the witness to summarize testimony.

Q. 372-73. On the assumption, Mr. Hogan, that the practical devices of the prior art referred to in this record are the Fleming valve, the DeForest audion, the gas X-ray tube, the mercury vapor tube and the incandescent lamp, I want to ask you one or two questions, the first being—is an incandescent lamp an electron discharge device?

A. No. The operation at the same time might conceivably be accompanied by some electron discharge across the filament terminals, but that is of no value; in fact, could only do harm, so I would not classify them among the electron discharge device group.

Q. 374. Then if we are ignoring incandescent lamps, and if we adhere to the assumption which I made with regard to the Fleming valve, the DeForest audion, the gas X-ray tube, and mercury vapor tube, and regard them as practical devices, will you please tell me what were the orders of magnitude of pressure in those four devices as they were used prior to 1912?

Mr. Darby: If your Honor please, I have to make an objection to this line of examination, on the ground that I think that the witness in answering the question would have to be going into the judicial field rather than the expert field.

The Court: The objection is overruled.

A. The pressure of the Fleming valve was that of the ordinary incandescent lamp, something of the order of ten microns. Possibly worse, possibly better, depending upon the lamp with which it is compared. The DeForest audions that I have measured showed vacua of about the same degree or pressures a little higher. That is something of the order of five to ten microns.

Q. 375. Excuse me, you said pressures a little higher?

A. Yes, pressures higher in some cases. I have gotten considerably higher pressures than ten microns in DeForest audions.

The Witness: X-ray tubes of the old-fashioned type, on the other hand, I have never measured, but I understand that the pressures there run from 3 to 10 microns.

THE COURT: No. Why should not that be stricken out, Mr. Davis; why should we have his understanding? It might be based on other things.

MR. DAVIS: I am perfectly willing, if your Honor please, to strike it out. I will ask another question, which I think will develop his answer.

THE COURT: The latter part of his answer will be stricken out.

Q. 375a. Let us first deal with the mercury vapor tubes; what was the order of pressure there?

A. Centimeters, that is to say, very high pressures.

Q. 375b. Now, the gas X-ray tube. It has been testified in this case as a fact, and I think by witness of both sides, that as the vacuum improvements in the old-fashioned X-ray tube developed, there came a time when no more current would pass through it, and then the tube became inoperative from the standpoint of the art, as it existed at that time. Does that fact enable you as an expert to state what the vacuum was in a working X-ray tube before that phenomenon occurred, if so, please state it?

A. That makes it perfectly possible to state that the vacuum before the discharge stopped, that is to say, as the pressure was being reduced, was something of the order of two to ten microns or thereabouts. I know from measurements that have been made by others and that have been published, that the pressure of the residual atmospheric gas has been measured over the operating range of hardness, and is from about 4 microns to about 13 microns in the old-fashioned X-ray tube. The hardest rays possible being produced at 3.7 microns. Now, that is clear confirmation of the view that if the pressure were reduced a little lower than 3.7 microns, no more X-rays would be produced but the tube would stop, because those two things go along hand in hand. For those measurements I am referring to a paper by Lindeman in the *Physikalische Zeitschrift*, 1912, February, pages 104 to 106.

Q. 376. Will you please discuss now the degree of vacuum necessary to the accomplishment of the purposes set forth in the first patent in suit?

A. That vacuum is not a fixed thing. It depends upon the spacing and the form of the electrodes and on the voltage to be used with the tube and the use of the tube. In general, it is such a vacuum as will give what we have been calling substantially pure electron discharge free from harmful effects of positive ionization and the pressure that will give that desired result will be different for different types of tubes, and possibly even for different operations of the same tube.

Q. 377. How can such a vacuum be obtained and maintained in a useful working tube?

A. If one should take, for instance, a prior art tube such as a Fleming or a DeForest tube or I suppose even an X-ray tube and convert that or try to convert that into a Langmuir tube of the patent it would require a preparation and evacuation of the tube and its electrodes in a very different way from that which was practiced in the ordinary manufacture of those old tubes.

It would require a final pressure for those geometries of a different order of magnitude and one that could only be had by combined and exaggerated, so to speak, use of all the preparation and evacuation steps that were known.

For instance, Dr. Langmuir's December, 1913, *Physical Review* paper at page 32 of the reprint, which I have here, gives the normal conditions and treatments that he would use for making one of these tubes. He says, first, speaking generally, that there must be an extremely high vacuum, and he refers to a pressure below one-tenth of a micron. At page 20 of the paper he gives a specific instance of .07 microns pressure. He says in this section No. 1, and in the two succeeding sections what one must do to get high vacua and the steps that he outlines are the elimination of all stop-cocks and wax joints; the heating of all the glass to 360 degrees C. for an hour or more; the avoidance of the old-fashioned anode treatment by an ordinary glow discharge. That I think it has been explained to your Honor that that results in releasing gas in the tube and sticking it into the walls so that it may make more trouble later on.

Mr. Richmond: I want to object to reviewing that Langmuir paper with this witness. It seems to me——

The Court: I will hear you, Mr. Davis.

Mr. Davis: I have asked the witness how this vacuum can be obtained so that it could be maintained in the tube. If he chooses to summarize it from that paper, I do not see why he should not.

The Court: I see no occasion for it. He is going far afield. The answer is stricken out.

Mr. Davis: Only the part where he begins talking about the paper.

The Court: Yes.

By Mr. Davis:

Q. 378. Then quite independent from Dr. Langmuir's paper, will you state what these conditions are which have to be fulfilled?

A. You would like me to itemize the desirable things that should be done to produce a tube of this sort?

Q. 379. If you please.

A. Elimination of the stop-cocks, and the wax joints of the old-fashioned exhaust system; heating of the glass of the vessel being evacuated at a high temperature, nearly the softening point of glass for a reasonable time; avoidance of the anode treatment by high voltages in the ordinary glow discharge; heating of the anodes or other normal cold electrodes to high temperature, as for example 2500 degrees, for a reasonably long time, as for example, ten minutes while they are in the apparatus being evacuated; heating of those electrodes, if they are of wire, by passing a current through them or if they are of a serially connected strip in the same way, or if they are not so formed, but in plate form, by bombardment at high voltages (possibly several thousand volts) and high currents of the order of 100 milliamperes or thereabouts, enough in any event to heat them to a bright red or white heat while they are on the pump. The cleaning of the filaments by heating them, and of course, the elimination of mercury or any other vapors by the use of a liquid air trap or carbon dioxide in a solid form or some equivalent.

Q. 380. In your answer, have you or have you not assumed the presence of such a material as magnesium on the inside of the bulb?

A. I have not assumed the presence of any such material.

Q. 381. Now, making the assumption that such material is present, does that modify these requirements to any extent?

A. Yes. If one is operating at relatively low volttages and using the tube cold or practically cold it is not necessary to go to the extremes of treatment in order to produce a satisfactorily low pressure that will remain satisfactorily low when magnesium is used both as a getter and keeper as it would be if there was no such chemical treatment and no such keeper available.

Q. 382. Do you regard the disclosure of the Langmuir patent as a matter of getting a little better vacuum than existed in the three-electrode devices, such for instance as the DeForest detector tube?

Mr. Darby: I object to that.

The Court: The witness may answer the question.

(Q. 382 repeated by the stenographer.)

A. The point there is that a change in pressure from two microns down to five-hundredths of a micron just assuming values for the purpose of the discussion, is of course a small change relative to atmospheric pressure. We would notice no such change in pressure as that, no such differential pressure as that in the room. On the other hand, it represents a change in pressure to something that is of an entirely different order, a factor of forty to one or something like that and of course such a range of pressure change as that as a matter of ratios would be more than any of us could stand. I mean that absolutely, in terms of pressure, the change needed to make a DeForest audion into a Langmuir tube, provided the electrodes have been treated and everything else was done that was necessary, would be small. The pressures themselves are small. But as a matter of what is really done, comparison of the one pressure to the other pressure in terms of their relative size, the change is tremendous and to an entirely different order, and of course I say that still with reference to the fact that absolute values must be defined only with respect to some particular tube and not in general.

Q. 383. Will you please discuss the practical results which that difference produces?

A. The result of making a tube with the treatments for the attainment and maintenance of the practically non-ionizing condition that we have been talking about, the results of that are dependent mainly on the two features that I have referred to, first, that the Langmuir tube is uniform in its operation, day after day and that it therefore can be standardized for a definite purpose; secondly, that the Langmuir tube is capable of either amplifying or rectifying or controlling large amounts of electric power, a matter of kilowatts or thousands of watts as against the thousandth parts of watts in the old tubes.

With regard to the uniformity of operation that makes possible simplicity. There is no necessary adjustment of the plate battery voltage and even the adjustment of the filament current is not critical; and because of that the operation of groups of tubes, for instance, in telephone repeaters or in multi-tube radio receivers, becomes practical. If one had to make individual adjustments of filament and plate current and voltage on each tube of a multiple tube radio receiving set, I venture to say that nobody, even the most skilled manipulator, would be able to run a superheterodyne with eight tubes, for instance.

Another consequence of this uniformity is that replacement of the tubes without changing the apparatus becomes possible. That is particularly important in telephone repeaters and in radio devices both of the receiving and transmitting type. One wants to know that he can replace a burned-out tube with a new tube without having to make substantial changes in the apparatus.

The third thing that arises from uniformity is the possibility of effective use of the tube in complicated circuits. The Langmuir tube does not vary as to its constants while it is in use; and because of that radio sets, for example, can be designed for high efficiency and kept constant at the high efficiency point because the tube does not change. In telephone repeaters, for instance, one can balance the line closely and keep it from singing by reason of the constancy of the tube.

The old tubes would not permit such adjustments in either of those cases because of their variability.

The fourth point flowing from the uniformity of operation is that special apparatus can be now made for special services, because the tube constants stay fixed. For example, special types of amplifiers are made which have special constants and the X-ray tube is a special tube which has a special set of constants. Neither of those things could be done if the uniform operation were not available to us.

With respect to the second point, that is power handling capacity, for telephone repeaters it was desirable to have more power than milliwatts, thousandths of a watt, because the quality depends upon the greater amplifying power as also does the intensity to give satisfactory service. For example, a present-day use of telephone amplifiers is in conjunction with the public address system which is used when a speaker wishes to talk to a large crowd of people. The power output of such a tube is really tremendous compared with the tubes used on the telephone lines and such power handling capacity could not be thought of in connection with the old art tubes.

For radio amplifiers, the amplifiers used in connection with radio receiving sets, the increased power handling capacity is very important. Every one who is well informed knows that the quality as well as the intensity of the response from a loud speaker depends not merely upon the loud speaker itself and upon the broadcasting station, but also on the power-handling capacity of the amplifying tubes in the receiving set.

It is very striking to change a small tube, and replace it by a good power-handling tube in a receiver and see what improvement in the quality comes from that change alone.

For oscillators in radio transmitting stations, the ordinary powers used are anywhere from fifty watts to fifty or more kilowatts. Twenty kilowatt single tubes are commercial tubes now. For modulators in radio transmitters, for tubes used to vary the intensity of the constantly flowing stream of electro-magnetic waves in accordance with voice outline, tubes of the same order of power capacity are needed and that again comes from the high power limit of those devices; and still further and last of all in rectifiers for industrial purposes it is necessary, as for instance in smoke precipitators or other places where industrial amounts of power are used, it is necessary to have such tubes to handle such amounts of power and that again flows from the feature I have discused.

Q. 384. Will you now discuss the prior art discussed by Professor Chaffee in its relation to the first patent in suit and in doing so, when you come to the discussion of the Fleming publications and the Fleming patent, please refer to Mr. Waterman's deposition in the old suit Marconi against DeForest which is mentioned on pages 1486 to 1489 of the record in the present suit?

A. I have already discussed a number of the references cited by Dr. Chaffee in connection with their application to the second, third and fourth patents but I will go ahead, taking the exhibits up in the order in which they were introduced here and when I come to those which I have already treated, I will refer to that fact and make any other comment which might be helpful in connection with their relation to the first patent.

The first exhibit is No. 2, the Dewar article of 1875. That describes simply a chemical pump, using heated charcoal, the vessel first being heated and the charcoal being allowed to cool so that it will condense a small residue of gas, and it can produce nothing of the order of vacuum required today. I think Dr. Chaffee agreed that liquid air was not available in 1875, at the time this article was published.

The next exhibit is Exhibit 3, an article by Scheele and Heuse published in the *Zeitschrift* for February, 1909, pages 45 to 50. That particular article is one of which I have no translation. I have had it read in German and understand that the evacuation mentioned was that of a device which had no electrodes, that a vacuum of approximately seven one-thousandths microns was measured with a McLeod gauge in this tube using charcoal and liquid air but that the McLeod gauge under those circumstances would not show any vapors which might have escaped into it.

I do not know whether the charcoal and liquid air was sufficient to condense all the vapors or not. I do not know how it was used. In any event, there is no mention of sealing off from the pump or from the cooling agent in the article except with relation to stopcocks; and of course we know that if a device, even pumped down to one one-hundredth of a micron, is sealed off from a pump on which it shows that pressure, by the ordinary methods of lamp sealing off, the gases given off will increase so that the final pressure after sealing off will be of the order of one or two microns.

This article has no mention of maintaining a vacuum nor of keeping it longer than it stayed on the pump. I should like to reserve any further comment on the article until I get a translation. That is my understanding from what has been given to me. In other words, everything that I have said is on the assumption that the oral translation is correct.

The same comments as to translation apply to Exhibit 4, Bessel-Hagen. We have no translation of that in written form but I have gone through the article with Dr. Dushman and understand that here again the device was not sealed off but the pressures were measured with the pump running. When an electrical discharge was sent through a pair of electrodes on the little tube at the right of Figure 8, the gas pressure increased from nine microns to seventeen microns and then again to thirteen microns upon the application of the current. There is no reference to heating the electrodes. And while a measured or recorded pressure of 8/1000ths of a micron is referred to it is very difficult if not impossible to read such pressures accurately and it is impossible to maintain them after a seal-off on the ordinary lamp basis. This particular paper was referred to in the Interference record by Dr. Langmuir at page 1488 and the Scheele and Heuse paper Exhibit 3 here, was treated by him at the same place.

Exhibit 5 in this case is Edison Patent 411,019 of 1889. It shows the heating of a lamp globe first in an oven and then through the exhaust it is warmed by a lamp applied to a chamber. It shows the use of phosphoric anhydride, P_2O_5. The tube is put on a Sprengel pump with rubber bands. While it shows a recognition of the desirability of removing enough water vapor from the tube to prevent the burn-out of the carbon lamp filaments, it certainly has no suggestion that the methods used with a thermionic tube would give a low pressure.

There were no anodes in the lamp and there was no suggestion of glowing the lamp filament, so that those reservoirs of gas would not have been emptied following this process.

The next is Exhibit 6, the Malignani patent, to which I have referred in the record at page 1568. This is a publication descriptive of a method which will attain a lamp vacuum of one or two microns up to perhaps ten microns, but of course it would require much better pressures than that except perhaps in tubes of exceedingly special design to operate without ionization at voltages that were above the ionizing potential.

Certainly no such pressures would be useful in a good tube, because it was the pressure used in the old Fleming valves.

Exhibit 7 is the Dwyer Patent 596,654. That also I commented on in connection with the last three patents in suit here, my discussion being at page 1570 of the typewritten record; and here again we have something which is no more than a lamp vacuum produced in a carbon lamp.

Exhibit 8 is an article by Duncan which was published in the *American Electrician* for May, 1896, pages 8 and 9. This refers to experiments on Crooke's tubes. The author shows some photographs of Crooke's tubes with luminous discharges and gives a large part of his paper to a discussion of the electrode connections which will prevent the discharges from crossing and gives a discharge that is better.

He showed an increase in the vacuum of X-ray tubes and lamps in their ordinary ~~use and~~ he believed that might be due to a combination of the residual air with vaporized carbon, as he states in column 1 of the article. I can stop here as well as any other place.

The Court: 2.15.

AFTER RECESS.

By Mr. Davis:

Q. 385. Unless there is objection to Mr. Hogan's testifying for the sake of saving a little space in the record, I am going to ask you simply to tell us what the investigations were which were referred to in this *Physikalische Zeitschrift* paper of 1912, which you referred to this morning, and you can read just that first part of the table which gives the results we are interested in.

A. This was a set of results of the measurements of hardness of rays produced by an ordinary gaseous X-ray tube when the vacuum or pressure within the tube was changed by measured amounts. To measure the hardness, the so-called Wehnelt scale was used, which I understand is the arbitrary set of numbers, having to do with the penetrating power of the rays, and the harder the ray, the higher the number; and the pressure was measured in microns or thousandths of millimeters. The table at the upper left-hand corner of page 105, gives the results for atmospheric residual air, and the first two columns are headed respectively "Pressure" ("McLeod Pressure") in the equivalent of microns, and second, "Hardness by the Wehnelt Gauge," and the numbers in the two columns corresponding to each other:

Pressure	*Hardness*
13.6	2.7
9.7	3.2

Perhaps the best way would be to let Mr. Smart typewrite this instead of my reading it.

Pressure	*Hardness*
13.6	2.7
9.7	3.2
8.0	4.2
6.6	4.9
6.8	5.5
6.8	5.7
5.7	6.5
5.2	7.8
5.0	8.0
3.7	10.3

Q. 386. If you will please continue your answer—

The Witness: Continuing then with Exhibit 8 the Duncan article, he suggests the same explanation. Vaporized materials might explain the clean-up in Crookes or X-ray tubes. He then talks about lamp makers, not being able to make satisfactory Crookes tubes in general, and that to make a good X-ray tube, lamp practice must be improved. That is, of course, exactly what one would expect if the simple procedure that is satisfactory for a lamp were applied to a tube having the large electrodes characteristic of the X-ray tube.

Not only would the gas be too high for an X-ray tube performance, that is above 10 or 12 or 15 microns, but probably a great deal higher, unless the precautions that Duncan suggests are followed. He says that he has gotten good X-ray tubes from lamp makers, and he says that he was simply trying to attain in these tubes a good X-ray vacuum, which, for high penetration, as I have shown, might be as much as 3 microns instead of a poor carbon lamp vacuum which might be as high as 10 microns, and would be considerably higher in an X-ray tube made according to simple lamp practice.

In his satisfactory tubes of the Crookes types he got a visible cathode ray discharge showing the intense ionization, and whatever vacuum he did get was of course not maintained, it being the essence of both the Crookes and the X-ray forms of tubes that the heating of the cathode by ion bombardment is essential, and of course there was no approach to the vacuum of the first patent.

The next exhibit is No. 9, the Dewar article, from the proceedings of the Royal Society, 1898, pages 231 to 238, which refers to the use of liquid hydrogen to produce vacuum. He used both electrodeless and sparking tubes for examination of the spectra in the glow discharge under various conditions. Apparently the cooled portions were never sealed off, and this was condensation of condensible gases or freezing of the gases in liquid hydrogen and not absorption of the gases by charcoal.

On page 234 of the article he got what he considered evidence of pressures below one one-millionth atmosphere, which corresponds to six-tenths of a micron, and in that connection, Dr. Chaffee on page 511, I think computed that is six one-thousandths of a micron, but he must have in mind six one-thousandths of a millimeter, or six-tenths of a micron. This suggestion of a freezing process would not maintain even such a vacuum after the liquid hydrogen had been removed. The form of the tube is shown on the sketches on page 234 and the article is described by Dr. Langmuir in the Interference record on page 1488.

The next Exhibit is No. 10, which is an article by Lenard appearing in the *Annalen der Physik*, 1900, pages 359 to 374. It has to do with experiments with photo-electric discharge on tubes with a quartz window, sealed on, and of course, exceedingly small currents, something of the order of billionths of an ampere, wherein there would be no space charge. He sealed the tube and passed sparks through it, and absorbed some of the moisture in the tube with pentoxide and at least once condensed mercury from his pump with solid carbon dioxide, the soda water treatment, so to speak.

Apparently he left the apparatus on the pump all the time. He said that the condensation produced no change in the discharge, so evidently that was not essential for his purposes. He may have had a harder vacuum, somewhat harder than the operating X-ray tube vacua, which go down to 3 microns or thereabouts, but he measured it by the point where the ionized discharge in the tube stopped, so that it could not have been very much below that, if any.

The whole tube is outside of the range of the thermionic vacuum tubes of the sort we use and get from the Langmuir patent. It had no filament, there was no substantial heating of electrodes in the preparation or in the use, and his process would be entirely inadequate to prepare a Langmuir tube. In the Interference record, both Millikan and Richardson referred to this as a pure electron discharge; that is to say, a photo-electric pure electron discharge, and of course there is no doubt that below ionization voltages, and in the saturation range, of photo-electric effects, even at the high pressures of these experiments, the discharge was substantially of the pure electron type, but that has nothing whatever to do with the pure electron discharges at ionizing voltages, and under space charge conditions.

Now, Langmuir discusses this paper in the Interference record at page 1465. I may not have mentioned that the diagram of the Lenard apparatus is shown as his Figure 1 on page 361 of the original, the sealed quartz glass window appearing below a portion of the plate.

Now, Exhibit 11 is the article "A Resume of Incandescent Electric Lamp Exhausting," by Doane, printed in the *Electrical World and Engineer* for May 21, 1904.

I discussed this article in connection with the last three patents in suit at page 2607, and I think the comments there apply here. There was no recognition of bombardment between the filament legs, although that was referred to by Dr. Chaffee at page 542. The blue glow that is referred to we have seen may produce more gas than it cleans up, if the tube has gas or partly prepared tube walls, or if there is gas in the filament joints or in the electrodes, and those Doane's tubes (being lamps) had no electrodes other than their filaments, and there is no suggestion of attainment in them of any of the lower pressures, than the carbon lamp vacuum which I think has been accepted by all of us to be somewhere between two and ten microns of pressure, and incidentally there was no heating on the pump in that article, so far as I recollect.

Now, Exhibit No. 12, is U. S. Patent No. 946,068, to Von Recklinghausen, and that also I discussed in connection with the last three patents, on page 1574 of the transcript. Dr. Chaffee classified it only under the vaporizable reagent and the alkali earth metal groups at the end of his deposition, where he classified all the references according to their disclosures, so I believe it is cited only as to the last three patents, but I think it is perfectly clear that a mercury device like Von Recklinghausen's would be a device that depends for its operation upon ionization, and that no operation free of ions could be produced under the conditions in such a mercury lamp.

Exhibit No. 13 is U. S. Patent to Merritt, No. 909,811. That also is a lamp patent which I discussed in connection with the last three patents in suit on page 1576 of the record herein. Dr. Chaffee referred to this as showing baking walls of the tube and heating the electrodes of a tube; but so far as I can tell from the patent, the bulb was oven-heated prior to the exhaust—there is a reference to that—but there is no reference to electrode heating other than the filament. I think by this process he would attain a lamp vacuum at the time of seal off of probably a few microns, but nothing more.

Now, Exhibits 14, 15 and 16 are respectively the Fleming 1905 article, or paper before the Royal Society, published in the proceedings beginning at page 476. The United States Patent No. 803,684, which is on the device described in the Royal Society of London paper, and the popular article in the *Scientific American Supplement* for January 20, 1906, which is a reprint, word for word, I believe, of the same article published in *Technics* for April, 1908, beginning at page 316, and which is, as I think Dr. Chaffee agreed with me, a popular resume of the disclosures and work described in the Royal Society of London paper. Therefore, I will treat all three of these together.

The disclosure, the showing, is of the well-known Fleming valve, and that attained its practical use, and I think its only practical use, as a radio detector. As it was used, and as I have used it, and without exception, so far as I have been able to learn, by direct inquiry from those who have used it, the filament voltage was from four to twelve volts. That is to say, different tubes had different filament voltages of from four to twelve, and they were never used with any battery other than the filament battery. Therefore, if the anode is connected to the positive terminal, the voltage with respect to the negative end of the filament, cannot be more than twelve volts maximum. If it is connected to a potentiometer, as was common in the use of the device, the potential on the grid can be varied from this value of plus 12, corresponding to the most positive point of the filament down to the negative end of the filament, which gives a zero potential with respect to that, since that is from where it is measured.

In other words, the anode I think was never charged to a voltage higher than the ionization potential of the residual gas, and, as the result of that, disturbing effects of gas on the discharge would not appear even though the device had pressures of the usual carbon lamps, say from ten down to two microns. If the pressure were very much higher than that, say 100 microns, the filament would be likely to suffer, and also I think there would be some interference with the passage of electrons, even below the ionization voltage.

Simply because of the obstruction, practically a mechanical obstruction produced by the inert gas molecules that would be in the way, even though no ions. Fleming recommended the incandescent lamp pressure, and there would be no advantage in going below this, because he operated below ionization potentials. In order to get pressures of that order, he found it helpful to heat his metals within the tubes to some extent. For instance, he suggests an external resistance coil, used to heat the cylinder contained inside the tube, and that would be helpful, I believe, to get that kind of a vacuum.

Mr. Darby: May it please your Honor, I move to strike that out because the witness is paraphrasing the Fleming article, rather than pointing out what the Fleming article states. I move to have his answer stricken out.

The Court; That portion of it, Mr. Davis.

Mr. Davis: That last few lines, is all I understand the objection is to, and I will ask him to continue his answer without paraphrasing.

The Court: That portion will be stricken out.

The Witness: Suppose we refer to the patent and read, page 1, lines 100 to 105 (reading):

> "The filament b can be conveniently heated by passing a current through it, while the cylinder c can be heated by surrounding the bulb a with a resistance coil through which a current is passed, the whole being inclosed in a box lined with asbestos or the like."

That has to do with the feature which I tried to state more briefly by summarizing. The curves that he gives——.

Q. 387. Just a minute, Mr. Hogan. I would like to have you state whether if you have not already done so, I am not quite sure how far back this order to strike out goes—whether or not that was an effective means of cleaning up the plate?

A. Why, no. It would help to get the sort of vacuum that Fleming needed. This was an incandescent lamp vacuum, and it is very probable that he could not have gotten down to even ten microns unless he had done something of that kind. It is not anywhere near enough to bring the tube vacuum down to a point that would give with the same construction a discharge free from ionization at high voltages.

Q. 388. Now, if you will please continue the answer which I interrupted.

A. I was about to refer to the curves that he gives on page 483 of the Royal Society paper, and to say that they show the sharp rise which is characteristic of gas conductivity in his devices. These curves were plotted on the logarithmic basis at the Interference record page 1320, and Dr. Langmuir discusses this whole situation, beginning on page 1308 of the Interference record. I put the reference here merely for convenience.

Now, I think you also asked me, Mr. Davis, to refer to Mr. Waterman's testimony on the Fleming valve in the suit brought by the Marconi Wireless Telegraph Company against the DeForest Radio Telephone & Telegraph Company under the Fleming patent, No. 803,684, which patent is our Exhibit No. 15. Do you want me to point out the parts of Mr. Waterman's testimony that I think have a bearing on this particular discussion?

Q. 389. Yes. Mr. Darby, I think, read some parts of it on the pages, which I indicated in my question, namely, pages 1486 to 1489, and I would like to have you say anything which you have to say which casts light on this deposition, and make any further quotation which you care to make from that deposition, but only from that deposition.

Mr. Darby: I have no objection to the witness making quotations from any part of the testimony, but I do not think the witness can explain this testimony.

Mr. Davis: If your Honor please, the only explanation which would be possible to have would be as to the use of terms at that time. The terms are used in the portion read by Mr. Darby and which to our ears in this trial have a certain standard of things and mean one thing, which may, and I believe did mean, an entirely different thing in that trial.

The Court: Can you control the testimony? Is it the intention to restrict the testimony to that?

Mr. Davis: Absolutely, your Honor.

Mr. Darby: There is no objection to that at all if the witness is cautioned that that is the purpose of it.

The Witness: On page 1088 of the printed transcript in the Marconi case, XQ. 218:

"What is the pressure in the bulbs used in the detector sets of the Marconi Company?"

Then follows for a page a discussion of detector sets, and so on, and the answer to the question comes in answer to XQ. 225, where the question is:

"I mean, give the actual pressures, what is it in millimeters of mercury, the ordinary way we use it in respect to lamps of this kind?

A. The pressure as I understand it is always less than one one-hundredth of a millimeter of mercury, usually as low as one one-thousandth and oftentimes so high that no test whatever will show the presence of any gas, no known test."

The two pressures correspond to ten and one microns respectively, as the pressures used in the device.

Q. 390. Let me see what year was that testimony given in, Mr. Hogan?

A. 1919, I think. I will have to check up.

Q. 391. 1916?

A. The record does not seem to print any dates. You are right, Mr. Davis, "Adjourned to March first, 1916," is at the bottom of page 996, just before the part I was quoting. At page 1102, the Court inquires to how good or how bad the vacuum could be, and Mr. Waterman's reply is:

> "I do not know. I do not pretend to be an ultimate authority and encyclopedia on this whole subject. I only know that in the course of the tests which we made, immediately for the purposes of this case, we made several hundred bulbs and we had air pressures all the way from atmospheric down to as nearly an absolute vacuum as we could get, and that they did not begin to act in a way which could have been even thought of at all for commercial use, until, well, I am a little hazy about that, but my recollection is that the presure was one-tenth of a millimeter; and they did not begin to be of any use until the pressure was a good deal lower than that. That established conclusively that what you want is a vacuum, a real vacuum, in incandescent lamp vacuum.
>
> XQ. 262. That is a real vacuum?
>
> A. It has always passed as such.
>
> XQ. 263. It does not need to be any lower pressure than that?
>
> A. Does not need to be any lower pressure, but it is very nice to have a lower pressure. You can get along with an incandescent lamp vacuum in very good shape indeed."

The pressure at which he began to get results, namely, one-tenth millimeter, corresponds to 100 microns.

Now, on page 1105:

> "XQ. 274. All right. Never mind answering if you do not want to, without taking up the time necessary to make all those distinctions, what is the pressure of an ordinary incandescent lamp?
>
> A. Mr. Pickard stated that it was from one one-hundredth to one one-thousandth of a millimeter, and that corresponds to my understanding. The present tungsten lamps are rather better than that, but that is a general definition."

The two pressures there, one one-hundredth to one one-thousandth of a millimeter again correspond from ten microns to one micron, which checks very well with our understanding here of the vacuum of an incandescent lamp.

The end of the answer to XQ. 279 on page 1107, is in connection with the general question as to X-ray tubes, and reads:

> "In the Coolidge tube, where you have the hot electrode and the absolute vacuum, there is no visible phenomena of any kind, that is, the X-ray tube which is revolutionizing things of the present day."

That is a statement of the "absolute vacuum" which has appeared in one or two other instances; in other words, the Coolidge tube vacuum, at which there is no visible evidence of ionization.

Page 1111, with respect to the White patent which is Exhibit 42 in this case, Waterman says:

> "In other words, it would appear that there is some special assistance there given by the trace of mercury vapor, but the vacuum is extremely high in these bulbs. It is an extremely high vacuum."

Then at the end of the page he says:

"Or, in other words,"—this is after quoting a portion of the White patent descriptive of the old audions—

> "Or, in other words, when in the so-called audion referred to here, the ionization becomes evident, then the bulb becomes useless, which is just what I said."

I think that gives us a better idea of what Waterman meant when he referred to a high vacuum and an absolute vacuum and an incandescent vacuum.

Mr. Darby: I would like to have the remainder of that answer read in. I think the remainder of it explains the passage that Mr. Waterman has just testified to.

By Mr. Davis:

Q. 392. Will you please read the rest of that answer on page 1111 and 1112?

A. Yes, certainly:

> "I have not for a moment denied that there were ions in there; nor have I denied that they are of a certain usefulness. On the contrary I have stated the theory. But just as soon as ionization becomes ionization which can be conducting; that is, as soon as ionization takes place in the path between the grid and the filament, then the valves go out of business, and I think very likely it might be very instructive to the Court to demonstrate that.
>
> "In these bulbs you will find as you urge the voltage up; that is, as you are working for the most sensitive point there will come a point where the signal disappears. In some bulbs this does not come suddenly, it comes gradually. In other bulbs, it comes all at once; the signal absolutely disappears. The better bulbs, the more satisfactory bulbs to handle are those in which the blue color comes gradually and not suddenly, and if you watch such a bulb critically you will find that as

you pass the point of good sensitiveness there is a little fringe of light begins to appear around the plate. It is between the grid and the plate along the edges of the plate. If you push it a little further you begin to see a blue which treads on the 'toes of the grid, so to speak, and then your signal quits. In other words, when the ionization action gets in between the grid and the filament, I mean the visible ionization action, I have never seen a bulb that would work; maybe there are some (I would not venture to make any positive assertion that a bulb could not be made to do anything), but I have never seen one. Just as soon as the ionization gets into the direct electron path, the effective electron path, the bulb stops."

Q. 393. Now, will you continue your answer?

A. I think the evidence of visible ionization there is——

MR. DARBY: I object to that. I do not think the witness——

MR. DAVIS: The witness has been asked to comment on a thing and say what the terms mean.

MR. DARBY: This witness was not asked as to any emphasis being there and I do not think the witness is qualified to state whether there is any emphasis.

THE COURT: The last statement is a volunteer statement and is stricken out. There is no question to the witness. If Mr. Davis wishes to ask a specific question, very well.

By MR. DAVIS:

Q. 394. I will ask you as a person skilled in the art and knowing the use of the terminology and the history of the art, what you say is signified by the terms highest vacuum and absolute vacuum in that deposition?

A. He defines that as a vacuum in the Coolidge tube. He says that is the closest approach to an absolute vacuum that he can get.

Q. 395. And when he speaks of conduction by ionization in the portion which you last read, what does that signify to you as one skilled in the art?

A. He defines that by saying that he means visible ionization, that is to say, ionization accompanied by blue glow. That is in his own words.

Q. 396. Now, will you continue with a discussion of the references?

A. Exhibit 17 is the Soddy Patent 859,021. I have discussed this patent with relation to the last three patents beginning at page 1577 of the record. This is the magnesium or calcium pump and I think Mr. Darby said it was not cited against the first patent but I also believe that Dr. Chaffee included it in his classifications of baking the walls, heating the electrodes and bombardment.

When it is used on a lamp—when the pump is used on a lamp Soddy proposes heating the filament, but of course there is no anode. When it is used on an X-ray tube there is heating to the extent of operating the tube. In the old X-ray tube, one of course must not have gas free electrodes or the tube would be more critical than ever. If we recognize that the pumping efficiency goes down, decreases, as the pressure goes down in a pump of this type, it is perfectly clear that it is simply another type of pump, this time a chemical one, which will attain a lamp or X-ray pressure of a few microns.

Exhibit 18 is the Soddy article in *Nature*, November 21, 1907, which I discussed in connection with the last three patents at page 1579 of the record here.

Here we have a description of an experiment in which there was no heating of the bulb, and no freeing of all the electrodes from gas, although running the filament and running the anode with an ionization glow present might have conceivably done the anode some good, and certainly would have helped the filament to some extent. Whatever vacuum Soddy got did not stay, for he says at the bottom of page 53, after a little while a very feeble glow started. That is, after the current had stopped. And he says that this was probably due to a further slow evolution of gas from the still heated surfaces. That appears at the top of page 54. Then he refers to more gas that was then generated within the apparatus by heating the third electrode. That is the first part of the first complete paragraph at the top of page 54.

Whatever vacuum Soddy got at the instant of the current stopping even, he did not investigate it, he did not use it, and he did not find out what the current was, or what the law of current was in it; and the cessation may well have been due to wall charges on the tube rather than anything else, but of course we do not know positively. All we know is that whatever was had was purely temporary. Dr. Langmuir discussed that publication at page 1510 of the Interference record.

Exhibit 19 is the Lilienfeld reply to Soddy in the *Physikalische Zeitschrift*, and I will take that up later in connection with the other Lilienfeld publications including Exhibit 31.

Exhibit 20 is the article by Hogg in the proceedings of the American Academy of Arts and Sciences for August, 1909. This describes work in which Hogg was working with a tube having no electrodes and a tube that was not removed from the pump. It was for the purpose of observing pressures and the mechanical effects of gases rather than their electrical effects.

Dr. Chaffee quoted from page 9, where the pressures were indicated as less than one one-thousandth micron, but on reading the paper as a whole I find that Hogg seems to have a good deal of doubt about the accuracy of such measurements even with the special McLeod gauge that he had; and of course that is reasonable because it is very, very difficult to read differential levels of mercury when those differential levels come down to less than half a millimeter. In any event, there is no suggestion that whatever vacuum was obtained, whether it was as low as this or not, could be obtained in a tube having electrodes, and there is no suggestion that if it were obtained it would have any utility nor that it could be maintained in a tube that had sealed off, this one having remained on the pump.

Exhibit 21 is the *Annalen der Physik* 1910 article by Hupka, which I discussed at the record, page 1584. This is illustrated by Dr. Chaffee only under the vaporizable reagents and alkali earth metals classification and is the paper in which Hupka said that he had tried the Soddy process, but that it was not adequate for his purpose. He indicated that he could get a hard X-ray vacuum at the moment of vaporization but nothing more. I have already commented on the process of Hupka with regard to present-day devices and I think that beyond noting that, although he used charcoal and liquid air, the device was a photoelectric tube which of course had extremely small currents, and probably it is not necessary to go into this further.

Page 185 refers to two cemented joints in the tube and page 184 refers to the fact that aluminum was chosen for the diaphragm because it gives off the least gas in a vacuum. There is a quartz window on the tube, white cement was used and he observed fluorescence in his experiment, fluorescence of the glass walls of the tube.

I think all of that goes to show that low pressure was not attained and it is clear that he did not suggest any utility for it in any such arrangements as are used today and have been used since Langmuir's application.

Exhibit 22 is an article by Von Baeyer, appearing in the *Physikalische Zeitschrift* for 1909, page 168. Dr. Chaffee said that this shows an electron-emitting cathode and that the ions present were measured by the third-electrode test. He also referred to the securing of a vacuum in the device by the use of charcoal and liquid air. He did not include the publication in any of his classifications as to baking the tube and so on. I think he said there were no data to compute the currents used.

At page 170, referring to elimination of mercury vapor Von Baeyer says: "I did not succeed, however, by the condensation of mercury vapor which was attained by the cooling . . . . in appreciably reducing ionization."

This is a condensation trap, with the use of liquid air, but that particular use is not in connection with absorption by charcoal. On page 171 he points out that there was ionization above 10.4 volts and very little below that voltage, and consequently he worked below ten volts. He thought that might be due to mercury vapor but found that the ionization was not reduced when it was cooled with liquid air. When he used charcoal and liquid air together he increased the vacuum, and the ionization could not be measured (as he says) with not too high velocity or at velocities not too high; that is to say, at accelerating voltages that were not too high.

There was some reference to his having had no measurable ionization at forty volts on one of the electrodes and to the effect that those forty volts were above the ionization voltage, but page 174 shows that this was a negative voltage applied to the counting electrode and it had no reference to the positive voltage that would produce the ions.

In other words, having already shown that he got all the ions to the counting electrode at twenty volts the increase to forty volts is not significant. At page 171 is the place he said that the ion currents did not increase with increased negative potentials on the negative electrodes.

As to the currents used, the table at page 170 shows a maximum deflection of 20,000 and refers to footnote 9, where he points out that these large deflections are not directly observed, but calculated from the deflections with properly chosen shunt resistance. Knowing the sensitiveness of the galvanometer as five times ten to the minus tenth amperes per division, we may find these currents from the deflections that he has given. That 20,000 deflections means ten-millionths of an ampere, ten microamperes. There are a few higher readings on the same page and that would correspond to approximately fifty microamperes, all extremely small currents.

This publication is discussed by Dr. Langmuir in the Interference record at page 1458.

Exhibit 23 is Thatcher U. S. Patent 1,028,636. This patent Dr. Chaffee referred to as showing the so-called filament clean-up to get high vacua as he said without vaporizable reagent in the tube. Thatcher brings his filament intensity up to a point that produces a glow in the tube, so that of course it could not be used with low voltage filaments as used in tubes. I think that was pointed out in connection with the Whitney paper which gave a limiting voltage of fifty or something of the kind.

We all recognize that the blue glow in an unbaked tube or without well-treated electrodes may give off as much or more gas as it tends to clean up while the filament vaporization is going on. Thatcher points out that instead of pumping to two millimeters, that is to say, two thousand microns, as is done by the Malignani process, and then depending on a chemical clean-up, Thatcher will pump down to two-tenths of a millimeter (which is 200 microns) on a mechanical pump and complete the exhaust by the intensive incandescence of his filament. That reference is at page 1, lines 88 to 98. On page 3, lines 29 to 35, he recognizes a rather limited range of clean-up that is possible by this vaporization process without too much disintegration of the filament.

On page 4, lines 3 to 5, he says that the disappearance of the blue haze may be relied upon to indicate attainment of the requisite high vacuum. That of course defines his vacuum as a lamp pressure of the order of microns.

I might point out in this connection that in a lamp bulb gas comes out of the filament very quickly and heating the wall, if that is done, will give off a great deal of water vapor and some carbon dioxide and some nitrogen, probably less of nitrogen than of the others. However, the action of the filament on nitrogen is not very rapid at normal temperature, the temperature of the filament has to be pushed up to a point where it would have a very short life in order to clean up nitrogen in the tube.

Exhibit 24 is the Friederich Patent 1,083,677, which is an X-ray tube patent, and which was quoted by Dr. Chaffee in connection with ridding the electrodes of all the gas contained in the metal.

This tube is of the old-fashioned X-ray type and the idea that Freiderich discloses is for a better regulation of the amount of gas in the tube.

On page 1, line 50, immediately after the portion that was quoted he states:

> "The regulating device should not be on the outside of the tube but should be located within same near the center so that the gases absorbed

by the regulator may be easily liberated for the purpose of forming a passage for the current."

So I think we need go no further on that patent in connection with the patents here in suit. He certainly had a very different idea as to what "all the gas" in an electrode was, from the idea that Langmuir has stated.

Exhibit 25 is the Lilienfeld paper in the *Annalen der Physik* of 1910 and the *Berichte* of 1911 and I will take that up later.

Exhibit 26, is an article by Dember, July, 1911. He uses a photo-electric cathode and he kept his device on the pump all the time. His structure is shown at page 602 of the original and has two ground joints, seals of the laboratory type, and a window sealed to the tube, and he speaks of the use of a wire gauze D (at page 604 of the original paper) for the purpose of preventing positive ions formed by collision ionization of the residual gas from entering the adjoining tube.

Your Honor will see the screen D here and that was to keep positive ions formed by collision ionization from entering this tube. That sort of performance is to be expected in spite of a gauge reading of one-twentieth of a micron to which Dr. Chaffee referred, if that is in an apparatus with untreated apparatus and wax joints. I think the last sentence of the paper refers to gas occluded in the metals.

The paper is discussed by Dr. Langmuir in the Interference record, page 1474.

Exhibit 27 is the Gehrts publication, an extract from his preliminary dissertation, but this copy does not carry the date.

Here again we have a photo-electric experiment in which the tube has two ground joints or sealed joints from which vapors may well escape, and while he may have had a low pressure or a fairly low pressure while the pump was in operation, the device was not taken off the pump and certainly could not have held that pressure if it had been.

It contains a good deal of untreated metal and even with the small photo-electric currents that he used, there was doubtless a good deal of ionization. A statement on page 13 of the translation speaks of the production of carriers, which is the production of ions, and gives data for ionization measurements, together with the statement:

> "Up to highest velocities used, there was no trace of ionization."

That sentence, I think, was quoted by Dr. Chaffee, but immediately afterward the article points out that it was conceivable that ionization, which would be noticeable at full photo-electric intensities, escaped observation in these particular measurements, because he had cut down the intensity of light on the screen when he made those observations.

When he was operating at normal light incidence, he apparently got ionization which he referred to at page 14 of the translation:

> "Thus the error caused by impact ionization is surely less than one per cent. and may be disregarded in the above measurements."

That would seem to indicate that he considered one per cent. of the space current carried by ionization, as having no effect on his particular measurements, and he may have been right on that; but one per cent. of the total current carried by ionization in a thermionic tube, would mean destruction of the space charge, and would be a tremendously high gas reading, so-called. If he got any such ionization as that at these small currents that he is using, it certainly is indication of extreme ionization occuring at large thermionic currents.

Q. 395-98. On that point, Mr. Hogan, you are referring to the action of the ion in neutralizing more than one electron; is that correct?

A. Yes.

Q. 399. Will you proceed?

A. Dr. Langmuir discussed this paper at Interference record, page 1463, and Dr. Millikan also discussed it at the end of Q. 8 in the Interference, where he said that Gehrts had a negligible ionization in the sense that the ionization of the current was less than one per cent. of the electron current.

The next exhibit is No. 28,—U. S. patent No. 1,205,022, issued to Marshall in 1916. I discussed that at page 1586 in connection with the last three patents in suit, and it is merely a way of attaining a pressure of a few microns in a lamp, following the Malignani chemical exhaust idea.

Exhibit No. 29 is the Child paper in the *Physical Review* for 1911. He is here investigating what causes the increased current in a vacuum tube when the luminous discharge begins, and he gives both a theoretical analysis of that and some practical experiments, from which he reaches his conclusion. He attacks the problem from a point of view that the large current observed in the luminous discharge of these tubes could not be carried by positive ions, only because they would, so to speak, get in each other's way and prevent the flow of a large current carried by particles or carriers of one sign——

THE COURT: Of what?

A. One polarity. He worked out for these positive charges the mathematical relation, (which he states on page 500 gives):

> "the largest current which it is possible to have carried by positive ions,"

for a given distance, and a given electromotive force; and we recognize now that the mathematical form of that equation is unchanged, if, instead of the positive ionization that Child was investigating, we use our more recently acquired knowledge, and apply it to negative electrons only. In that case, of course, it has no relation to the luminous discharge which Child was attempting to explain or investigate.

After he reaches this relation, he points out that the greatest amount of current that additional positives could carry, after a certain current had been assumed as necessary to neutralize the current carried by electrons, would not be enough to account for the greatly increased current as the luminous discharge begins, and so then, in a section, beginning at page 501, headed:

> "Increase in Current not due to Change in Field."

He takes up the possible effect of the negative charges and the positive charges to each other. He says:

> "it is conceivable that it (the increase) is due to a change in field produced by them"—(the positive ions) and that "When there is no ionization of the gas, the electrons coming from the cathode may be so numerous as to reverse the direction of the field in part of the space."

And he thinks that that could actually occur in practice. He goes on to show from the data taken with an exploring electrode, the results of changing from a calcium oxide cathode to a clean platinum cathode, and then on page 505, he gives what he calls the correct explanation. And on page 510, what he calls the summary, he says, at the bottom of page 510:

> "The phenomena may be explained by assuming that ionization is produced at the cathode by the bombardment of its surface by positive ions

and that such ionization occurs very much more easily with a very hot cathode than with one which is cold."

That is his explanation of the large increase of current when the blue discharge in the tube begins, namely, the more complete or easier ionization emission, the emission of ions by the hot cathode under these conditions.

In the paper there is no work at low pressures, no experimental work at low pressures. I think the lowest pressure recorded is fourteen microns.

That is natural since he was investigating the glow discharge, and the whole question of positive ionization.

Theoretically, that is as to the theoretical part of the paper, there is no suggestion that his mathematics could be applied to the electron current so far as I can find. That is a thing which we learned later. There is no suggestion that the increased current in the tube is really due to neutralization of an electron field by positives. Practically, his work was with high pressures, with discharges, which even when they were non-luminous, nevertheless, were strongly ionized (because we recognize that the disappearance of the luminous discharge does not mean the disappearance of ionization), and all his work, both theoretical and practical, resulted in his acceptance, of the conclusion that I have read from the next to the last page of his paper.

Now, Dr. Langmuir discusses this paper at page 1013 in the Interference record.

The next exhibit is No. 30, which is a paper by Majorana, published in 1912. Majorana, according to the paper, built a duplicate audion and exhausted it and took some characteristic curves. Those curves are plotted on a very small scale at page 238 of the original article. He took the curves under three conditions

—first with grid to positive filament (that is what he calls on the curve "grid neutral"), and he gives the filament voltage as 3.8; therefore, this "grid neutral" curve is taken with the grid actually at the positive potential of 3.8, and consequently causes current to flow in the grid circuit through the tube. The second curve going from the top down is marked "grid negative," and in that case he put ten volts negative potential on the grid; but he did this from the positive terminal of the filament, so that there was a net potential of ten minus 3.8, or minus 6.2 volts on the grid. The third curve is marked "grid positive" and that is taken with a voltage of ten positive on the grid; so that the actual grid voltage with respect to the negative end of the filament is 13.8, that is the sum of the grid battery and the filament voltage drop.

He concludes from the three curves (which show lower currents for the same plate voltage, whether the grid is charged negative or whether it is charged positive). He concludes that charges, either negative or positive, applied to the grid will cause a decrease in the plate circuit current; and curiously enough, for the same reason that misled DeForest in his 1913 paper. That is to say, by the application of too high a positive potential to the grid, and the failure to measure the electron current which that drew to the grid, Majorana has made the same mistake as to the theory of the audion as did DeForest. He shows and states a reduction of plate current for either positive or negative charge applied to the grid, and that, of course, is not the way an audion works, and if it did work that way, it could not be used for amplification, or any of the work that flows out of amplification.

I mention this because the only curve here upon which one is entitled to draw any conclusions, is the one marked "grid negative," that being the only curve for which no current flowed to the grid. When the grid is at the negative end of the filament, there is no tendency of course for the grid to get current except by ionization.

The other two curves can not be used to give a basis for an understanding of the tube, certainly by the application of the 3/2 power law, or any of the other tests, because we have no data as to the amount of current which was diverted from the plate and caused to flow through the grid circuit by means of the grid potentials.

Now, Dr. Chaffee said that these curves did not indicate any ionization up to 50 volts, but I think he must have overlooked the situation with respect to the positive connection to the filament of the grid, because if one plots the data from Majorana's "grid negative" curve, as well as it can be taken from the small sketch, there is a characteristic rise of slope in the neighborhood of 15 volts, which makes it quite clear that ionization came in to the Majorana tube and that he really succeeded in duplicating the DeForest tube, not only as to dimensions, but also as to the amount of gas present.

The next exhibit of the defendant is the Lilienfeld-Rosenthal article of 1912, published——

By Mr. Davis:

Q. 400. I just want to suggest that might be a long part of the answer, if your Honor wants to take a short recess?

The Court: Very well; we will take a short recess now.

(After a short recess.)

A. This Lilienfeld-Rosenthal paper, Exhibit No. 31, has to do with the so-called first Lilienfeld X-ray tube which your Honor may recall, as shown at page 257 of the article in German. I agree with Dr. Chaffee as to that tube, that there must be sufficient positive ions present to maintain the main or X-ray producing discharge, that is to say, the high voltage discharge. Now, as to the auxiliary discharge so-called, that is the discharge between the hot electrode, the hot cathode, and the cylinder anode in the tube, not the X-ray anode, I think it is perfectly clear that currents as large as 180 milliamperes, which is the sort of current that Lilienfeld got in that discharge path could not flow if there were space charge limitations there, nor if the discharge tube were sufficiently free from gas so that the negative grid action, or current—stopping action, of the 30,000-volt main cathode could act upon the auxiliary discharge. Dr. Langmuir explained both of those points in detail, at page 1276 of the record here, and I do not see any need of repeating them now.

This first Lilienfeld X-ray tube is illustrated, in fact I think the cut is the same, at page 212 of the *Hand Book of Radiology*, by Marx, dated 1915, and that hand book with respect to Figure 69, which shows the first form of Lilienfeld X-ray tube, states as follows:

> "The arrangement has, however, two disadvantageous features. Firstly, the current strengths in the primary discharge exceed by far the current strengths in the secondary discharge. Secondly, moreover, the high voltage secondary discharge influences the primary discharge which operates with relatively lower voltage drop in such a manner that surges occur, especially if it is desired to obtain very hard rays. The high voltage occasionally quenches the primary discharge, and it is not very easy to avoid these disturbances by inserting high voltage resistances and similar devices."

That is a practical demonstration of this current stopping effect of the high voltage cathode to which Dr. Langmuir referred, and it is described in this publication as occurring in the attempt to get very hard rays, which of course is the higher voltage operation, because the penetration goes up as the voltage is increased.

Later on the next page, page 213 and page 214, with reference to Figures 71 and 72, which show later forms of Lilienfeld X-ray tubes, the author says:

> "Finally, the fluorescence of the front half of the sphere which otherwise exists in tubes does not occur."

That is in these tubes of Figures 71 and 72, and,

> "This shows that no reflected or secondary cathode radiation reaches from the focal spot to the glass sphere."

The absence of glass fluorescence in the second and third forms of the Lilienfeld tube, therefore, is worthy of comment in relation to the operation of the first tube; and I think that it has been stated in this record, but for fear that it has not I had better say so, that if a discharge is practically free from ionization and occurs at high voltages, high speed electrons will hit the glass under conditions where they can reach the glass, and will start to make the glass fluoresce. However, they will charge the glass negative on their arrival and consequently no more electrons will arrive at high speed and consequently the glass will not fluoresce when the negative charge remains on the wall of the tube.

On the other hand, if there is substantial ionization such as would destroy the space charge, then the wall charge may also be destroyed, that is to say, the accumulation of negative charges on the wall may be destroyed by the positive ions (or it may even become positive) and in that case the fast-moving electrons will hit the wall and cause ionization. That is the way in which fluorescence may be a sort of test for the presence or absence of ionization.

There is another publication with reference to this Lilienfeld tube and that is an article by Lilienfeld himself in the *Berichte* of the Academy of Sciences of Saxony, 1914, pages 76 to 79.

This shows a photograph of the second type of Lilienfeld X-ray tube at page 77 and in connection with the production of that type of tube points out that in order to do away with starting potentials, so to speak, one has to get electrons from the cathode without relying upon the main field to do so. It is a sort of an introductory statement to his general discussion of producing of electrons.

He says: "One must use a glowing electrode to get such a discharge condition." And when I will quote from the translation: "It remains now only to consider how we can prevent the electro-static field around the cathode from unfavorably influencing the discharge coming from the incandescent electrode and necessarily passing by the cathode. Such an unfavorable mutual influence of two gaseous discharges always occurs if the carriers of electricity which provides the current conduction get into a field which crowds the carriers of electricity from their path. Consequently we have the simple principle that if two gaseous discharges are to occur simultaneously, their electrostatic field must show the same direction and the same sense. From this knowledge follows the construction of the tube." And he refers to the new tube in which your Honor will see that the filament, cathode and anti-cathode are in line, so that this "reaching in" effect or grid effect of the high voltage negative no longer occurs in this tube.

These two references have to do with the change from the first form of Lilienfeld tube to the second and third forms and both refer to the effects of instability that Dr. Langmuir described in connection with the grid action of the third electrode.

There was some attempt to prevent the stopping of the auxiliary discharge, that is to say, the filament discharge, by increasing the voltage applied to the anode of that filament discharge to about 500 volts and I thought that was referred to in the Lilienfeld-Rosenthal paper, but I am not able to find it at the moment.

The situation is then that even in the auxiliary discharge of 'the Lilienfeld first type of X-ray tube, there must have been ionization rather than control of the amount of current by space charge. The situation then with respect to the tube becomes that he approaches, as he said, an X-ray tube which would operate at pressures somewhat below those pressures at which an ordinary X-ray tube would stop operating but clearly not at such pressures as would stop the auxiliary discharge, because when that would tend to stop by further clean-up, the whole tube went out of operation and the unstable effects occurred.

Mr. Davis: With your Honor's permission, I will now interrupt the examination for the sake of asking Dr. Arnold some questions. Dr. Arnold, will you take the stand?

John V. L. Hogan, resumes the stand:

Direct Examination (Continued).

By Mr. Davis:

Q. 401. I think you have dealt with the Lilienfeld-Rosenthal article.

A. That is correct. That first X-ray tube was, I believe, the first practical device that Dr. Lilienfeld suggested. The 1910-1911 papers in the *Annalen der Physik* and the *Berichte* refer to the experiments on the rather complicated form of tube with exploring electrodes. Your Honor may recall Figure 6 on page 685.

By The Court:

Q. 402. Those sounding electrodes?

A. Yes, your Honor. That tube, of course, was not a tube made to do work. It was for a scientific experiment and it was never sealed off of the pump so far as I can find. There is some reference in the *Berichte* paper to the use of a glass valve which cut down the rate of diffusion of gases between the pump and the tube and that is shown, I think, at page 435 of the *Berichte* paper, but, of course, that is a very different proposition from a sealing off and maintenance of pressure under operating conditions in a sealed-off tube.

Lilienfeld in the text says that he had plenty of positives present, to put it colloquially, that is, he made the explanation that there were as many positive charges present as there were negative charges and of course he insisted that because of the care he took in evacuating his tube that his positive charges could ~~not~~ have been due to gas ionization.

He advanced the theory and seemed satisfied with it that the empty space within the tube dissociated into positive and negative charges; and that is a theory which nobody from his time to now has been able to bring himself to accept, if only because they asked themselves the question, after space is dissociated into positive and negative charges, what is left? It just does not mean anything to any of us nowadays.

A much more plausible explanation of the presence of the positives is that there actually was either vapor from the hot glass walls of his constricted tube or that there was some gas present that would have been ionized at the very high voltages he used, in spite of his efforts to get extreme vacuum.

He does not give us any measurements of the over-all voltage on the tube, but his earlier papers refer—and I think this 1910 paper also refers to the high voltage machines from which he derived his potential.

Across the short distance of the sounding electrodes he measured drops up to about 400 volts and I think all the evidence together with the fact that he referred to using series resistances of values varying from something like 11,000,000 ohms to something like a thousand million ohms, if my recollection on that point is correct as to the figures, I think all of those things go to show a high voltage applied to the tube of the order of thousands of volts certainly, and tens of thousands of volts probably.

Under such potentials and even with vacua that were high compared to those used in X-ray tubes or any of the common experimental tubes of Lilienfeld's time of 1910, I think that gas would be the most natural way to account for the positives that he said were present.

There has been evidence argued in discussion of these Lilienfeld papers of 1910 and 1911, to show that he had no gas, but I think that all of that is argumentative and indirect. One point that has been made is that there was no difference stated as to the current voltage relation of the discharge as the pressure was reduced. In other words, if one takes one relation between voltage and current (as determined by Lilienfeld), and another one as determined by him when he had changed the pressure in his tube, for instance, by applying liquid air or something of that sort, one finds that those current voltage relations are unchanged.

That was said to be analogous to or the same thing as the criterion which has been described in connection with the Langmuir tube, namely, that you knew you had a good ionization free discharge when you found that reducing the pressure in the tube did not affect that discharge, or rather, its law of voltage with respect to current, to a material extent.

In the Lilienfeld case the discharge which was not affected (or the law of which was not affected) as the pressure was changed, was not the main discharge and that point I hope to make very clear.

In the Langmuir case we are talking about the voltage current relations overall, that is the real useful discharge of the tube. In the Lilienfeld case he was talking about the current voltage relation between these sounding electrodes, and it was not even the current that flowed into the sounding electrode circuit but the current that flowed past the sounding electrode circuit.

Your Honor may recall that the electrodes were connected to an electrometer so that no current flowed in their circuits. Therefore, although as a matter of words those things sound alike until one analyzes them, as soon as we get into the facts we find they are quite different.

If Lilienfeld had given us the changes in voltage over the tube and the currents through the tube and had had as a result of that data a law that indicated that there was no change in the current-voltage function as the pressure was reduced, it might have been in the absence of other factors a fair assumption that he had an ionization-free discharge or a substantially ionization-free discharge.

On the facts here, however, since those measurements are subject to all the errors that probe measurements can be, I think the criterion is a false one as to this case.

There was a second criterion, a second piece of indirect evidence which has been argued to show that the Lilienfeld experimental tube of 1910 was operated in the absence of gas ionization and this, your Honor, in spite of the statement by Lilienfeld that electrons did not predominate, that he had equal numbers of positive charges. The second point is that with the device there was attained a constancy of current as the filament temperature was increased.

Lilienfeld said if his filament were hot enough it did not have to be hotter, or that it made no difference in the discharge if he once got it hot enough whether or not he increased the temperature. That has been called the flat top temperature curve, which is a demonstration (in the case of a measurement of the overall discharge) of the ionization-free condition, because with a properly observed and stated flat-top temperature curve, we know that the saturation portion has been left and that something other than saturation is controlling the amount of current passing through the tube. That other thing is in general space charge and that is the controlling agency, the current limiting agency in the practical tubes of the Langmuir patent.

An effect which is a little bit similar in its superficial aspects to the flat-top temperature curve may be had from an altogether different cause if one has in series with the devices being measured, a high external resistance, because the change in the tube current with the filament temperature does not go up indefinitely when a voltage drop commences to develop across that resistance by reason of the current passing through it multiplied by the resistance itself, and commences to be subtracted from the voltage supplied to the tube.

One may offset the other so that an apparent flat-top relation is had. I think in so far as we can tell from the data given us by Lilienfeld that this statement of his may be fully accounted for by the high series resistance, and the measurements that he took between his exploring electrodes instead of on the main discharge.

A third point that has been argued to show that Lilienfeld had no gas in his tube was a statement that his current was limited by space charge. Lilienfeld himself in the *Berichte* article emphasized his conclusion that there was no space charge in his tubes and I cannot see that measurements taken by exploring electrodes in the narrow tube where wall charge, that is to say charges on the constricted walls of the tube, may have a prominent effect, I cannot see where measurements taken at such a place in the absence of similar measurements taken for the entire tube as bearing on its full discharge, can be used as an indication that there was space charge limitation.

Lilienfeld did not seem to think so and I do not think it is properly arguable now.

The fourth point that has been made was that the Lilienfeld discharge at some part of the range from lowest currents and voltages to highest currents and voltages followed the 3/2 power law that was propounded by Dr. Langmuir and which is used often as a test of a working tube.

In the first place, there has been no agreement between the witnesses in the Interference and those here as to where on the Lilienfeld curves that 3/2 power law applies. Dr. Chaffee here said that the point at which the 3/2 power law is to be taken is down at the bottom of the curve, in the initial sloping portion of the curve where curvature is changing, and that he tied up with Lilienfeld's statement that the variation of current as the 2/3 power of the voltage, Lilienfeld, of course, deriving that relation by the insertion of a constant and various changes in the curves.

Richardson in the Interference replotted some of Lilienfeld's data and found an agreement with the 3/2 power law over a high voltage range over in the portion of the curve that Lilienfeld said followed the square law.

I do not think it matters where if at all the discharge in Lilienfeld's tube shows indications of agreement with a 3/2 power law over a limited range when we remember that what we are talking about is the main current through the tube, and not that passing by a pair of probe electrodes as related to the voltage measured between those probe electrodes.

In other words, no matter what part of these characteristics taken by Lilienfeld we may use, we are in no event taking the current voltage relation of the main discharge. That is the important thing in the Lilienfeld tube, the tube of the Lilienfeld article, and by that I mean the main discharge and its voltage current relations. And I think it is technically unsound, and that is putting it rather gently, to use probe measurements (of probe voltages where no current flows) against main current flowing past the probes, to derive any current relation applicable to a main discharge.

If one replots the Lilienfeld data and takes out the "correction" that looks like eleven volts but is really something very much higher, he finds that even between the probes the voltage current relation starts off, instead of agreeing with the 3/2 power, it starts off something like the 20th power and then slows down, that is, the power slope of the curve becomes lower.

Of course, any curve passing from a high power to a low power is going to come for a part of its range through any exponent you may choose that lies between the extremes, and I see no significance beyond that, of the characteristic curve relation—even if we should assume for the purpose of the argument that measurements taken between the probes and not across the entire tube were of any real significance.

Considering the tube itself, there was an experimental apparatus that was used on the pump or while cooled by liquified gases and in that tube Lilienfeld probably got an unusually high vacuum, a vacuum higher than that common in the tubes of the day.

He did not use it or suggest its use for a pure electron discharge so far as we can tell from the publication. He gives no data on his main discharge current relations and he did not take his apparatus away from his vacuum producing means.

He got no current through his tube at all until the overall potential reached a value of something like 105 volts measured between the probes. What that meant in the outside potential we cannot tell but it must have been exceedingly high. That is totally unlike any tubes of the Langmuir patent that I have ever seen.

Further, he had a starting electrode shown at Z in this Figure 6 at page 1685, the use of which is not explained by him but which from its name and position is probably analogous to the starting electrode that was common in the mercury arc ionization devices and which was used in the Arnold tube as described in one of his patents that has been put in.

I cannot see that Lilienfeld added anything to the practical art in the way of accomplishment or suggestion. What one can find in his paper by looking back at it now is rather slight, and even its effect was undoubtedly discounted by the muddy statements—the lack of clear-cut statements and by the false theories, or at least the theories which we have not yet been able to accept, that accompanied it.

> Mr. Haight: I do not know what the line of objection has been or the line of ruling, but it seems to me that that part of Mr. Hogan's answer that begins with "I cannot see that Lilienfeld added anything" to either the practical art, and from then on is objectionable and should be stricken out.
>
> The Court: Motion granted.

A. (Continued.) Turning to Exhibit 19, which is Lilienfeld's short note in the *Physikalische Zeitschrift* 1908, page 193, we find that this is a suggestion that is directed to the Soddy experiment of Exhibit 18 where the current suddenly stopped and then started again, where he vaporized his magnesium or calcium anode, and we find Lilienfeld's suggestion that space charge was what limited the current in Soddy's work, this particular bit of Soddy's work.

We know now that if there had been any such space charge limitation in the Soddy tube it was probably due to charges on the wall of the tube rather than to a space condition.

Dr. Langmuir has discussed all three I think of these Lilienfeld publications and certainly the 1910 and 1911 publications in the Interference transcript beginning at page 1364.

Defendant's Exhibit 32 is an article by Kunz and Kemp in the *Physikalische Zeitschrift* for July 1, 1912, beginning at page 593. I covered this in connection with the last three patents at page 1587 of the record.

Dr. Chaffee includes the publication only in his list having to do with vaporizable reagents and I think it is perfectly clear from the publication itself that the highest vacuum attained was that corresponding to an X-ray pressure of a few microns. The authors speak of blue glow, violet layers, and the yellow sodium light observed within the tube on their spectroscopic analysis.

Exhibit 33 of the defendant is the Whitney article of 1912 in the A. I. E. transactions. I covered this at page 1588 with respect to the last three patents in suit and I see no bearing on the first patent because it has to do with lamp practice only.

Perhaps I should point out that even though a lamp in running its life does clean up beyond the exhaust value, that is, the value at which it left the pumping systems, to a relatively small fraction of a micron, no such effect would be available in a vacuum tube which must work from the moment it leaves the factory.

You cannot rely on a long time clean-up of that sort. If a vacuum tube had untreated anodes they would give off so much gas as to make the filament clean-up unrecognizable. One thing would more than offset the other.

Exhibit 34 is the Clark Patent 1,121,802, and that is the Mirror patent that I referred to at page 2634 and I do not think it would be worth while to discuss it further.

Exhibit 35 is an article by Angerer in the *Annalen der Physik* 1913, pages 1 to 26. It has a late date, 1913, with relation to Langmuir's work and the vacuum measurements in it are very doubtful, although measurements of what are apparently very low pressures are included in the text.

The author made two forms of tubes both of which are rather complicated and contain a great deal of untreated metal and also a number of parts covered with rust which is rather difficult to imagine in the interior of successful tubes today. Throughout the apparatus sealing wax was used, one of the tubes contained water glass, and the article has many comments about rays emitted in diverging streams and about positive ions and gas molecules in the tube, so that I think that in spite of the notations as to vacuum the author's own statements that he had to extrapolate beyond the point which his vacuum gauge would read in order to get these lower figures, I think that taken with the references to ionization make it unnecessary to consider the article further.

Exhibits 36 and 37 are the Clough and MacKay patents which were both filed October 30, 1915, and which are both late with respect to the first patent in suit and also have nothing to do with ionization-free operation since they are on high pressure devices.

In general, a great many of these publications are simply plans for pumping, such as charcoal and liquid air in a side tube or attached to the main tube, and I would like to say that pumping itself is not a serious problem in the preparation of tubes that behave according to the Langmuir first patent, that is to say, the Langmuir tubes. A good laboratory pump, a Sprengel pump with a liquid air trap or with carbon dioxide—I think I spoke to Mr. Darby on cross-examination on this—a reasonably good pump would be enough to give a good tube provided the treatment of the anodes, and the glass and the filament, has been carried to the extent that is necessary to make it possible to pump the tube out.

It is not a case of pumpability or pump capacity but what the tube itself will give off in the preparation. An improperly prepared tube, one that has not been degased thoroughly, cannot be pumped out and be made to stay pumped out even on the best and fastest pumps that we can get today. I think that covers the question, Mr. Davis.

Mr. Davis: If your Honor please, there are certain citations—I prefer to call them that rather than references—which have not yet been put in evidence by the defendants, and I assume that if they ever are we may discuss them when they are put in.

The Court: You may have a chance to reply when they are put in by the defendants on sur-rebuttal.

Mr. Davis: It is hardly that. Mr. Darby stated he did not have copies of certain references.

By Mr. Davis:

Q. 403. Mr. Hogan, you may assume that there is testimony in this record that Dr. Arnold on or about

November 1st had a certain discussion with Mr. Colpitts and I think Dr. Jewett and that there were two phenomena among others which he discussed and one was the phenomena that when the B-battery voltage was too high the tube broke into a blue glow and under those circumstances it would not repeat at all or repeat very badly. The other phenomenon was that when the B-battery voltage was lower than that so that the tube did not break into blue glow, it was possible to converse and get amplification provided the voices were not raised above a certain loudness, however that may be, whereas, if it were louder then there also was an effect which was noisy and prevented the amplification from being carried on. Mr. Arnold spoke of this as a quite separate phenomenon which should be kept distinct.

Will you please state the technical facts underlying those two phenomena and the difference between the two phenomena? And I may add for completeness that there seems to have been referred to by some of the witnesses an intermediate condition between those two in which the tube broke into blue glow when it was talked into and not when it was not talked into.

A. Let us first think about overload, that is I think the condition that you mentioned second, as a matter of fact, but by overloading I mean the inability of a tube to continue satisfactorily to amplify as the applied intensity increased.

Q. 404. That is, as a person talked louder?

A. Yes. Suppose one talked at a certain intensity and that resulted in a certain alternating voltage applied to the tube and we got as a result of that a certain larger response in the plate circuit. That would be a normal operation of the tube, the increase in response in the plate circuit being the normal amplifying function of the tube. Now then, suppose he talked louder, and that caused larger vibrations in the input voltage, so that the output current was called upon to pass through a larger swing or cycle than it was capable of doing, then the tube would be very severely overloaded, and would fail to amplify properly.

An extreme case of that would be where the plate current was of a definite value, say a certain number of microamperes and the current swing necessary to respond to the input energy properly employed would involve a change of more than that number of microamperes. It is perfectly clear that the current is not available in the plate circuit to cause a reduction down beyond the limiting point, the zero point, and the current can not reverse, of course; as I say, that would be an extreme case of overloading, that conceivably might have been experienced with tubes having a low plate circuit power limit.

The other effect, that is to say, the appearance of blue glow, and the failure of the tube temporarily, failure of the tube while the blue glow is present, is an ionization effect, and was caused in the old audion by the passing of more than a certain electron current, a certain plate circuit current at more than a certain voltage across the tube. The adjustments of both those values at which the tube would break into blue glow, being different for different tubes, and those for the same tube at different times. When the blue glow passed, the tube ordinarily ran right into saturation, if it had not already been saturated before the blue glow appeared; that is to say, all the electrons that the filament was capable of emitting under the particular conditions, were drawn to the anode during the blue glow condition. Of course, with strong ionization of that kind, the filament may have been overheated by positive bombardment, and caused in that way to give off more electrons, simply from the increased temperature, and consequently a run-away current might be produced, but that would be an effect over and above the filament battery current.

Q. 405. Now, if the tube is saturated, because of blue glow, can the tube in that condition amplify?

A. No. That is the point I was about to come to. When the tube is in this condition, it is dead; the amplifying power has gone.

Mr. Davis: I wonder if that is clear, your Honor?

The Court: It is not at the moment. I think I shall work it out.

Mr. Davis: It is simple and I think I had better stop and make it clear; on the saturation point, you are at the point of the curve where the current is independent of the voltage.

The Court: Yes.

Mr. Davis: And therefore the current is independent of the voltage on the grid and so no change of voltage on the grid would change the current in the tube

The Court: Let us see. It is independent of voltage, both of grid and filament?

Mr. Davis: Yes, sir, because all the electrons are going across that come out. I do not mean but what you might put a voltage on the grid.

The Court: I have it. I had overlooked the grid in that.

Mr. Davis: The point where your current curve is flat, and the whole theory of amplification is to have a sloped curve; is that right?

The Witness: Yes.

Q. 406. Will you please continue?

A. I think that he has distinguished between the two points, the two phenomena. I might take the transition that you mention, that is, point out that if a tube has been overloaded—perhaps that is the wrong word to use, because I have used it in the other sense—

if a tube is "adjusted," so that the voltage and the electron current, the space current, are about all it can stand without going into blue glow, then the effect of a large voltage applied to the grid will be the same as an additional voltage applied to the plate and may carry it over into the blue glow state. Of course, that is another instance where there is what the old art called a non-self-sustaining discharge, that is to say, a discharge which required the heated filament to keep current passing, but still one in which there was large ionization.

Q. 407. Now, coming back to overloading, Mr. Hogan, is it possible to overload a good high grade modern tube?

A. Yes. The capacity of the tube for handling power is not extended to the limit, so to speak, simply by making it a pure electron tube.

Q. 408. And if you have a tube which under certain circumstances in use as a telephone repeater is overloaded, and it is a good modern tube, what would you do to cure that difficulty?

A. I would put in a larger tube.

Q. 409. And by a larger tube, what do you mean there, in what respect?

A. The main criterion is filament emission, I think; of course it would require to be able to handle more power in the plate circuit, but that would come with the increased filament emission as a general rule.

Q. 410. And if you would raise the current in the tube, the possibility of current in the tube only had had what relation to the changes that were made by your telephone transmitter?

A. Until it was amply large to permit the changes I wanted.

Q. 411. Now, on the other hand, if you had a tube which was failing, a tube such as this DeForest audion, which was failing to transmit properly, not because it was overloaded, but because it broke into blue glow, and because of actions of which the blue glow was symptomatic, would you or not feel that by increasing the vacuum so that it would not break into blue glow, that would cure that difficulty?

A. No, it would not cure it, because there is a large range where blue glow does not appear in a tube running at voltages of 100 or 200 even, and below, where ionization will interfere with an increase of power capacity. Of course, in answering that, I assume that you mean a condition in which ionization was in the tube.

THE COURT: Suppose Dr. Arnold was wrong, and if I understand that question, I was wondering as it is pretty nearly time to quit, if you will tell me the pertinency of that, because it seems to me that is probably intended to meet Dr. Arnold's diagnosis of the DeForest tube, it seems to me that his diagnosis was theoretically wrong, but actually right.

MR. DAVIS: If your Honor please, I am trying to make a very specific definition. With regard to the definition of overloading, Dr. Arnold speaks of four things he had to do—better mechanical construction; of course, that is not part of the invention. Longer life of the filament; that is not any part of the invention. Overloading, curing overloading; that is not any part of the invention.

THE COURT: By "overloading," I understand you mean higher voltages on the grid?

MR. DAVIS: No, sir. I mean the failure of the tube to respond to the voice by reason of the fact that the change in current called upon is greater than the tube is capable of making.

THE COURT: And that being by reason of the higher potential or better voltages on the grid.

MR. DAVIS: I think that is true.

The Court: That is as I recall it.

Mr. Davis: You are trying to make the tube work on a bigger range than the tube is capable, and that has nothing to do with this invention absolutely. He could get rid of that by four audions in parallel or having audions with the filament spread out more and bigger plates. Now, we come to the thing which, if any, might have something to do with the invention, which is this suggestion of his with reference to blue glow, and the suggestions testified to repeatedly in all this, both in the Interference and here, which is: I said I could make a tube which would be pumped so well that it would not blue glow, or Dr. Arnold told me that he could pump a tube so well that it would not blue glow. Now, our position there in the Interference was, and it is the same here—that that is not enough; that you may exhaust a tube, so that it will not blue glow, and yet it will not be the tube of issue, and not be a satisfactory tube. That is there is a very considerable range of vacuum intermediate between the vacuum in the tube where it breaks into blue glow, and the vacuum in which that particular tube acts, that is one of the points in the Interference.

The Court: Can you help me a step further; but the higher the vacuum, the more remote you make the blue glow stage and the more remote you make that stage to which you refer, which comes before the visible blue glow stage, don't you? I thought probably they travelled together, with the ionization stage preliminary to blue glow, you might say, that it would come shortly before blue glow?

Mr. Davis: There, I think that is important, if your Honor please, and I think your Honor is wrong there. I think that is one of the vital things you have put your finger on. I had not seen it before like that. If I understand it correctly, a tube which is going to show ionization, which will interfere with space charge, it is going to show that very soon after it gets above ionization potentials. On the other hand, the tube which is going to break into blue glow, may not break into blue glow until it gets up to a high voltage, and I do not know any relation between those two things. There may be one but I do not know of it.

The Court: I had rather assumed, not knowing anything about it, that one came shortly before the other.

Mr. Davis: I think not.

The Court: Maybe that the voltage will have to be only perceptibly lower. That does not express what I mean. Suppose you get the blue glow at thirty volts. Put it that high. Then you would expect ionization at 20 or 25 or 30?

Mr. Davis: That is quite true; but on the other hand, a tube which would blue glow at 100 or 150, would be showing departures from the 3/2 power law, and the other criteria, almost from twenty volts, that is my understanding of it.

The Court: Then my guess would not have been contrary?

Q. 412. Mr. Hogan, is that substantially correct, that statement of mine?

A. Yes, I think we could work up some curves if you wanted them that would show the pressures in the DeForest audion, also the effect on the 3/2 power curve, and such a vacuum that would not give a blue glow until you got to eighty or ninety volts in a DeForest audion.

The Court: That the ionization would cause a departure from the 3/2 power curve long before you reached the blue glow?

The Witness: Yes.

Mr. Davis: Yes.

The Court: That explains a lot of things.

Mr. Davis: That is one point which I tried to make in the opening, but it seems so long ago that I can hardly remember it. The other point, the whole point is that we did not think Dr. Arnold disclosed to Dr. Jewett that he understood how to make a tube which when put on a Gaede molecular pump or any other pump, could be used practically, and hold that vacuum, because the thing, we cannot say too emphatically in this case, is that the invention is not of the vacuum.

The Court: As I understand the witness, he adds to the pumping of vacuum, a preliminary treatment of the internal walls of the tube and the middle part that is in it?

Mr. Davis: It is throwing money into a sewer to pump a vacuum in a badly prepared tube.

The Court: Now, then, have we reached the point where we can take a recess? Is the reason that the incandescent lamp, the filament of that does not emit electrons—I had better not because——

Mr. Haight: You understand that our position of course is that blue haze was simply a manifestation of ionization going on, and that made apparent to Dr. Arnold of what was happening in the tube, and the cure that he offered for the defect, which was being manifested by the blue haze was the modification of the vacuum, and that is the invention. Simply because at that particular time, the kind of filament used, and everything else, the condition that was going on was manifested by blue haze, is no reason at all for assuming that Dr. Arnold did not at that time know that ionization would take place before blue haze was manifested under certain conditions.

The Court: That I understand. If I understood the witness, he said that an incandescent lamp did not emit, the filament of the incandescent lamp did not emit?

Mr. Davis: I do not think the witness said that. I understood him to say that any emission was undesired and unutilized.

The Court: All right. It does not make any difference except I was wondering just why there had to be another electrode in the device, in order to cause the emission.

Mr. Davis: You have these two legs of the filament. First, take the two legs of the filament where you go in and go out.

The Court: Different potential?

Mr. Davis: There will be an Edison current of some magnitude.

The Court: I wonder if the electrons boil off from a hot electrode any way?

Mr. Davis: They will boil off any way, but they will probably fall back, if there is not any voltage to pull them away. My understanding is they do not go very far, if there is no voltage, but take the part that is most negative, where the negative current goes into the lamp, and there you have a hot cathode in a sense, and you remember that Dr. Langmuir spoke about the talk he had with Professor Richardson, and asked him why it was that there was not a measurable current, and Dr. Langmuir finally concluded it was space charge that held that current down.

(Whereupon, at 6 P. M., an adjournment was taken until Wednesday, November 10, 1926, at 10 o'clock A. M.)

U. S. District Court, Wilmington, Del.,
Wednesday, November 10th, 1926,
at 10 o'clock A. M.

NINETEENTH DAY.

Before:

HON. HUGH M. MORRIS,
U. S. District Judge.

Appearances: As before.

JOHN V. L. HOGAN, resumes the stand.

DIRECT EXAMINATION (Continued).

By MR. DAVIS:

Q. 413. What would be the relation, Mr. Hogan, in a tube, between the pressure at which blue glow would be visible, and the pressure at which positive ions would not substantially modify the space charge, assuming a tube to be operating at 50 volts or 100 volts, or something of that sort?

A. That matter of blue glow has two basic features that must be considered. In the first place, the blue glow depends upon the spectra of a particular gas or gases that may be within a tube at any time; and in the second place, the occurrence of a visible blue glow will depend upon both the current passing through the tube and the voltage across the tube. That is to say, on the power that produces the ionization. It is not simply a function of voltage alone. Considering the matter of the spectra, there is no connection, so far as I have been able to find out, between the visibility of a certain gas when strongly ionized by sufficient electric power, and the capability of that same gas, when ionized, to affect or neutralize a space charge. For instance, in the case of argon, we have a gas which gives relatively little light when it glows. It produces a purplish blue glow, but not very much light, largely because its ionization spectrum is, for a great part, above the visible light frequencies and in the ultra-violet rays. On the other hand, argon itself, this same gas, has got strong ionization properties, so to speak. That is, it is effective in neutralizing a space charge in a vacuum tube. Neon is a different type of gas. Neon gives a great deal of light when it is glowed. It has a characteristic reddish glow, and yet on the other hand it has much less ionization effect, and it is hard to ionize, requires a higher voltage for ionization, and I think it is of all the gases the least effective in reducing space charge.

On the matter of intensity, that is to say, the power relation, we might consider a good vacuum tube having a large current passing through it, 50 milliamperes or 100 milliamperes of electron current at a fairly good voltage, perhaps even 100 volts or so. If we leave the voltage the same and the electron current the same, and gradually increase the pressure, the gas pressure in the tube, the ionization in the tube will gradually increase. As we have all recognized, there is some measurable ionization, even below points at which ionization harmfully affects the space charge. There is no sudden beginning or sudden stoppage of ionization as a physical fact.

If the pressure in the tube then is increased, the ionization will gradually increase and there will come a time, I should say that as the ionization increased, since the electron current is constant at this assumed large value, the ratio of ionization to electron current will increase as the ionization goes up. It is that ratio which is one of the measures of the effect of ionization on the space charge. For a given tube when the ratio of the ionic current to the electronic current becomes too high there is a destruction of space charge in the tube as is evidenced by departure from the 3/2 curve.

With so much current and substantial voltages the energy, the power, in the ionization may be sufficient to produce a visible glow very soon after the percentage of ionization to electronic current has reached the point where space charge is badly affected, so that there may be little margin (and in the case of a very large voltage high current tube there may be no margin at all) between the point at which ionization hurts the space charge and the point at which visible blue glow sets in.

On the other hand, if you take a tube such as the DeForest audion or one of the small radio tubes or telephone repeaters, with a relatively small electron current, a current for instance of 100 or 200 microamperes such as is common in the old audions, put on that 50 or 100 volts, say 100 volts, and gradually increase the pressure again from a very, very low pressure on up. Here again the ionization current, the ionization in the tube, will increase gradually as the pressure of gas increases and so will the ratio between the ionization of the electron current increase.

But the ratio of the ionization current to the electron current will reach a value that affects the space charge and causes a sharp departure from the 3/2 power law above ionization long before the energy in the ionization discharge will cause a visible blue glow. That is because the electron current is so small that it is affected by a much less ionization current or energy than is necessary to give the visible glow.

There is then no direct connection between the appearance of the blue glow and the departure from the ionization free operation by space charge. In a small tube the break in the characteristic at ionization voltage, that identifies the gas effects on the space charge, will occur at pressures and low currents and lower voltages long before the voltage reaches the point where it combined with the energy flowing through the tube will make the glow visible and (as I think I said) in contrast to that, in a large power tube the blue glow may set in practically as soon, if not absolutely as soon, for all practical purposes, as the ionization becomes intense enough to offset the space charge effect of the large current.

Q. 414. In connection with Defendant's Exhibit 25, which is the Lilienfeld 1910 article, I refer you to XQ. 881, of Dr. Chaffee's cross-examination, at page 338 of the record, and his answer at page 339 and ask you what you can say as to the extent of secondary electron emission in the lower range of operation discussion by Dr. Chaffee in that answer, that is, that portion of the range which I understood him to suggest conformed to the 3/2 power law.

A. Yes, sir. That question had to do with the secondary emission of electrons in the Lilienfeld tube, and I think Dr. Chaffee agreed that in the larger energy part of the operating range of the Lilienfeld experimental tube, which is the long tube of the 1910 article and not the X-ray tube, that in the upper part of the characteristic, so to speak, the secondary emission effect became important. He thought that it might exist, as I recall the answer, below what he thought was the square law characteristic, but that it was not so prominent. In that connection I would just like to point out that the Lilienfeld tube of the 1910 article was one which had to be started, that is to say the current did not begin as soon as voltage was applied between the main anode and the cathode.

Before current flowed, electrons from the cathode came out and charged the narrow tube walls and presumably prevented the passage of current at low voltages. That condition had to be overcome, and when sufficient voltage was applied along the straight portion of the tube, as for instance, by putting a spark coil on the starting electrode, then the probability is that the electrons were caused to strike the tube walls hard enough to set up secondary emission of electrons perhaps aided in their high velocity impacts by whatever positives there were present in the tube.

That condition is what seems to result in the lower part of the Lilienfeld curves and represents the situation in the use of the tube where a voltage of 105 or something like that was measured between the sounds and representing a condition below which no current at all would flow through the tubes.

If we can assume, for instance, that the impact of the electrons on the wall when driven by sufficient electromotive force to start the discharge, will be great enough to knock two electrons out of the glass wall for each impact (and that would not have to occur for every impact, but only for some of the impacts), then the walls would have a net positive charge; that is to say, more electrons by some margin would be leaving them than would be striking them, and that would aid in neutralizing whatever negative space charge there might exist. It would co-operate with whatever positives existed in the tube, and give somewhat the same effect. Thus, the charge would be prevented from building up negatively to the extent that would again stop the current, and the rate at which that secondary emission would occur would follow some law dependent upon the secondary emission of glass under the impact of electrons. Now, if one plots Lilienfeld's data, taken between the sounds, it is found that there is no break from a 2/3 law to a 1/2 law of current variation with voltage, even when the main current is compared with the sounding potential, a sounding electrode potential; but there is a smooth curve swinging off from a very high power to a lower one; and I see no reason from Lilienfeld's data or from any further consideration that I have been able to give that tube, why secondary electron emission should not be as necessary and as prominent as far as permitting the discharge to start at the low current and voltage values, as at the high. That is to say, the discharge does not start at all until a certain condition is reached. If the negatives are there strongly on the thin tube, the discharge won't start at all, and I think one of the large factors in even the beginning of the discharge, is the secondary emission which Dr. Chaffee agreed was prominent at the latter part of the discharge, well after the current flow had begun. Also we might note in this connection, as to the bombardment of the narrow tube by the electrons, that the liberation of the discharge energy to the walls of the tube, which is characteristic of those Lilienfeld 1910 results, is a very different thing from the delivery of the energy of the discharge to the anode, and the heating of the anode as in the practical thermionic tubes.

Q. 415. Could you make a Langmuir tube, the tube of the patent in suit, by pumping a DeForest audion?

A. Not without preparation. If the anodes and glass and grid had been thoroughly prepared, a good tube could be made, but pumping alone would not cause the pressure to remain low. In fact, it would be impossible to get the pressure low by pumping alone.

Q. 416. Will you please explain why you could not make a Langmuir tube by pumping a DeForest audion?

A. Because the glass and grids and plates are not cleared of gas in the ordinary manufacture.

Q. 417. To what extent, if at all, were the methods used for cleaning up the electrodes with mercury devices, such as the Cooper Hewitt lamp, described in his patent, to which Dr. Arnold referred, and the mercury arc repeater, to which Dr. Arnold referred—to what extent, if at all, were those methods capable of being applied to the DeForest audion?

A. Well, they are so different—the conditions are so different that they are not directly applicable at all. In the mercury arc, for bombardment of the anode, one has amperes of current, watts of power, a great deal of power available to heat the electrode, and that is normal because that corresponds to the operation of the mercury arc device. On the other hand, in the audion, you are limited to certainly a few milliamperes, perhaps even less than a milliampere in many tubes, and to low voltages, the energy of which is very, very small, and the heating effects of which must therefore be very, very small.

Another difference is that in such a mercury arc tube as the Arnold repeater, there is a great deal of positive ion energy available for bombardment of cathodes, such as the metal cathodes on the sides of the tube, and there is nothing like that quantity of positives available in the audion, of course.

The DeForest audions with their tantalum filaments, were altogether too limited to permit electron bombardment of the plates to any effective extent, without either burning out or seriously affecting the filament. The little DeForest plate would take something like 50 milliamperes at 100 volts or about five watts, in order to heat it up to a red heat, say 800 degrees C., and we know that fifty milliamperes is far beyond the capacity of that sort of a tube.

Of course, the need of bombardment could be overcome by using wire anodes, such as Langmuir used in some of his early tubes and as Arnold used in the strip form in the 1915 power tube, where current could be sent through from the outside to heat the anodes, and in that way, the need of bombardment of that electrode avoided.

I spoke of red heat in connection with the audion, and perhaps I should point out that even though a device is going to be run on light power, small power, so that it really remains fairly cool in operation, nevertheless for the maintenance of a very low pressure in the device, the preparation of that tube should include the heating of the gas containing metals to a very high temperature.

The point is that the gas has got to be taken out of those electrodes during the pumping operation and preparing operation which will last only a relatively short time, a matter of minutes and it must be taken out in that short time to such an extent that in the later life or normal life of the tube it will not come out to an extent that it will bother operation.

The life of the tube, instead of being a matter of minutes will be in general a matter of hundreds or thousands of hours and consequently in the very short time of manufacture the tube must be cleared so well of gas that the long period or after life will not result in any appreciable accumulation by the slow evolution that is bound to follow if some gas is left in.

That is to say, one must for the operation of a device at rather small powers and under room temperature condition, one must in preparing it go far beyond the operation conditions and it is customary in making the little receiving tubes even to heat the plates to a bright yellow or white heat just for this reason.

On the other hand, of course, if a large device is going to be used under conditions where the anode is actually heated by the operating discharge to a high temperature so that it will glow yellow or white in use, then a statement to the effect that it is unnecessary to carry the treatment in exhaustion beyond the temperature used in operation would be correct, because the operating temperature attains the same high value that is necessary to get out all or practically all of the gas from the electrodes.

Q. 418. You spoke of this limitation of energy. What was the cathode in the mercury device?

A. A pool of mercury.

Q. 419. And was there any limitation to the current you could put through that pool?

A. No practical limitation except what the tube itself would stand in the way of heat.

Q. 420. Whereas in the case of the tube with a filamentary cathode what was the limitation?

A. The emission of the filamentary cathode itself, at temperature which would not destroy the cathode. Also of course if one attempted to attain a high emission with a good deal of gas there comes in the matter of ionization and positive bombardment which might destroy the filament.

Mr. Davis: I wanted to be sure that that was clear to your Honor.

The Court: It was made clear to me in the discussion the other night. The emission is increased by the size of the filamentary cathode?

By Mr. Davis:

Q. 421. Is that right?

A. That is correct. You can build cathodes that will give within reason whatever emission you may want.

Q. 422. Perhaps this might illustrate the point. Suppose you had the problem today of building a DeForest audion which would operate as one of the tubes in issue and were free to make little changes in the design, what is the first change you would make?

A. Of course, one of the things you do to get power today would be to increase the size of the filament. The various other changes follow from what we have discussed.

Q. 423. Referring to the data of Arnold's tube No. 20 in the condition in which it was known as 20.2 and in the condition in which it was known as 20.4, which I understand were the molecular pump exhaust of that tube, and which I believe is in Arnold's priority Exhibit 8, is or is not the information given sufficient to enable a conclusion to be drawn that this tube in these two exhausts or either of them would operate without substantial ionization?

Mr. Haight: May I ask what you are referring to in the word data?

Mr. Davis: I am referring to the data furnished by Arnold or on behalf of Arnold in the Interference with respect to that tube.

Mr. Haight: Exhibit——

Mr. Davis: It was Exhibit 8 in the Interference and which consists I understand with certain readings of current and voltage and certain E. S. curves.

Mr. Haight: That is all right with that limitation. I wanted to understand what the word data meant.

Mr. Davis: I meant the data furnished by Arnold.

Mr. Haight: You mean the data in the exhibit.

Mr. Davis: Yes, and any other data which the defendant furnished with reference to that tube.

Mr. Haight: Has there been any other furnished?

Mr. Davis: I do not know whether there has been any other data.

The Court: If the witness refers to any other data then call it to our attention.

Mr. Davis: Yes. If he is going outside of the bounds of this Exhibit 8, he should call it to our attention. You Honor may remember that Dr. Arnold said a little about this tube in his direct. A. I do not find this curve to show tube 20.2.

By Mr. Davis:

Q. 424. I am sorry but I should have referred to Priority Exhibit 19 rather than to Exhibit 8. Eighteen is the sheet and 19 is the blueprint that goes with it.

A. The curves on E. S. 86,907 summarize the data which we have with respect to this audion 20.2 and this shows two runs as to a voltage current relation of the plate discharge. The data does not give information as to what behavior this tube would have in the space charge and operating range well above ionization potentials and below saturation if it was capable of use in that range.

The curves show saturation between 20 and 30 volts. Each of the two curves has a large loop in the saturation range and those loops are indications of gas effects and not of temperature effects. They represent the sort of thing that happens when the surface of the cathode is either cleaned up or contaminated by gas effects, for example, ionization.

It is not possible so far as I know to determine the extent of the gas effects on space charge from the information that there is sufficient gas to cause some effects on emission. I see no reason from these curves to expect reproducible operation in the tube above 25 volts or so and in fact there is every reason to look for the contrary but the data are not sufficient to let me reach a positive conclusion either as to the presence of large amounts of gas or its absence.

As to 20.4 the blueprint E. S. 86,908, shows two runs in dash lines, I believe, for 20.4. They are marked molecular pump at the middle of the sheet.

Q. 425. The other two curves were on some other tube, were they, Mr. Hogan?

A. The other two curves are marked "mercury pump," and I think that had to do with the 20.3 condition of this same bulb No. 20, from the legend at the upper left-hand corner of the exhibit. Now, there was a third run covered by the data in the notebook, and I believe we have a plot of that third run.

Referring to the first, which is the curve extending highest of the dashed lines, ~~it~~ is clear that the operation was irreproducible above 40 volts; that is to say, the two curves depart and do not return together until approximately 40 volts. The second run showed a much smaller loop, but the third run, which was not plotted on E. S. 86,908, shows at a somewhat higher filament current, a very much more rapid increase of current with voltage, and the appearance of a dim haze, together with an increase of current running off the scale of the plot.

This pair of curves on the blueprint E. S. 86,908 shows the same gas loops at the saturation point, and in the case of 20.4 on the third run, we have a blue haze shown at the region corresponding to 90 volts or so. I think that these records are not proof that the tubes were even substantially free of gas ionization; that is to say, I think the data are not sufficiently complete to let me reach that conclusion as a scientific matter. On the other hand, I could tell definitely what these tubes were if we had more performance information concerning them. Points that are useful in connection with the complete study of any vacuum tube from this angle, include matters not given here, such as to which terminal of the filament the plate voltage was measured; how the grid in the tube was connected during the run, or whether it was not connected to any electrode; what the grid current amounted to during the run, if the set-up did show a connection and grid current; what the effect of the filament drop was as could be determined by using the rotating commutator; what was the effect produced on the general characteristic by contact potential between the filament and grid, for instance, if any contact potential existed, as it often does, and whether that contact potential remained constant; what the law of discharge was below ionization voltages, that could be had from current voltage data taken in the absence of these other complicating factors at low voltages, and would give a clue to the performance of the tube before ionization could have set in; what amplification constant the tube had, and finally, so that saturation effects could be eliminated from consideration, a set of data for several operating temperatures.

Very often that kind of information will give a definite idea of the performance of a tube which would not be suspected from a run taken at a single temperature. For example, in connection with this 20.4, when the filament current was increased from the .64 amperes used on the second run, where it showed fair reproducibility up to about 100 volts—good reproducibility in so far as this curve indicates—as soon as the filament current was increased to .69 amperes, an increase of .05, 1/20 of an ampere through the filament, the blue haze, and so-called run-away condition of the third run set in.

Q. 426. I ask the same question about Dr. Arnold's tubes identified in the Interference record as A-3, B-3 and B=19 (?). That last was the way the tube was referred to in the notes, B=19 (?).

A. Audions A and B, which I believe are the A-3, and B-3, to which you refer, are represented on this same blueprint E. S. 86,907. In the two dashed curves A at the bottom and B through the middle of the sheet. These data are inconclusive on the points as to which you inquire, because we do not know how much the effects occurring below ionization cause the steep slope in the curve, and carry it above, and are projected above ionization voltages. Measurements below ionization potentials here are absent or uncertain. Ordinarily, a break to a steep slope around ionization potential would prove substantial gas ionization; but here the break, if it actually occurs, is masked by reason of undetermined factors, or at least of unknown factors below ionization. For example, contact potential and filament drop, as affected by the amplification constant; and consequently I think the data is inconclusive with respect to A-3 and B-3. Now as to B-1[illegible]——

Q. 427. Just a moment. Let me see that curve. May I ask a moment to be sure I am getting those curves right, if your Honor please?

A. You will have to find the curve.

Mr. Davis: I think, if your Honor please, the witness has been talking about A on E. S. 86,907. Perhaps my question was ambiguous, but I was referring to another exhaust in the same tube.

The Witness: I might point out that the A curve shows on this sketch a great departure on the rising and falling, even below actual saturation, and that that is ordinarily an evidence of gas, and probably is in this case, and that a similar departure above sixty volts is shown in the B curve, that irreproducibility extending well down below the final saturation point.

Q. 428. Now, if you will take the curve of A-3 and B-3 as distinguished from A.

Mr. Davis: I would like to hand to the witness the plot made in the Interference which appear in some of our briefs, and I hand the witness the data from which the plots were made which is on pages 114 and 115 of the Pierce notebook which is Arnold's Priority Exhibit 8, the plot which I referred to is on page 2078 of the priority record, but it was a plot made by or on behalf of Dr. Langmuir instead of being made by Arnold

I am wrong in saying that it was a plot made in the brief. It is a plot made in the record.

A. This sheet, referring to the same tubes on the exhaust marked 3 which is on page 2078 of the Interference record, shows these same departures or loops on the saturation part of the curve and extending down somewhat below and into a transition portion and also shows the steep slopes which are, as I said, in general, characteristic of gas ionization when they appear above the ionization potentials.

I do not know how such steep slopes could be had in a tube which did not have gas ionization but I cannot make the complete comparison without further information as to the tube below ionization potentials and the effects of filament drop, contact potential and so on.

In any event, the data would have to be further explained if they were to lead to any other scientific conclusion than that there was substantial gas present and gas in sufficient amount to cause ionization that would interfere with space charge operation.

Q. 429. Have you dealt with the curve B-19 or not? It is on E. S. 86,907.

A. I think I did. Yes, I am quite sure I covered that. It is the one which is in the middle of 86,907 in dash form. Have we not a log plot of that particular curve?

Q. 430. Just look at the data of that B-19 and compare it with the plot and see if you notice any discrepancy in the lower part of the curve or points omitted in the consideration. That data is on page 107.

A. To answer your question I will have to check each of these points.

Mr. Davis: I thought the witness had done so and we will postpone this question until he has had an opportunity to do so.

Q. 431. It has been testified when the Arnold tubes went into operation in Philadelphia in the fall of 1913, the energy was limited to four milliwatts and we may assume that to be the testimony. What if anything in your judgment made that limitation necessary?

A. I think it has also been testified that the difficulty that caused limitation of the energy in the Philadelphia work was the singing of the repeater circuits using the tubes and that is to my mind perfectly reasonable. The singing in balanced telephone repeaters will easily occur, and will be hard to control, if the repeater tubes or the other repeater elements used are irregular in their operation.

If one balanced for one condition and the tube constants changed for any cause it may be necessary to rebalance and consequently an unstable tube will give a great deal of trouble.

These audions could be made stable, or could be made of increased stability, at least, by reducing the voltage applied to them and that of course at the same time reduces the amplifying power of the tubes and the two things together aid in attaining the balance.

A steady tube of higher amplification than the Kendall report shows was used, would be perfectly capable of balancing.

Q. 432. Arnold's Exhibit 23 on Priority consists of a report or memorandum of Kendall dated October 1, 1913, on the use of the audion as a telephone repeater. That report speaks of a resistance which may be used in series with the audion, when used for that purpose, and speaks of a current of about 500 microamperes or half a milliampere and the resistance of 10,000 to 50,000 ohms. It also speaks of a B-battery from thirty to fifty volts. Please assume that the larger resistance, 50,000 ohms, is to be used with the larger B-battery voltage, fifty volts, and tell me what the voltage is on the terminals of the tube on that assumption?

A. That is a simple computation based on subtracting the voltage drop in the series resistance, caused by the current flowing through it, from the battery voltage. The resistance is 50,000 ohms and the current is five-tenths of a milliampere so that the voltage drop in the resistance is 50,000 times .0005 in volts or 25 volts. Therefore, the resistance reduces the drop of 50 volts from the battery to 50 minus 25 which equals 25 and leaves 25 volts at that current, applied to the audion.

Q. 433. That computation is based on ohms law?

A. Yes.

Q. 434. Which is C is equal to E over R?

A. Yes, and in this form is the voltage equals the resistance times the current flowing through it.

Q. 435. E equals C. R.?

A. Yes.

Q. 436. And that is true of any part of a circuit?

A. Yes, for instantaneous values anywhere.

Q. 437. Please make the assumption that the lower resistance of 10,000 ohms is to be used with the lower B-battery voltage mentioned which is 30 and tell me what the voltage would be on the terminals of the tubes?

A. In this case we multiply the resistance of 10,000 by the same current, .0005 ampere, that is 500 microamperes, giving a product of five volts and we subtract the product thus obtained, five volts, from the battery voltage 30, and get the difference of 25 volts available from the battery after passing through the resistance for application to the audion.

Q. 438. In the blueprint attached to this report, for example, blueprint E. S. 123,785-L, do you see anything representing that resistance?

A. Yes, the element D appears in a one-way repeater circuit, arrangement 1, and again in the one-way repeater circuit, arrangement 2.

Q. 439. And what is this thing marked E?

A. E is a condenser shunted across that resistance, the resistance being in series with the plate circuit.

Q. 440. Now, will you please compare that resistance and its connections with the resistance shown in Arnold's Patent 1,114,845 on page 2346 of the Interference record?

A. The diagram of this patent 1,114,845 is on page 2347 and shows a resistance element 8, shunted by a condenser 9, the two being directly in series in the plate circuit. In the patent the resistance and condenser are on the plate side of the primary coil of the transformer marked 6, whereas in the blueprint accompanying the report they are on the battery side of the transformer primary winding, but this makes no difference in practical use.

Q. 441. Will you now please analyze the tests and curves testified to by Dr. Kelly in this suit, first certain curves on tubes said to be good tubes and said to show laws other than 3/2 power law and second on tubes said to be tubes of relative poor vacuum and said to show laws like the 3/2 power law?

Mr. Davis: Before the witness answers this question I will offer in evidence Plaintiff's Exhibit D for identification being certain data supplied by Dr. Kelly at plaintiff's request.

(Received in evidence and marked "Plaintiff's Exhibit No. 185." *See Volume IV, Plaintiff's Exhibits, page 167.*)

Mr. Richmond: I object to the question as entirely too general, giving the witness unrestricted permission to review a large field of testimony. It seems to me the question ought to be more specific and directed to particular matters.

The Court: Suppose I take your objection under advisement and as the witness goes afield from it, if you will call my attention to it we will see whether a number of questions will have to be put.

A. If we take up first Exhibit 48 which represents some data on audion 64, later No. 91, I believe that Dr. Kelly said of this that the plate of Exhibit 48 showed the tube to be a high vacuum or ionization free tube because the 4/9 plot of the current with respect to the voltage was a straight line.

Mr. Richmond: I do not understand that Dr. Kelly said that.

The Court: You think the witness is setting up a straw man to knock down instead of the real testimony. That is vital in this case. Then if you will, will you make your questions specific, Mr. Davis?

Mr. Davis: Then we will see what Dr. Kelly did say. I will withdraw the question.

By **Mr. Davis:**

Q. 442. I ask you to take up such of Dr. Kelly's exhibits as you think desirable to take up and discuss any scientific facts that you want to with respect to those exhibits?

Mr. Richmond: I object, your Honor.

The Court: Can you not narrow the latter part of that, Mr. Davis? It seems to me it is pretty broad. It is passing the disposal of the answer over to the discretion of the witness.

Q. 443. Will you please take up, Mr. Hogan, the exhibits introduced by Dr. Kelly such as you deem important and discuss scientific facts in connection with those exhibits relative to the matters in controversy in this case?

Mr. Richmond: I object.

The Court: I think your objection is well taken and suppose we take our short recess now because I think the questions should be limited so that I may determine from the question rather than from the answer as to the field which the witness is called upon to cover.

We will take our morning recess.

(After a short recess.)

By Mr. Davis:

Q. 444. In one of your answers this morning you spoke of a number of pieces of information which were or might be useful in connection with the study of the curves of the performance of certain tubes. I want to ask you whether or not it is your opinion that all of this data is necessary with respect to a particular tube?

A. No, of course not. In many cases a single characteristic will show all that one needs to know about the tube. In other cases a single characteristic may leave one in doubt and some additional information will be helpful in that event.

Q. 445. Coming back to this matter of Dr. Kelly's data, will you please refer to Exhibit 48, one of Dr. Kelly's curves, and tell me whether or not the data on that curve, and of course any other data which Dr. Kelly furnished, is sufficient to show the character of the tube or the discharge in the tube?

A. This set of readings (in the direct form, that is to say, plate volts against the micro-amperes in the plate discharge) has been plotted on logarithmic paper from the numerical information given us by Dr. Kelly and I think now introduced as one of plaintiff's exhibits.

A tube in which there is no substantial ionization effect on the space charge operating characteristic in general shows a gradual attainment of the 3/2 power slope as the voltage applied to the tube increases for the reason that the modifying factors or effects of contact potential and of filament voltage drop and so on, as they are reflected in the plate circuit by the amplification constant, become as a rule less and less important as the voltage becomes higher.

For that reason the Langmuir tubes in general show a slope starting at a rate somewhat higher than the 1.5 or 3/2 power and below the 3/2 power line and then slope into the 3/2 power line as the voltage is increased.

This tube 64 shows an opposite characteristic, that is to say, although there are no data given below twenty volts when one plots what figures we have logarithmically, it is seen that the curve bends upward and away from the 3/2 power line of less slope as the voltage increases.

Saturation will, of course, tend to pull down the slope through a transition range, but in this case I think saturation was higher.

That increasing slope indicates the presence of gas in the tube. On the other hand, the ionization measurements calibrated by Dr. Kelly's duplicate tube gave a pressure of only .015 microns and that to my mind should show on the log plot a good ionization free operation. I cannot explain that inconsistency on the information that I have.

The tube is somewhat blackened, the inside of the wall of the bulb is somewhat blackened and a good deal of the filament material is gone so that it is entirely probable, almost certain in fact, that evaporation clean-up in the tube may have improved the vacuum during the period that the filament life became exhausted; that is to say, we cannot be certain from a pressure measurement taken now what the pressure of the tube was in its normal condition or its original condition. I think it is entirely probable that that destruction of the filament——

Mr. Richmond: I object to the conjecture, your Honor.

Mr. Davis: It seems to me——

The Witness: My experience with tubes of this kind—is that a proper approach, your Honor?

The Court: I think Mr. Davis wanted to say something.

Mr. Davis: I wanted to suggest that a man who has had many years' work in this field, as Mr. Hogan has had, and he finds a phenomenon which is found here, that the tube is practically destroyed, all Dr. Kelly said so far as the utility is concerned and the fact that the Wehnelt cathode materials comes off and as an expert he is entitled to state what conclusions he draws from that.

Mr. Richmond: I should think so if there was a degree of certainty attached to it but this is a conjecture as to what he thinks is probable.

The Court: Of course, we deal in probabilities in law as we deal with probabilities ordinarily. The witness used the words "I think the probabilities are," and "probably" in his interpretation and it is a feeling of judgment and how strong that judgment or probability is I think is a question for you to determine on cross-examination. You may proceed, Mr. Hogan.

A. (Continued): All I want to say on that point is that clean-up from a filament that has been destroyed in this way might have been accompanied by a knocking on of filament particles by positive ionization in the tube, that is to say, the filament may have been destroyed not only by temperature but by bombardment.

THE COURT: I think in that part of the witness's answer he has gone into the field that is objectionable where he said it might have been. When he puts it into the realm of possibilities we are not interested in that.

MR. DAVIS: I have no objection to that being stricken.

THE COURT: Yes, I think that should go out.

MR. DAVIS: I will ask a question to bring out that point.

By MR. DAVIS:

Q. 446. If a tube with a Wehnelt cathode such as this tube 64 was originally is operated with gas in the tube, what if anything is the effect of that gas on the Wehnelt cathode?

A. The effect of the gas may be or will be to change the emission or to bombard the filament mechanically, the two things may go together, and depending upon the extent of the bombardment and the kind of gas and the kind of filament emission will be changed or even the filament will be destroyed.

Q. 447. And when you say the filament will be destroyed, will you please give us a little more of the mechanism of that action of destruction?

A. Sufficient ion bombardment will mechanically dislodge particles of the filament material.

Q. 448. Have you finished your answer with respect to that tube 64?

A. I think so.

Q. 449. Will you now please refer to Defendant's Exhibit 49, which I think has to do with defendant's tube 102? In your opinion as an expert is the law of the discharge of that tube or not the 4/9 power law?

A. To analyze this tube I have had the data which Dr. Kelly gave us plotted in logarithmic form.

Mr. Davis: May I interrupt the witness to offer that last plot before we get so far that we will lose it? I offer in evidence the logarithmic plot referred to by the witness in his discussion of Defendant's Exhibit 48.

(Received in evidence and marked "Plaintiff's Exhibit No. 186." *See Volume IV, Plaintiff's Exhibits, page 175.*)

By Mr. Davis:

Q. 450. Will you please continue your answer, Mr. Hogan?

A. This is standard 102-D vacuum tube and is generally recognized as a good electron tube.

Q. 451. That is one of the Western Electric tubes?

A. That is correct, yes.

Q. 452. And it has a Wehnelt cathode?

A. Yes. The logarithmic plot of the data shows the decreasing slope approaching the 3/2 power as the voltage is increased to fifty and 100 and to the final reading of 130. The 3/2 slope being indicated on this sketch by a straight dash line.

The slope of one and a half or three-halves is not quite attained at the highest voltage given, 130. I think that higher voltage readings would not have made any break in the other direction, but that the characteristic would have come still more closely on the 3/2 slope. This particular tube, the 102-D, is a tube with a very high amplification constant, an amplification constant of 30, I believe, is the rating. This has something like five times higher than the normal radio or ordinary amplifying tube has. Of course, that high amplification constant exaggerates the effects of contact potential and filament drop that in a tube with a lower amplification constant would not affect the 3/2 characteristic the logarithmic plot characteristic to such high voltage.

I think that while the straight line through the 4/9 current voltage relation of Dr. Kelly's Exhibit 49 shows a conformity of the values observed with that function, the reason that that occurs is because of these steepening effects of filament drop and contact potential as carried into the higher voltages by the amplification constant, and I feel quite confident from my own experience with other tubes that have shown these similar effects, if one took out the contact potential effect and the filament effect by using an opposing battery for the first and a rotating commutator for the second that this tube would show a very different relation with respect to the 4/9 power.

In other words, while the 4/9 approximates the unmodified readings, the readings taken under these conditions, the true law of the discharge in the absence of those factors would not be the figure of that sort but the discharge would approximate closely the 3/2 power toward which the curve is approaching.

In that connection I would like to refer——

Mr. Davis: I will offer that logarithmic plot referred to by the witness in evidence in his last answer.

(Received in evidence and marked "Plaintiff's Exhibit No. 187." *See. Volume IV, Plaintiff's Exhibits, page 176.*)

A. (Continued.) In this connection I would like to refer to a logarithmic plot of the characteristic of a small receiving tube that was introduced as Arnold Exhibit 79 to in the Interference record and which is reproduced at page 563 of that transcript.

This is testified to by Van der Bijl at the top of page 652 in which he says that this is the logarithmic plot of the characteristics shown in Figure 44 which is printed on page 651 and refers to the same small receiving tube.

His testimony continues: "The slope of this line for the operating range of voltage is about three." On the curve it is shown as 2.9. "This high value for the slope is due to the contact potential difference between the filament and the grid which manifests itself much more strongly in the tubes operating at low voltages than in high voltage tubes. When this is corrected for we get the characteristics shown in Figure 46," which appears on straight paper as Exhibit 80, page 654—"and the log plot of this characteristic is shown in Figure 47," which is reproduced on page 655.

Van der Bijl says with respect to that, the slope of this line for the operating range of voltage is 2, in other words, he reduces the slope from about 3 to about 2 by what he calls a correction for the contact potential difference which we have been discussing this morning.

In connection with that curve at page 655 I would like to point out that the agreement with the line of slope 2 is not good, the lower and the higher points are below the line and the middle points are above the line, so that a careful curve drawn through these points will be a curving line and not a straight line. That simply indicates that the contact potential correction of 8 was not enough in this instance and so I have had plotted another curve from these same data with a correcting contact potential of 12.5 as it applies to the plate voltage, the anode voltage.

This curve is marked log plot of characteristic of small receiving tube corrected for contact potential difference by 12.5 instead of the 8 volts used by Van der Bijl.

Mr. Haight: May I interrupt just a moment? Did I gather that the witness is now using some testimony of Dr. Van der Bijl to support his contention regarding some of the work of Dr. Kelly or some of Dr. Kelly's testimony? If he is I submit that it is improper.

(Discussion.)

The Court: The portion of the answer with respect to the Van der Bijl reference is stricken out.

Mr. Davis: It means that I will have to do the same thing over again.

The Court: You may but it will get opinion rather than argument. I think the objection is a proper one and it is sustained.

By Mr. Davis:

Q. 453. Please refer to the transcript of the Interference record at page 653. There you will find a curve plotted or produced in behalf of Arnold in the testimony of his witness Van der Bijl. The witness Van der Bijl says:

> "The slope of this line over the operating range of voltage is about 3. On the plot itself the slope of the line is 2.9."

That is at page 652. Mr. Van der Bijl has testified on the same page as to the replotting of that curve, making a certain assumption, which assumption is that you may correct for the contact potential of that tube by assuming eight volts contact potential. He recalculates, as I understand it, and gets the curves on page 654 and particularly the logarithmic curve at 655. I will ask you if you have made a similar recalculation and replot of the data referred to but with a different assumption as to contact potential?

A. In the first place, Mr. Davis, the contact potential itself is not eight volts. It does not run as high as that, but the effect of that——

Q. 454. When I said contact potential I meant contact potential multiplied by amplifying power of the tube.

A. Or whatever other constant is involved.

Q. 455. Yes.

A. I have had a curve plotted with a correction at 12.5 volts instead of 8 volts and that shows a straight line from the lowest reading of 7 volts to the highest reading of 43 volts, subject not to a systematic variation but to slight fluctuations causable by difficulties of reading instruments.

Q. 456. And the slope of that line is what?

A. 3/2.

MR. RICHMOND: Your Honor, you will tell me whether my point goes to the weight of the evidence or makes a valid objection, but it seems to me that this was a matter of cross examination of Van der Bijl and it is quite improper at this stage to attack his testimony in this way.

MR. DAVIS: Cross-examination of Van der Bijl?

MR. RICHMOND: Yes.

MR. DAVIS: In the old case?

MR. RICHMOND: Yes.

THE COURT: I think this is admissible, Mr. Richmond. It comes close to the border line and for that reason I will admit it.

MR. DAVIS: I offer in evidence the plot referred to by the witness.

(Received in evidence and marked "Plaintiff's Exhibit No. 188." *See Volume IV, Plaintiff's Exhibits, page 177.)*

By MR. DAVIS:

Q. 457. Have you finished your answer with respect to that tube, Mr. Hogan?

A. Yes, I suppose that you do not want any reference to this type G tube of Van der Bijl.

THE COURT: What page is the Van der Bijl plot?

MR. RICHMOND: 653, as I understand. Let Mr. Davis check it up.

MR. DAVIS: 653 in the first page to it, yes.

By Mr. Davis:

Q. 458. Did you in a similar way replot Mr. Van der Bijl's curves at pages 651–652 of the record, Mr. Hogan?

A. I have here both 2/3 power of the current against grid volts and plate volts, and also a logarithmic plot of the tube, the type G power tube referred to in the Van der Bijl diagrams on pages 661 and 662, Arnold Exhibits 87 and 88, the two page-references being to the Interference record, showing a good agreement with the 3/2 power law for a tube of this sort in which the voltage readings run up into the hundreds of volts, in fact, to one thousand volts, on the 2/3 power plot.

The 2/3 power of the current plotted against the anode voltages give a good straight line both for the grid volts equals zero, and for the grid volts equal minus 35 and the 3/2 power plot showing anode corrections of 55 and 475, both giving good 3/2 power agreement.

Mr. Davis: I offer in evidence the two plots referred to by the witness, consisting of two sheets of cross section paper.

(Received in evidence and marked "Plaintiff's Exhibits 189 and 189-A." *See Volume IV, Plaintiff's Exhibits, pages 178 and 179.*)

By Mr. Davis:

Q. 459. Does that finish the discussion of that tube?

A. Yes.

Q. 460. Now, will you please in the same way discuss Defendant's Exhibit 50, which is a plot of the tube 201-A and tell me whether or not the 4/9 power is the law of the discharge of that tube?

A. This 201-A tube is a plaintiff's tube and I have data on that extending outside of the range of 25 volts to 80 volts which were used in Dr. Kelly's plot, Exhibit

No. 30. That plot was made without correction either for contact potential or filament drop. I have here a logarithmic plot from data on a 201-A tube taken in three ways, first according to curve A without rotating commutator and without compensation for grid contact potential.

That curve shows a rather steep slope. Then curve B is taken with the rotating commutator which eliminates the filament drop effect and that has caused the curve for the same tube to show higher current for given voltages and to show a bend. When a negative voltage of one volt was applied to the grid to compensate for the contact potential and the rotating commutator was used, curve C was had which is shown repeated at the right-hand side of the curve and which shows a good 3/2 power agreement from 10 volts to 140 volts, thus indicating the law of the discharge in the tube as of the 3/2 power when disturbing factors are eliminated.

This is marked UX-201-A and I think your Honor understands that the only difference between UX tubes and UV tubes which have been referred to in connection with the 201 tubes is that the UV has the old style base with the short prongs but the tubes are the same.

Mr. Davis: I offer in evidence the plot referred to by the witness.

(Received in evidence and marked "Plaintiff's Exhibit No. 190." *See Volume IV, Plaintiff's Exhibits, page 180.*)

Q. 461. Now, refer please to Defendant's Exhibit No. 52, and will you discuss that from the same standpoint?

A. Exhibit No. 52 shows 4/9 current plot of this tube 100, later 105, Arnold priority Exhibit No. 32, and a similar 4/9 current power plot of the tube L-399, which is the so-called approximate duplicate of that tube No. 100.

Q. 462. Then I will ask you, Mr. Hogan, perhaps my question was not quite definite, to add to your answer as to whether the data given is sufficient to judge the character of the tube?

A. Exhibit No. 61 is a 2/3 power plot of these same tubes. The 105 tube is the only one I am considering, and for that we have no data below 30 volts where Dr. Kelly said, I believe, that no current passed through the plate circuit at voltages lower than 30. I do not understand that.

Mr. Richmond: Your Honor, must I wait until cross-examination to challenge the accuracy of the statement?

The Court: No, because that may mislead any Court if it is not accurate. If there is inaccuracy in the statement, then you may object.

Mr. Richmond: Then I object. The statement does not correctly represent the witness's testimony.

A. (Continued.) Perhaps, your Honor, I was wrong in saying that Dr. Kelly made that statement. The point was that the data given us showed no current for 20 volts and a measured value of current at 30 volts, and that was expressed to me as the statement that there was no current flowing below 30 volts. I do not know whether that is a proper statement or not, but we have no data below 30 volts.

Mr. Richmond: I think that is all right. I do not challenge it now, but I will look it up for cross-examination.

A. (Continued.) Starting then, I have no data below 30 volts, and a 20-volt reading in the data sheet showed no current reading; this is the thing which I find hard to understand. I do not know why a tube of the sort we are talking about here should not show a substantial current flow at 20 anode volts with a reasonable filament temperature.

I have had the data replotted on a logarithmic sheet and would point out that the slope of the line showing the increase of current against voltage is something like the eighth power from 30 to 40 volts; that is to say, is a very steep rise and that from that point on, the slope is about 3.9 for the next few readings.

I think that this was a tube having high amplification constant which would accentuate the effects of filament drop and of contact potential and also some of its peculiarities might be explained by the position of the filament with respect to the rather small and incompletely shielding grid.

In any event, I think the information is not sufficient to show whether the tube has a high slope due to gas or due to some other complicating factor at the higher voltages, and I would hesitate to draw a positive conclusion though I believe that the performance is unusual with respect to a normal "hard" tube in a good many particulars.

Q. 463. Will you now please refer to Defendant's Exhibits Nos. 53, 54 and 54-A, which have to do, as I understand it, with tube 9.111, and say whether or not the data given is sufficient to show the characteristics of that tube?

Mr. Davis: I would like to offer in evidence the plot referred to by the witness in the last answer.

(Received in evidence and marked "Plaintiff's Exhibit No. 191." *See Volume IV, Plaintiff's Exhibits, page 187.*)

A. There were three exhibits introduced in connection with this tube A-9.111. Exhibit No. 53 and 54-A are marked A-9.11, and Exhibit No. 54 is marked A-9.111, but I understand that these were for the same tube and that discrepancy in the marking did not appear to me until just now. Perhaps that ought to be solved right now. I had thought that this was the tube which has a logarithmic plot reproduced as Langmuir Priority Exhibit H at page 2085 of the Interference record.

MR. DAVIS: It is my impression that that was called to Dr. Kelly's attention during his examination that is, Exhibit 53 is headed Arnold A-9.11 but on the curve itself it says 9.111, and Dr. Kelly stated on cross-examination that the lines were for the same tube, that is, the one that has three ones after the nine.

A. (Continuing.) And that would apply also to 54-A, in which the curve is not marked.

By MR. DAVIS:

Q. 464. You may proceed on that assumption, and if it is wrong, the defendants will correct it?

A. That is supposed to be a correction of the lowest line of Exhibit No. 54, and I think it would be the same tube.

Q. 465. There is no tube 9.11 in the case, so far as I know.

A. Then we may take Exhibit No. 53 as comparing this tube A-9.111 with tube No. 100, later 105, on a 4/9 power current plot, and Exhibit 54 as showing four curves of the tube A-9.111 for four values of grid voltage, the plate current being plotted against the plate potential after the plate current is raised to the 4/9 power. And also Exhibit 54-A is the correction of the lowest line in Exhibit 54 after the error in plotting the upper three points was discovered.

The three plots at the top of Exhibit 54 are for positive values of grid potential 1½ volts, 2.6 volts and 4 volts. And it seems to me that unless the grid current for these positive voltages is either included in the current reading or is shown to be negligible that the three curves based on that data would not be conclusive.

As to the lowest plot, which is taken with a zero grid potential, and that I assume as grid connected to the negative leg of the filament and not the positive connection which Majorana called the neutral potential, then the grid current need not be considered as a general rule.

There was some difficulty with respect to the lowest point, the twenty-seven-volt point on the curves of Exhibit 54 and 54-A. That point is shown in a logarithmic plot at page 2085 of the Interference record and a curve is drawn through the various readings and compared to a theoretical 3/2 power straight line drawn through the lowermost point. If that point is a good point, that is to say, if it represents a real measurement as we have always assumed up to now with respect to the—perhaps I should not say that, but if that represents a good measurement then the curve shows a sharp gas effect and if it is an error in measurement, I think it would be very difficult to say what the curve shows.

Again we have a case of steep slope which would indicate gas, but the break would not be given because with that point omitted, we have no data below forty-nine volts, which is well above ionization potential.

As to the way in which the 4/9 plot may be used to represent a straight line, I think a comparison of the upper seven points, near which or through which the lines are drawn on both Exhibit 54 and 54-A, will show that the straightness is not a very exact test for even when the three highest points were moved upward to a fairly substantial amount, one large space on the paper, it was still possible to draw a straight line that looked fairly representative of all the points though of course the slope on that line is quite different from the slope of the straight line drawn through the points as originally plotted and which reach the upper intercept 25.8, and which I have re-plotted for comparing in red ink on a copy of 54-A.

Incidentally, on the original basis, the slope of the line through the lowest readings for grid voltage zero, was practically parallel to the three lines at the upper readings, but when the lower line is corrected, it is no longer parallel as it should be if the upper reading were to be used, and I think that is a further indication that they can not be relied upon.

Mr. Davis: I offer in evidence the plot referred to by the witness, being a copy of Defendant's Exhibit No. 54-A with certain additional lines drawn thereon.

(Received in evidence and marked "Plaintiff's Exhibit No. 192." *See Volume IV, Plaintiff's Exhibits, page 182."*)

By Mr. Davis:

Q. 466. Now, will you please refer to Defendant's Exhibit No. 57, which is blue print of a Kelly diagram for helium filled tube, the tube itself being in evidence as Defendant's Exhibit No. 56? Will you tell us what technical conclusions you draw as to the nature of the discharge and the effect of the helium pressure said to be present in that tube on the discharge?

A. Here we have measurement data taken down to ten volts plate, and running up to 120 volts with corresponding plate currents, and also a converted plot on the same exhibit, giving the 2/3 power relation of the currents down to lower voltages, the only break being at very low voltages where a failure to correct for contact potential or filament drop emission caused the deviation.

This tube had from 3 to 3.9 microns of helium gas in it, and also had a very low amplification constant, the value being given as from 2 to 2.5. The grid was extremely close to the plate, the separation being only 8/10 of a millimeter, or something between 1/3 and ½ the normal grid-plate spacing.

Moreover, the grid is shown on Exhibit No. 57 to have been at zero potential, that is to say, at negative filament potential, so that the plate drop was developed in the tube only across that 8/10 millimeter space, the full voltage being there most effective.

Helium has a very high ionization potential, 25.6 volts, I think, and in helium the probability of ionization at any given pressure is less than that of any other gas, so that with helium and these pressures and these spacings, that is to say, the extremely small distance for the electrons to go and the consequent extremely small probability of ionization in travelling that distance under the accelerating voltage, we get what is really a good Langmuir tube, a tube that is good in all respects as far as can be judged from these data.

It is a very interesting example of how the pressure itself at which freedom from ionization is sufficient to prevent Interference with space charge effects, may be varied, dependent upon the content of the tube and the geometric arrangement of the electrodes, even to pressures that would be altogether too high if used with some other kind of gas, or in a tube of some other construction.

Of course, in that connection I should note that the gassy readings, if one wishes to call them that, that is to say, the readings of voltage and current in this tube, even at 3 or more, 3.9 microns, were reproducible, and that that was so because there was no ionization of substantial amount, and because the pressure stayed constant for the reason that the tube had been previously cleaned up, it had been given a Langmuir treatment, as I think it stated on the cross-examination. I think that is all.

Q. 467. Will you now refer, please, to the Defendant's Exhibits Nos. 58, 58-A and 58 B, which had to do with a tube testified to by Dr. Kelly, at which various pressures of nitrogen were introduced, and state what effect this nitrogen had on the nature of the discharge?

A. Exhibit No. 58 is of this tube No. 7510 at a nitrogen pressure of .02 microns. Exhibit No. 58-A is a similar 2/3 current plot for the same tube with a pressure of .64 microns and Exhibit No. 58-B is a similar plot, the pressure having been increased to 1.2 microns. So far as I can judge from the data available, this tube operated as a good space discharge or Langmuir tube at this lowest pressure of 2/100 microns.

A logarithmic plot of the data given for that pressure of .02 microns shows the effect which I have discussed in connection with some of the other tubes, namely, the decreasing tendency from a rather steep slope toward or to a 3/2 power slope, which is in general characteristic of a good tube. Here the last two points which are at 110 and 120 volts, are actually on the 3/2 power curve, and I believe that if higher voltage readings had been given the characteristic of the tube would have continued on that slope, the steepening effect having become inconsiderable at that potential for those conditions.

At the higher pressures the curve does not slope over to the 3/2 power line at the voltages given and so far as I can judge would not have reached the 3/2 power until a transition to saturation had set in. The increased current corresponding to the pressure of 1.2 microns is shown in the upper curve on this same logarithmic replot. I have not shown the intermediate curve for the intermediate pressure, simply because the points would be confused, but I think it is clear that the slope of the last data given is considerably steeper than the 3/2 power, and that while there is a general reduction in slope, there is no way to tell how much of that is produced by a transition, perhaps a long transition into a saturation region.

Here again we have readings of voltage and current which I understand and believe were reproducible just as in the case of the helium filled tube. I am not certain that it was testified to that they were reproducible, but I assume they were, because definite characteristics were given without any evidence to the contrary, and that would follow from the fact that this 7510 tube, like the other tube, was well cleaned, given a Langmuir evacuation before gas was put in, and from the further fact with relation to 7510 that the pressure was held constant by keeping the tube on the pump during the time that these measurements were made.

Mr. Davis: The curve sheet referred to by the witness in his last answer is offered in evidence.

(Received in evidence and marked "Plaintiff's Exhibit No. 193." *See Volume IV, Plaintiff's Exhibits, page 183.)*

Mr. Richmond: The very last statement of the witness, I think is contrary to the evidence, and so I object to that about the connection being maintained to the pump. I think the testimony will show that it was trapped off.

The Witness: In any event, my understanding as to the clean-up is correct, is it not, that is, the tubes were given a good clean-up?

Mr. Richmond: Yes, that appears.

The Witness: But I was wrong in believing that it was open to the pump?

Mr. Richmond: Yes.

The Witness: Then I will not stand on that statement.

THE COURT: Then suppose that be stricken out, the last statement, and the witness bases his conclusion on the corrected understanding.

MR. DAVIS: Yes.

THE WITNESS: The only point is that with high gas pressures in a discharge, one could hardly expect constancy, one could not expect it at all, unless the tube had been well cleaned out so that the pressure could be held uniform, whatever pressure the tube is made to operate at.

By MR. DAVIS:

Q. 468. I understand, Mr. Hogan, that you wish to make a correction to your answer that you made on page 2937. I ask you to make any statement you care to.

A. This is question 394 asked of me by Mr. Davis and saying according to the report:

> "I will ask you as a person skilled in the art and knowing the use of the terminology and the history of the art, what you say is signified by the term highest vacuum and absolute vacuum in that deposition?"

Q. 469. That deposition being Mr. Waterman's deposition?

A. Yes. My answer was:

> "He defines that as a vacuum in the Coolidge tubes. He says that is the closest approach to an absolute vacuum that he can get."

I must have missed what the reporter got, namely, the fact that the question called for a reference to two terms, highest vacuum and absolute vacuum. What I answered was with respect to the absolute vacuum, which your Honor may recall Mr. Waterman related to the Coolidge tube. I think it is perfectly clear from Mr. Waterman's testimony that he uses the term highest vacuum over and over again with respect to the Fleming tube, and also that he means there the highest vacuum attainable by the lamp exhaust, which was what was used on the Fleming tubes.

Mr. Davis: Direct examination closed.

Mr. Edmonds: May I ask one more direct question so as to correct a minor matter in the record of yesterday?

The Court: Yes.

By **Mr. Edmonds**:

Q. 470. In your answer to Q. 42, you were referred to the General Electric tube UV-201-A. There is an exhibit in this case of the General Electric tube marked UX-201-A. Will you explain what difference, if any, there may be between those two tubes?

A. They are the same tube except for the base.

Q. 471. That is to say, contact pins on the under side of the tube?

A. Yes, otherwise they are the same.

Mr. Edmonds: That is all.

Mr. Haight: If your Honor please, I understand that part of Mr. Hogan's cross-examination is to be conducted by Mr. Darby who is away today and will be back here tomorrow morning and it was arranged between him and Mr. Davis, if agreeable to your Honor, that he should conduct his part of the cross-examination tomorrow morning.

Mr. Richmond tells me that he will conduct his part of the examination with a little more speed and dispatch if he can have from now until after recess to collect his thoughts and get them in some ordered fashion and possibly we can use up some of the time in offering other exhibits.

The Court: As you like. If you can save time by consuming the next half hour, all right, but we do not want to make it up and not gain anything by it.

Mr. Haight: I thought maybe it would be agreeable to your Honor to adjourn a little bit earlier.

Mr. Davis: This is the last witness. We have only left the matter of the notebooks about which I have talked with Judge Haight this morning.

The Court: And you are not ready with that?

Mr. Davis: I have not had an opportunity to talk to Judge Haight about it and there are a few exhibits to offer, and otherwise we are through.

Mr. Haight: There will be no difficulty about the notebooks. What Mr. Davis wanted is a stipulation that a certain notebook contained reference to certain matter only at certain pages. That will require an examination of the book by Dr. Arnold or Dr. Kelly and they will do it just as quickly as they can get to it. However, I want to have a little more clearly defined than Mr. Davis outlined it to me this morning exactly what he wants and I will take that up with him at recess.

The Court: Then we can save time by leaving counsel free until 2.15?

Mr. Haight: We can go ahead with some offers now and take some time up that way.

Mr. Davis: Mr. Howson has a few offers to put in evidence.

Mr. Haight: We will save time that way.

Mr. Howson: I offer in evidence the paper which was marked Plaintiff's Exhibit C for identification, being Compton & Van Voorhis paper and referred to during the examination of the witness Kelly.

(Received in evidence and marked "Plaintiff's Exhibit No. 194." *See Volume IV, Plaintiff's Exhibits, page 185.*)

Mr. Howson: I also offer in evidence from the Interference file of the Arnold-Langmuir Interference, paper No. 4, being Arnold's first preliminary statement.

(Received in evidence and marked "Plaintiff's Exhibit No. 195." *See Volume IV, Plaintiff's Exhibits, page 203.*)

Mr. Howson: I also offer in evidence from the same Interference file, paper marked No. 6, being Patent Office letter dated September 8, 1916.

(Received in evidence and marked "Plaintiff's Exhibit No. 196." *See Volume IV, Plaintiff's Exhibits, page 204.*)

Mr. Howson: I also offer in evidence from that same Interference file, paper No. 9, being Patent Office letter dated September 18, 1916.

(Received in evidence and marked "Plaintiff's Exhibit No. 197." *See Volume IV, Plaintiff's Exhibits, page 205.*)

Mr. Howson: I also offer in evidence from that same Interference file, paper No. 10, being Arnold amended preliminary statement.

(Received in evidence and marked "Plaintiff's Exhibit No. 198." *See Volume IV, Plaintiff's Exhibits, page 206.*)

Mr. Howson: I also offer in evidence from that same Interference file, paper No. 32, being Supplementary Motion of Arnold.

(Received in evidence and marked "Plaintiff's Exhibit No. 199." *See Volume IV, Plaintiff's Exhibits, page 207.*)

Mr. Howson: I also offer in evidence from that same Interference file, paper No. 85, being letter from the Secretary of the Navy to the Commissioner of Patents, dated February 7, 1918.

(Received in evidence and marked "Plaintiff's Exhibit No. 200." *See Volume IV, Plaintiff's Exhibits, page 208.*)

Mr. Howson: I also offer in evidence the Option of December 16, 1912, and Agreement of December 15, 1912, between Peter Cooper Hewitt and the American Telephone & Telegraph Company reproduced from page 1439 of the printed record in Hewitt against the A. T. & T. Co., referred to in the cross-examination of the witness Jewett.

(Received in evidence and marked "Plaintiff's Exhibits Nos. 201 and 201-A." *See Volume IV, Plaintiff's Exhibits, pages 210 and 214.*)

Mr. Howson: I offer in evidence copies of the Hewitt patents referred to in that agreement, the first being No. 781,001; 781,002; 749,791; 749,792; 749,793; 758,650; 954,434; and 991,304.

Mr. Haight: I would like to reserve the right to object to these patents. I do not know anything about them and I will have to confer with Mr. Richmond and Mr. Ballard about that.

The Court: You may do so if you desire to do so.

Mr. Howson: They are the patents enumerated in this agreement which has already gone into evidence.

Mr. Haight: But that agreement provided for patents that covered applications and patents that were to issue and things of that kind.

Mr. Howson: These are specifically enumerated by number in the agreement.

The Court: You may reserve a motion to strike. It will be given a number now.

(Received in evidence and marked respectively "Plaintiff's Exhibits Nos. 202, 203, 204, 205, 206, 207, 208 and 209." *See Volume IV, Plaintiff's Exhibits, pages 235-255.*)

Mr. Howson: I offer in evidence page 281 from the printed record in the Cooper Hewitt against the A. T. & T., table of repeaters referred to in the testimony of Mr. Gherardi.

Mr. Haight: I object to that. We have produced Mr. Blackwell here and testified exactly what the condition with respect to repeaters are.

Mr. Howson: The schedule I am offering was referred to by the witness——

Mr. Haight: Only on cross-examination.

Mr. Howson: And his evidence is more or less unintelligible without these papers.

The Court: What witness was that?

Mr. Haight: On the cross-examination of Mr. Colpitts, Mr. Colpitts, as your Honor will recall, testified that in—he said taking a day, for instance, January 1, 1915, I think it was, may be 1914, there was probably half a dozen repeaters in service; whereupon on cross-examination they showed him these tables which were contained in the testimony of Mr. Gherardi given in the Peter Cooper Hewitt suit against the Telephone Company.

The Court: That is what these are?

Mr. Haight: Yes, that is what these are, and they asked him various questions about it, Mr. Colpitts went back home and investigated the matter and then came down here and said he had made a mistake as to there being a half a dozen, and as a matter of fact there were thirty. Then we put Mr. Blackwell on to show exactly the repeater situation, mechanical and whatnot. The objection that I have to these exhibits, I mean the real objection to them, is that they refer to one-way repeaters and things of that kind, none of which has been explained, and I can not assume that the other side are going to attempt to offer in evidence pages of testimony given in another case, and consequently I have not attempted to go into that and explain this situation.

THE COURT: This page is not in the Interference record?

MR. HAIGHT: No. I think the whole repeater situation is covered by Mr. Blackwell's testimony.

MR. HOWSON: I do not think it is and I do not see that this cross-examination of Mr. Colpitts is intelligible without these things before the Court.

MR. DAVIS: My recollection is that Mr. Colpitts accepted this statement of Mr. Gherardi as being correct.

MR. HAIGHT: He said he supposed it was.

MR. DAVIS: I do not think it is at all important how many repeaters there were in the case.

THE COURT: What is the purpose of this? It is not for the purpose of contradiction?

MR. HOWSON: Not at all. It is to confirm what the witness said.

THE COURT: What he said is not disputed.

MR. DAVIS: It is simply a matter of understanding the testimony.

THE COURT: It was used and it was referred to and it was used as a basis of cross-examination and I think that it should be admitted as supplementing and explaining the cross-examination. If it should become necessary to call another witness, it is unavoidable, but it is so interwoven with the testimony, and it is not intended as contradictory testimony.

(Received in evidence and marked "Plaintiff's Exhibit No. 210." *See Volume IV, Plaintiff's Exhibits, page 261.*)

Mr. Howson: Similarly I offer page 290, which was treated in the same way at the same time.

The Court: That is as to repeaters?

Mr. Howson: Yes.

(Received in evidence and marked "Plaintiff's Exhibit No. 210-A." *See Volume IV, Plaintiff's Exhibits, page 262.*)

Mr. Howson: I also offer in evidence the Pring & Parker article in the *Philosophical Magazine*, Volume 23, 1913, page 212.

(Received in evidence and marked "Plaintiff's Exhibit No. 211." *See Volume IV, Plaintiff's Exhibits, page 263.*)

Mr. Howson: I also offer in evidence copy of the Fleming U. S. Patent No. 954,619, April 12, 1910.

(Received in evidence and marked "Plaintiff's Exhibit No. 212." *See Volume IV, Plaintiff's Exhibits, page 269.*)

Mr. Howson: I also offer in evidence copy of the DeForest patent No. 879,532.

(Received in evidence and marked "Plaintiff's Exhibit No. 213." *See Volume IV, Plaintiff's Exhibits, page 273.*)

Mr. Howson: I also offer in evidence, copy of the DeForest patent, No. 1,201,273, granted October 17, 1916.

Mr. Haight: What is the relevancy of that?

The Court: What is the relevancy of that?

Mr. Howson: I offer that in evidence because of the statements in this specification on page 2, line 39, showing that at that time DeForest tubes were ionizing tubes.

Mr. Haight: I do not think that that is admissible.

THE COURT: I do not see that, Mr. Howson.

MR. HOWSON: The evidence that has been endeavored to be put forward in behalf of DeForest was that earlier than this DeForest was saying that he was making these tubes——

THE COURT: The California depositions?

MR. HOWSON: Yes, and the arguments which they seek to draw from that; and here is evidence that the same man applying for a patent in this country after that is treating his tubes as ionizing.

MR. HAIGHT: I will ask that the offer of these two patents be withheld until Mr. Darby can go over that, because I am not familiar with the California testimony.

AFTER RECESS.

CROSS-EXAMINATION.

By MR. RICHMOND:

XQ. 472. The intensity of visible blue glow is proportional to the ionization, is it not, in any given tube?

A. It is proportional to the energy of the ionization current. I think that is what you can define it as, yes.

XQ. 473. And if the ionization increased the blue glow becomes more manifest, more intense, does it not?

A. As a general rule, yes.

XQ. 474. And reciprocally if the ionization decreases the blue glow becomes fainter?

A. Yes.

XQ. 475. And the reason why blue glow ceases to become visible is rather a physiological reason, the eye is not any longer able to appreciate the small quantity of energy coming to it as the ionization becomes less and less?

A. That certainly would be one reason. Another might be a radiation which you would not call blue, that is to say, there might be substantial ionization without a visible radiation by reason of the spectrum effect rather than the intensity effect.

XQ. 476. Would the spectrum change in any other way than in intensity as the ionization got less and less?

A. I do not know.

XQ. 477. You do not have any reason to suppose it would?

A. I was thinking of the change in color with reduction of pressure in an incandescent lamp exhaust where you get a pink glow at rather high pressure and a bluish glow at higher pressures. That might indicate such a change as I mentioned.

XQ. 478. And in cases of ionization where there is no visible blue glow there is radiation of energy from the residual gas, is there not?

A. I suppose there is some very small radiation of some sort.

XQ. 479. That radiation is probably proportional to the ionization, is it not?

A. It may be, of whatever kind it is.

XQ. 480. If I understood you correctly, you said that it would be impossible in a DeForest audion to heat the plate sufficiently by bombardment to get the gas out of it properly. Did I understand you right?

A. I think I used as an illustration there the power of five watts which would be enough to heat a plate to redness, about 800 degrees or rather dull redness, and said that at 100 volts the current would be 50 milliamperes, which unless my arithmetic was wrong would be far above anything you would expect to get from an audion filament. If the audion were pumped to a much higher vacuum so that a higher voltage could be used for electron bombardment it is conceivable that the energy required to heat the plate could be had at a smaller current which the filament would support.

XQ. 481. So that if it were pumped adequately or properly you think it might be that you could heat the plate sufficiently by electron bombardment?

A. I think that it is perfectly clear that what you need to heat the plate is power, energy delivered on the plate and that if you are limited in current and if other conditions are right (whatever those might be) you could with a lower current get a heating effect by increasing the voltage and therefore the impact by the electrons corresponding to that lower current. Whether that could be attained or not in pumping in any except a carefully treated tube I do not know. I do not think it could.

XQ. 482. And in raising the voltage you could go away over on the saturation part of the characteristic, could you not, for bombarding the plate in connection with pumping?

A. If there were no gases present you could increase the voltage and of course be limited by saturation current. That is about what I said, yes.

XQ. 483. Do you mean that you have to get practically all the gas out in order to remove the gas by bombardment?

A. I mean that you would have to have the tube so well treated that if the initial bombardment were accompanied by a glow, because of the high voltage used, that glow would not increase the pressure or put gas back into an electrode or into the walls of the tube so that it would come out later. I think it is a question of the pre-treatment of the tube.

XQ. 484. I thought it was the pre-treatment that we were talking about. I thought you assumed that the DeForest audion had not been pre-treated?

A. That is correct.

XQ. 485. And I want to know about the treatment to which it must be subjected to make it a high vacuum tube. Is it not true that if you have a good pump and keep pumping you can gradually increase your voltage and get up to a sufficient dissipation of energy to clean up the plate, of course, assuming that the tube is being baked meanwhile in the usual manner?

A. And I suppose assuming that the grid is tied in to get the benefit of the bombardment, and that your pump is adequate to remove all the gas that comes out. I suppose one could even with a limited filament emission of a few milliamperes get a reasonable clean-up in that way. I think we would have to make other tests to find out just what could be done under specific set of conditions.

XQ. 486. Referring to audion 20.2 and the characteristic curves shown in Arnold Priority Exhibit 19, sheet E. S. 86,907, I understood you to say that those two loops drawn in solid lines were in your opinion due to gas, is that right?

A. I think I said that loops of that sort in the saturation range were usually gas effects on the filament in changing its surface conditions, and I thought that that was a fair explanation of those changes reflected here.

XQ. 487. You are not willing quite unqualifiedly to commit yourself on your judgment of these loops?

A. I think that is the best that can be made of that. I think it is not a temperature effect.

XQ. 488. Why do you think that those loops are due to gas, those particular loops in that blueprint?

A. Because the changes in emission are large and irregular and change with time so that they would be the sort of thing to be expected from a change due to some chemical action of gas on the surface or due to a change, a physical change due to bombardment by gas ions.

XQ. 489. And in what respect are they different from what you would get if there was a gradual decline in the temperature of the filament as time goes on?

A. A gradual decline of temperature as time goes on would cause a gradual decrease in emission, and these are gradual increases with respect to the first part and with respect to the return loops, so to speak, they are the sort of thing which is too irregular to be accounted for, I think, by a simple change in temperature occasioned by running down of the battery for instance, or something of that sort.

XQ. 490. In your last answer I understood you to say that there was an increase of one part and a decrease on the other. Are you sure of that?

A. I mean that the curves go to a very high point before they start to break down.

XQ. 491. When this curve is going up initially and begins to form the upper loop, saturation is not attained until it gets to the upper part of the loop, is it?

A. That may be. I do not know just where it is coming in. I do not know where it begins.

XQ. 492. I understand that saturation means when you are getting all of the electrons that are emitted and if there is no change on the filament you are not getting them until you get up to the top of the loop?

A. There is no flat part indicating saturation until you get to the top.

XQ. 493. And when you get to saturation you have with time a decreasing emission until you get back onto the space charge part of the curve?

A. You have a decreasing emission, certainly a decreasing space current. I do not know that that vertical portion is the space charge part of the curve, at least until the curve is returned to the same point.

XQ. 494. Suppose we assume, as you suggest, that these loops are due to gas. Would it require enough gas to make those loops to materially affect the space charge part of the characteristics?

A. I do not know, Mr. Richmond. That is what I said this morning.

XQ. 495. In the middle of this same sheet E. S. 86,907, is a dotted characteristic curve for audion B-19. You testified about that this morning, did you not?

A. We referred to that, yes.

XQ. 496. And that is the characteristic on which the Board of Examiners in Chief named a date for reduction to practice for Dr. Arnold, is it not?

A. I do not know.

XQ. 497. Did I understand you to suggest this morning that irregularity in behavior of the audions used at the repeaters in Philadelphia in the latter part of 1913, would be a cause for faulty balancing?

A. I think I pointed out that it was difficult to balance anything that changes and that consequently with reference to that Philadelphia work changes in the audion constants in operation would make it difficult to balance.

XQ. 498. Will you point that out a little more specifically, just how would the difficulty come in and if you care to I will suggest referring to Defendant's Exhibit 59, which is a diagram for a telephone repeater, in connection with your answer?

A. The point is simply that in order to balance any opposing amplifying circuit, one must keep the amount of reflected power, if I may call it that, down below a point where it will produce the singing effect, that is to say, if there is too much energy reaching the input circuit of either tube from its output side, that will force the whole system to break into some particular oscillation usually of audio-frequency and produce the harmful effect that we call singing.

If the repeating element is not uniform but at one instant puts out more power than at another instant, or if its characteristics change so that the balancing network, as I understand it, is not a true replica or a reasonably true replica within these energy limits of the lines it is intended to balance, and if the constants of either of those circuits are affected by changes in the repeating element, then the balance cannot be maintained and one has to do either or both of two things, cut down the amount of amplification, that is to say, the gain, or steady the conditions so that things remain fixed and the transient irregular effects do not occur.

No matter how much one may reduce the amplification alone so long as he was getting a real amplification he would not be able to stop singing, if the irregularities persisted, but if the two things come down together then the singing can be stopped.

XQ. 499. There were just a few words in your last answer which seemed to indicate that, aside from changing the degree of amplification, a change in the audion might change the condition of balance between the line and its network. You did not mean that, did you?

A. Any change of impedance in any circuit connected to any other circuit through transformers or directly will change the effective constants of the connected circuit and if such changes produce different effects on the line side and on the balance side then of course they would not remain compensated. If they produce the same change then they would be compensated.

The point is, putting it very roughly, you can not get a balance for changing conditions, but without changing conditions you can get a balance even with higher gains, using apparatus that is balanced to the same degree of precision.

XQ. 500. Your position is that if the amplification given by the audion is variable then although you may at one time have it down low enough to avoid singing, this variability may at some other time bring it up high enough to produce singing; is that what you mean?

A. I think that is not the whole point. I do not think that the only change that would make trouble would be one of amplification. I think that general changes of voltage-current relations, of impedance, would be reflected unequally to systems connected to a plate circuit and to a grid circuit on a tube, so that a shift in constants other than mere amplification would be likely to destroy balance.

XQ. 501. Do I understand that it is your judgment that the singing at Philadelphia was due to such irregularities in the audion elements there?

A. I do not know enough about the Philadelphia circuit to state that as a fact, but I consider that a very probable occurrence. I think that the audions not merely were reduced in amplifying power by cutting down plate potential but also increased in steadiness.

XQ. 502. In reaching that opinion, have you given consideration to the matter of the spacing of the loading coils on the lines that were balanced by the net works?

A. No, not specifically.

XQ. 503. Did you give consideration to the design of the balancing net works?

A. Not specifically, I do not think we had any real data as to that.

XQ. 504. Did you give consideration to the arrangements that were incorporated in the system for ringing currents?

A. No, except that I knew that they were there and should not have affected the points I mentioned.

XQ. 505. Do you mean that the arrangement for ringing did not produce any unbalance?

A. No, I do not mean that. They would have to be compensated for.

XQ. 506. And is that an easy thing to do?

A. Probably not. No balancing operation is easy.

XQ. 507. Did you take into consideration the arrangement for superposed telegraphy on the line; what they call compositing?

A. No, I did not even know that those lines were composited.

Mr. Davis: I move to strike out the question because there is nothing in the testimony about this imposition of telegraph lines. I think the question here should be confined to the data given to the witness and given to the plaintiff.

The Court: I will hear you, Mr. Richmond.

Mr. Richmond: It is my impression that those features show on the blueprints. That is what I was relying on.

The Court: You are not trying to introduce new factors into the situation?

Mr. Richmond: No.

The Court: Then Mr. Davis challenges that and can you show that there is evidence in the case to support your contention?

Mr. Richmond: The circuit diagram is too complicated for me and I will cheerfully withdraw the question.

By Mr. Richmond:

XQ. 508. It is an important factor in the matter of balancing lines with net works whether the impedance characteristic of the transformer is non-linear with respect to frequencies, is it not?

A. I think that would certainly have to be taken into consideration; if you are balancing for all frequencies you must include any distortions due to transformer efficiency changes as well as line changes generally. I am making that statement not from great experience with telephone line balancing but from the analogous balancing of radio receivers.

XQ. 509. And it is a fact that it has been a very difficult problem to get transformers with linear characteristics over a range of frequencies, is it not?

A. I know that it takes skillful design to make a transformer that will give reasonably uniform efficiency over a very wide range of frequencies, that is, within the audio range.

XQ. 510. I understood you to say that the characteristic curve for Western Electric tube 102-D in Plaintiff's Exhibit 187 would approach the 3/2 law if the voltage had been carried high enough. Did I understand you correctly?

A. My point there was that this tube was behaving in spite of its high amplification constant, and the consequent exaggerated effects of the contact potential and filament drop, it was behaving as good tubes in my experience ordinarily do behave.

The curve was showing a decrease in slope tending toward a 1.5 slope at the higher voltages where the masking effects of which I have spoken are less prominent in proportion to the actual voltage used. That is shown by this plot and I think I hazarded the view that if I had had higher voltages this would probably have continued further with that bending and therefore approached still more closely, but I also stated that I did not have those voltages and therefore I could not offer the view as a fact.

XQ. 511. In any case where you have a tube with a steep characteristic, that is steeper than 3/2, it is going to bend over and pass through the 3/2 value as it approaches saturation, is it not?

A. Yes, I mentioned that also. That is to say it was hard to tell whether we were approaching saturation in some of these other curves and without data based upon changes of filament temperature it would be difficult to resolve that. I think we all recognize that even with a good tube, if for some reason the steep slope exists, as that gets into saturation, the transition effect will pull the slope down.

XQ. 512. Now, in Plaintiff's Exhibit 186, which is your characteristic for audion 64, you did not draw a 3/2 slope line through the top point as you did for the Western Electric 102-D tube on Plaintiff's Exhibit 187, did you?

A. There is no line drawn here, no. There is a slight decrease in slope at the value 125, 131 microamperes which may again represent a transition approach, that is, an approach toward saturation. Of course, the point I was discussing in connection with that curve was the increase in slope in the neighborhood of 25 and 30 volts, which I think does not appear in the 102.

XQ. 513. It seems to me that that is another matter. Though perhaps that would constitute an excuse for not drawing the line in one case although you did in the other?

Mr. Davis: Is that a question?

Mr. Richmond: Mr. Davis, I seemed to be questioned and I was trying to answer. I will get away from it as quickly as I can.

XQ. 514. The remarks that you just gave about the factors that reduce the slope of a curve at higher voltages would be exactly as applicable for Exhibit 186 for audion 64 as for Exhibit 187 for the 102-D tube?

A. The effect of transition toward saturation would be but with an increasing slope around ionization potentials I think the disappearance of the other complicating factors would be much less important, if important at all.

XQ. 515. I understood you to remark in connection with Defendant's Exhibit 54, which is a plot of the data by Dr. Kelly for tube 9.111 that with positive voltages on the grid, the grid currents should have been included?

A. I think I said they should have either been included or shown to be negligible, and that the fact that the zero grid curve after correction was not parallel to the other three indicated that one had best not put much reliance on the other three in the absence of that information.

XQ. 516. Is that your only ground for thinking they were not negligible?

A. I do not know anything about the tube except that four volts and even 2.6 volts and probably 1.5 volts on the grid may give currents which would have a substantial effect.

XQ. 517. If these positive grid currents were to be taken account of it would be in some such equation as that discussed by Dr. Langmuir and indicated at the right of Defendant's Exhibit 54?

A. It would be in some such equation only when one is considering the effects of the combined potentials.

XQ. 518. Now, please look at the bottom of page 278 of Plaintiff's Exhibit 104, which was Langmuir Exhibit 84, in the Interference, Langmuir's Radio Engineers paper, read April 7, 1915, and published September, 1915, in the official publication of the Institute of Radio Engineers, and see if I am correct that the equation there is given for the current to the anode alone?

A. The quotation with reference to this or the passage with reference to this equation is "For different anode potentials, these curves are shifted vertically, by amounts proportional to the change in anode potential. In fact, it is found that these curves can be represented with fair approximation by a function of the form"—and then follows the equation—"Where i is the current flowing to the anode V_a is the voltage on the anode, V is the voltage on the anode, V_g the voltage on the grid, and k the constant which depends on the relative shapes and positions of the electrodes." I think therefore that "I" is intended to be the current flowing to the anode for that approximation.

XQ. 519. Referring to Plaintiff's Exhibit 188, produced by you this morning, this relates to the peanut tube, an exhibit produced by Van der Bijl?

A. I do not know what tube it related to except that it was characterized by Van der Bijl as a small receiving tube.

Mr. Richmond: I presume there will be no need to get the witness to verify it. That is correct. The record shows that this was a tube developed for aeroplane use during the war.

By Mr. Richmond:

XQ. 520. On this diagram of yours, Exhibit 188, where did you get the 12½ volts that you applied as a correction?

A. That was a value chosen by making a 2/3 plot and getting the intercept, as I recall, that is to say, it was noted when the lower voltage, I think 8, used by Van der Bijl, was applied, the curve was not a straight line on the 2/3 plot or a current plot generally, and therefore, a higher value was determined by the intercept method.

XQ. 521. The value of 12.5 is determined by discovering what value is necessary to come closest to the 3/2 law, is it not?

A. I do not think it is fair to state it that way. The value is a value that could be determined with information had by the measurement of contact potentials and the amplification constant, and it can also be determined by drawing the curve for which we have a reasonable theoretical basis, namely, the 2/3 power curve and taking the intercept from that. You might call that finding the value which fits the 3/2 power but I think that contains an unfair implication.

XQ. 522. Is not that exactly what your second method amounts to? You mentioned two ways, one is to find out by some direct method of measurement what the contact potential is or to find this intercept, and if you use the second method you are really finding the value that will bring the curve nearest to the 3/2 power law fit?

A. That is the result, yes. But there is a very good physical basis for it.

XQ. 523. On that diagram that you have before you for the peanut tube, Plaintiff's Exhibit 188, I notice the legend "Corrected for contact potential difference." Do you not think it would have been more accurate to have said corrected for assumed contact potential difference?

A. I have no objection to that. The assumption is the same type as that used by Van der Bijl in connection with the other constant.

XQ. 524. Referring to Exhibit 189 introduced by you this morning I ask your pardon if I am asking for a repetition, but will you please tell me how those curves were obtained?

A. These particular curves were taken from the current voltage data given by Van der Bijl in the record and were plotted from that. The amplification constants were determined for the changes in anode volts for change of grid volts and the intercepts determined the corrections of anode voltage for the plot on 189-A.

XQ. 525. And what did you find for that intercept?

A. The two corrections are minus 55 for grid volts zero and minus 475 for grid volts minus 35, that high value of course representing not only a contact potential but a filament drop to be included in connection with the amplification constant of the tube.

XQ. 526. And these values were ascertained from 189-A and then were embodied in 189; is that correct?

A. No, I think the process was the other side up. Dr. Dushman made the computations for me and I think that was his process.

XQ. 527. 189 shows how the intercept values were obtained?

A. I think that is correct.

XQ. 528. And on 189-A the resulting plots are given by making those corrections?

A. I think that is the method used.

XQ. 529. Did you do this in all your plots that you introduced this morning?

A. I should have to see all these plots to say.

XQ. 530. Here they are.

A. Exhibit 188 is taken directly from Dr. Kelly's data. Exhibit 187 is similarly taken directly from that data. Exhibit 190 is taken from actual measurements of a UX-201-A tube and shows the effect with the commutator and of the application of minus one volt. Exhibit 193 is taken directly from Dr. Kelly's data. Exhibit 191 is taken directly from Dr. Kelly's data. The corrected curve on Exhibit 192 is taken directly from his data. It would appear that the only two in which we did not know the relations of which we were speaking were those two that you and I have just discussed.

XQ. 531. I understand that in these other cases you consider that there was no occasion for such a correction as you made in Exhibit 189 and 189-A; is that right?

A. It depends on what one intends to do with the data, what one is looking for. I think that I was showing in one case the effects of those uncorrected masking properties.

XQ. 532. Which case was that?

A. In 186 there was no relation to this situation at all. There I was showing the upper change in slope carried by the observed numbers. In 187 I showed how the factors as plotted gave a curve which was approaching, with this high amplification tube, this 3/2 slope as the voltage increased. Conceivably that could be corrected for in the same way if one determined what the effects of the potential drop on the filament and contact potential as influenced by the high voltage amplification of the tube, and in that way compensate for that departure or that steepness in the lower part of the curve, but that was not done.

Similarly on Exhibit 190, I was trying to show what the effects of measurement with and without a rotating commutator and with and without a corrected potential amounted to. With reference to 193 there again we have a tube which, as the data is provided, shows a steeper slope approaching a 3/2 power slope and I have no doubt that the effects which make that slope steeper could be compensated for by measurement, but it was not done as you suggest. On 191 I think the same is true. As to 54-A, that factor did not come in at all.

XQ. 533. The data for Plaintiff's Exhibit 190 produced by you were obtained from a different tube than the identical tube of the Warner paper?

A. Oh, yes, I did not know what tube Warner had and these tubes vary a little from one tube to the next, but they are rather close to the figures that Warner used. It was a typical 201-A tube in any event.

XQ. 534. What was the basis for assuming that value of minus one volt, that you have for curve C, on Exhibit 190?

A. I believe that value has been measured time and time again and the normal value for this type of tube was used.

XQ. 535. You mean that that is an ascertained and stated voltage value pertaining to that type of tube?

A. I do not know that that voltage would apply to all 201-A tubes. In fact, I think there are variations as the manufacturing process are changed in detail; but I have no doubt that that value was determined for that particular tube.

XQ. 536. Was it determined so as to bring the curve as near as possible to the 3/2 power law?

A. I think not. I think that was the result, but I do not think that was the purpose.

XQ. 537. And you do not think that that was the method by which the value was arrived at?

A. No.

XQ. 538. Do you know?

A. No.

XQ. 539. Please tell us just how you got this minus one volt, was it on somebody else's authority?

A. Yes. I took that from the General Electric records. Dr. Dushman plotted the curves for me.

XQ. 540. In this curve C on Exhibit 190 you have made no correction for the initial velocities of the electrons, have you?

A. I think that would be included in the correction, both that and filament drop effect, because the filament drop effect is compensated for by the commutator. There is no specific correction for it unless it is included in the additional voltage supplied to the grid.

XQ. 541. Is it included?

A. I do not know.

XQ. 542. If it is not included then if you made that correction it would take your points off from the 3/2 law materially; would it not?

A. I think the change would be very small.

XQ. 543. I understood you to say that the 3/2 power law which was propounded by Dr. Langmuir is often used as a test of a working tube. Do you know of any purchase specifications for practical tubes that recite this law?

A. No, I do not know anything about purchase specifications.

XQ. 544. Do you know of any manufacturing specifications for vacuum tubes?

A. No, I am not familiar with them, so that I do not know whether they are in or out.

XQ. 545. Do you know of any catalogue information which refers to this law?

A. No, I have never seen any.

XQ. 546. In all of the curves by Dr. Kelly that you considered this morning the data were plotted directly without any corrections at all, were they?

A. I assumed so with the exception of 54 in which there was an error in plotting. I have not checked them, but I assume that Dr. Kelly would plot them correctly.

XQ. 547. But by corrections I mean adjustments for what are supposed to be disturbing factors?

A. I think he plotted his data as he observed it, if that is what you mean.

XQ. 548. Yes. He plotted his volts and amperes as they were obtained——

A. Of course, I do not know. All I can say is that he has given us certain voltage current data and that those are the data reflected by the plots. Beyond that I do not see how I can go. I do not know what adjustments he made before he took the experimental data.

XQ. 549. Have you had any practical experience in telephone engineering?

A. I have never worked for the Telephone Company, if that is what you mean. I have had a great deal of practical experience in audio-amplifying work connected with radio, that is, with the use of audio transmission over wires in so far as they are involved in reproduction of speech and music and amplification of the voice or telephone currents to radio transmitters or what-not, but I have never worked in the telephone plant either as an engineer or investigator.

XQ. 550. Restricting yourself to wire telephony just give us a little more idea of when and where you have had such experience?

A. I have had no experience at all on the telephone company's lines. I have for years been familiar with the transmission of telephone currents over wires in connection with radio apparatus. While that is not wire telephony, but merely an extension of the radio apparatus it involves the same phenomena and is the same thing from the purely physical point of view. I am not sure just what your question is directed to, but I do not want to pose as a practical telephone engineer who has had any experience at all in connection with the Telephone Company's line work.

XQ. 551. And that experience you speak of, does that include two-way telephony?

A. I have had a little experience with two-way telephony, but not a great deal.

XQ. 552. What do you mean by a little?

A. That is to say I have balanced one particular audio-frequency against another particular audio-frequency, but I have never experimented on a commercial or even experimental or artificial voice line with the telephone company's repeaters.

XQ. 553. What practical experience have you had in the matter of balancing telephone lines for repeater work?

A. None on the telephone lines. I have had the physical equivalent of that in connection with audio-frequency work, but as to the manipulation of the telephone company's plant I pretend to know nothing other than the things which would be based upon definite physical consideration that I know as a matter of engineering.

XQ. 554. When you testified this morning about balancing, on what did you base your knowledge of that matter?

A. Certainly not on a detailed knowledge of the telephone company's plant, but on an engineering knowledge of the physical fundamentals involved in such work.

XQ. 555. How long a line did you have to balance in this audio-frequency balancing that you have just mentioned?

A. Nothing but laboratory work, not a balancing of an outside line at all.

XQ. 556. Just balancing one artificial line against another?

A. Yes, I would not even call them artificial lines because they had lumped constants rather than distributed constants.

Mr. Richmond: That is all of my cross-examination. I understand Mr. Darby has some further plans for cross-examination.

Mr. Davis: There is no redirect on this cross and we reserve the witness for Mr. Darby's further cross-examination.

It seems to us proper to show the relation of the Telephone Company to this patent. It is already stated in a general way in a letter which Mr. Folk wrote to the Law Examiner in the Interference which is now in.

I offer in evidence this contract or copy of a contract entitled "Modification of License agreement dated July 1, 1920, between the General Electric Company and the American Telephone & Telegraph Company," to which I understand there is no objection.

(Received in evidence and marked "Plaintiff's Exhibit No. 214." *See Volume IV, Plaintiff's Exhibits, page 277.*)

Mr. Davis: I understand it is stipulated that H. D. Arnold and the Western Electric Company began an equity suit on April 29, 1926, against

Irving Langmuir and the General Electric Company in the United States District Court for the Southern District of New York under Section 4915 of the Revised Statute, praying the Court to adjudge Arnold the first inventor of the subject of the claims which were in interference 40,380, and praying the Court to authorize the Commissioner of Patents to issue to the Western Electric Company, Inc., as assignee of Arnold a patent for the subject matter of the interference, and that such suit is now pending undecided in the Southern District of New York.

Mr. Haight: It has never been tried.

Mr. Davis: I understand the Bill was filed and the answer is filed and the case is in that condition.

Mr. Haight: That will be stipulated, but I do not see the materiality of it, but if it has any materiality it can be made to appear by the stipulation—I do not mean the materiality may be made to appear, but the fact which is stipulated, I do not think is material.

The Court: You agree to stipulate anyway and give them an opportunity to show the relevancy and materiality at any time in the future.

Mr. Haight: Yes. I will not ask your Honor to pass upon it now.

John V. L. Hogan, resumes the stand.

Cross-Examination (Continued).

By Mr. Darby:

XQ. 557. Am I correct in understanding that you measured the pressure of the early Fleming valves?

A. Not of the Fleming valves.

XQ. 558. You have not measured the pressure of the early Fleming valves?

A. Not of the Fleming valves.

XQ. 559. I rather got the impression from your testimony on page 1660 of the record, from the discussion had at that time that you had and I wanted to clear it up.

A. Were not we talking about audions there?

XQ. 560. Yes, we were. And the next question, and perhaps my last, you have measured the pressure of the early DeForest audion?

A. I have measured the pressure of tubes which I bought from DeForest in 1914 and 1915.

XQ. 561. You have not measured the pressure in tubes of 1912?

A. No.

XQ. 562. And when did you measure the pressure of the 1914 and 1915 tubes?

A. Some time in 1925, I do not remember just when.

XQ. 563. In 1925?

A. Yes.

XQ. 564. What method did you use in measuring it?

A. The gas test, so-called, calibrated from a duplicate tube as Dr. Kelly described in connection with his measurements.

XQ. 565. And you have no way of telling whether or not the condition in the tube had changed from 1914 to 1925?

A. None, except that the performance was about the same.

Mr. Darby: That is all.

Mr. Davis: No re-direct.

(Witness excused.)

DEFENDANT'S SUR-REBUTTAL PROOFS.

JOSEPH A. BECKER.

Joseph A. Becker, was called as a witness in sur-rebuttal, on behalf of the defendants, being duly sworn testified as follows:

Direct Examination.

By Mr. Richmond:

Q. 1. Please state your name, age, residence and occupation.

A. Joseph A. Becker, twenty-nine years, residence is Denville, New Jersey, and occupation is Research Physicist for the Bell Telephone Laboratories.

Q. 2. Please tell us in outline about your experience and training with discharge phenomena in vacuum tubes?

A. As an undergraduate I specialized in physics and then after receiving my Bachelor's degree I was employed by the Bureau of Standards in research work and later on by the Westinghouse Electric & Manufacturing Company in East Pittsburgh, and also at what was then the research organization of the Western Electric Company in New York. After this I returned to college for my doctor's degree and during this time did research work involving discharge phenomena, especially X-ray tubes.

Upon receiving my degree I was awarded a National Research Council Fellowship in Physics and for two years worked in that capacity under the direction of Dr. Millikan in California.

During this time I was working on a problem involving discharge phenomena, especially in connection with soft X-rays, that is, lower voltages than are used in an ordinary X-ray tube. Soft X-rays are X-rays which do not penetrate very much through ordinary matter. During this time I had to familiarize myself with discharge phenomena.

Also in that laboratory there were some thirty-odd experiments going on, most of which dealt with discharge phenomena and I was actively interested in most of them, talked with the people that did the work and discussed their problems and also discussed any particularly interesting features of them; also once or twice a week we had meetings at which topics of especial interest occurring in the literature were discussed and most of those dealt with atomic physics, and a good many of them dealt with discharge phenomena. During this time I was able to gather information from the experience of very many renowned physicists who occasionally came to see us.

In 1924 I was employed by the Engineering Department of the Western Electric Company in the Research organization and later on the name of this organization was changed to the Bell Telephone Laboratories.

Since 1924, I have been engaged in vacuum tube work, especially in connection with thermionics, or the emission of electrons from hot bodies. I might say that before being employed by the Western Electric Company during this interval between the time that I was serving as a National Research Fellow and the time at which I went with the Western Electric Company, I was an assistant Professor in Physics at Stanford University and during this time I gave a lecture demonstration course on modern physics.

Q. 3. From what institution did you receive your doctor's degree?

A. From Cornell University.

Q. 4. To what extent are you familiar with Plaintiff's Exhibit 99 in this case which is Sweetser's notes of his experimental work in and about August, 1912?

A. I have carefully gone over these notes and I familiarized myself with the experiments which they performed and the procedure during these experiments and the methods of working up the results.

Q. 5. Referring to Plaintiff's Exhibit 163, which is based on a part of those notes, can you distinguish successive stages for the events that are there recorded?

A. Yes, I believe it is convenient to divide this experiment into three stages. During the first stage, as recorded in both run 1 and run 2, the current is limited by the temperature of the filament. The blue glow pervades the whole tube and the current is independent, to a great extent, of the voltage between the filaments, the separation of the filaments, the size of the bulb, and various other factors.

The temperature is about the only thing upon which the current depends in this first stage, that is, the stage while the pressure is changing from five microns to about .54 microns.

Then I think it is convenient to call the short time interval during which the current suddenly drops, the second stage.

Then the third stage is the one when the pressure is less than about .54 microns and during this stage the current does not depend on the temperature of the filament but does depend on quite a number of other things, the chief things being: the distance between the filaments, the voltage between the filaments and the gas pressure.

So that I should say it is convenient to divide this run or these runs into three stages as I have stated.

Q. 6. Referring to that sudden decrease of current to which you have apportioned the second stage, was this a new type of phenomenon in August, 1912?

A. I do not think so. This sudden disappearance of blue glow accompanied by the sudden drop in the current I think was well known and had been met with in lamp clean-up as was testified several times before. In the clean-up of these lamps the blue glow would suddenly disappear, also it was the same phenomenon as occurred when in the audion as the pressure decreased the blue glow disappeared. So that as far as the sudden disappearance of the blue glow goes and this disappearance is always concommitant with a decrease in the current, I should say that the phenomenon was not new.

Mr. Davis: I move to strike out the portion of the answer that has to do with the disappearance of blue glow in the audion as being an attempt to establish something about the audion that has never been suggested in this case at all, and therefore entirely improper sur-rebuttal. I have no objection to the testimony about the lamps, because that has been talked about, but bringing in entirely new testimony as to what goes on in an audion is improper when the DeForest audion was never pleaded, is entirely improper.

Mr. Richmond: Your Honor, it seems to me, if my memory does not fail me, that Colpitts and Arnold both told about how the blue glow suddenly blinked out in an audion. It is a tedious matter to hunt it up, but I have not thought of it as being challenged and if Mr. Davis insists I will consent to strike it out.

Mr. Davis: I do not want to begin the case all over again and therefore I do insist.

By Mr. Richmond:

Q. 7. What does this sudden decrease of current that you have referred to as the second stage, what does that signify?

A. It signifies that there was a new type of discharge. Before the drop the current was limited by the temperature of the filament. After the drop it was limited by space charge. That is all it signifies.

But when I say limited by space change I do not want it to be understood that this is equivalent to saying limited by a pure electron space charge. All that there is necessary for this drop to occur is that subsequent to the drop the current should be limited by space charge. That might be a mixed space charge and the current might still be greatly influenced by positive ions. The mere occurrence of the drop tells you nothing whatsoever about the purity of the discharge subsequent to the drop.

Q. 8. On what does the magnitude of drop of current depend?

A. The easiest way to answer that is to see clearly on what the current depends before the drop and on what it depends after the drop. Before the drop it depends on the temperature of the filament and practically on that only. After the drop it depends on the distance between the filaments, the voltage between the filaments and the pressure of the gas that is present. If we keep the distance between the filaments constant and the voltage between the filaments constant and vary the temperature only then we can make the drop big or small; and instead dropping from 16 to 5 milliamperes we can make it go from 100 to 5; or by decreasing the temperature lower than was used in run 1, we could make it change from 6 milliamperes to 5 or by placing the temperature a little bit lower still we can make it that there is no change at all practically during this period 2, whereas subsequent to this we would still get any changes due to changes in pressure.

So that the magnitude of the drop can be made anything you please within limits by changing the temperature of the filament and keeping the distance between the filaments and the voltage across the filament fixed.

This is well illustrated by run 2. In run 2 the temperature of the filament was a good deal lower than in run 1. In run 1 it was 2225 degrees and in run 2 it was 2105 degrees. In run 2 the drop is quite small. There is a slight complicating factor in this case due to the fact that for run 1 the voltage was 250 volts and for run 2 it was approximately 200, but even for the second run if the voltage had remained at 250 the magnitude of the drop would have been quite small compared to the magnitude of the drop in run 1.

Q. 9. Is the occurrence of this phenomenon, this sudden drop in current value, conditioned by structural features and if so please explain about them?

A. As I have already mentioned, the distance between the filaments enters into the magnitude of the drop; but there is a very important other factor, namely, the change in the wall charge. This sudden drop is dependent upon and conditioned by a sudden change in the wall potential. If you have a tube in which the anode encloses the cathode, such that there are no changes in the wall charges or if there are any they cannot reach into the place where the discharge is taking place, that is, between the cathode and the anode, if you have the anode completely enclosing the cathode it is then my belief that you would not get such a sudden drop at all and the more nearly you approach that condition, that is, the more nearly the anode completely encloses the cathode, the less prominent this sudden drop becomes, so that I should say in summing up my answer to your question that it is dependent upon and conditioned by changes in wall potential.

Q. 10. Can you trace the changes in the wall charge during the experiment that is recorded on that Exhibit 163 through those three stages that you have mentioned?

A. I think I can. Suppose we begin at the beginning of this experiment and let us take run 1 as an illustration. At the beginning of the experiment when the pressure is approximately 5 microns the wall potential is quite close to the potential of the anode; that is, if our cathode is at zero potential and our anode is at plus 250 volts, then at the beginning of the run the wall potential will be about plus 250, pretty nearly the same as the anode.

As the pressure decreases it is found that the potential on the wall moves towards the potential of the cathode, and for example, about the middle of the first stage, the wall potential might be plus 100 volts, that is, the cathode is at zero and the wall is at plus 100 and the anode is at plus 250.

Then when we approach the condition where the second stage is about to begin, that is where the blue glow is about to disappear, we then find that the wall potential is, let us say, about 15 volts positive with respect to the negative end of the filament. If, for example, we have a 10-volt filament drop, the wall potential might be somewhere in the neighborhood of plus 15 volts. Then when the drop occurs and immediately after the drop one finds that the wall potential has changed from plus 15 to something like 4 or 5. The exact amount depends on various other factors but is of that general order and I should say that under that condition the walls are still positive with respect to the negative end of the filament, not very greatly positive but still positive.

Then as you pump out more gas and as you go even beyond the pressures which were used in run 1 of Plaintiff's Exhibit 163, that is, as you actually pump the gas out of the tube and get a good vacuum, then and not until then do the walls assume a negative potential with respect to the negative end of the filament. These figures I have given are general.

If you modify the type of structure sufficient to bring out just certain points I would not dare say that it was impossible to have the wall negative immediately after the drop, but from my experience I should say that one would have to take a very special structure to do that. And in general the walls are positive, slightly positive immediately after the drop and they do not become negative until the pressure is decreased considerably. But the most important thing I think is that just before and just after the occurrence of the sudden drop the wall potentials undergo a sudden change.

Q. 11. In your opinion what is the significance of this sudden drop relative to the question of the purity of the electron discharge immediately after the drop?

A. I certainly think that it does not mean that immediately after the drop the discharge is a pure electron discharge; in fact quite the contrary is true. I think the mere fact that you get this sudden drop is an indication that immediately thereafter you are still removed from a pure electron discharge and that you have to reduce your pressures to quite an extent, something like a factor of 8 or 10 before you really at that voltage have a pure electron discharge in which the positive ions play a non-substantial part.

Q. 11a. Can you say anything about the value of the current soon after this sudden drop as compared to its ultimate value when the pressure is very low?

A. Yes, I can. Immediately after the drop the current has a certain value which depends on various factors. If you now decrease the pressure by a factor of 8 or 10 or it might be 5 in a particular type of structure, but if you decrease the pressure by a considerable amount, then you find while you are decreasing the pressure the current decreases continuously and it is not until you have reached a good deal lower pressure that the current then becomes independent of the pressure, that is, independent of a still further decrease of pressure; and when you have reached this stage the current is two to three times lower than the value of the current soon after the break. In some cases I think it is possible to get the current to reduce by a factor of five and in case you have an anode which partly encloses the cathode that factor can be made even greater.

Q. 12. Referring to what you have distinguished as the third stage of Plaintiff's Exhibit 163, what evidence is there in Sweetser's Notes, Plaintiff's Exhibit 99, as to further change of current with further change of pressure after the drop?

A. If we consider only points in Plaintiff's Exhibit 99 for which the current was not fluctuating rapidly, then every single time that the pressure was decreased the current decreased. I think this is illustrated very well in the plot of the logarithm of the current versus the logarithm of the voltage, part of which has been shown before.

On this sheet which is a logarithmic plot of the current in milliamperes against the voltage between the electrodes, I have indicated every instance in which the current was limited by space charge in Plaintiff's Exhibit No. 99 by a point enclosed by a circle. That is, there are three positions at 250 volts and four independent ones at around 200 volts. Some of these positions are repeated in several experiments. There are only five experiments recorded in that exhibit in which this sudden drop occurred, and thereafter the current was limited by space charge.

The first experiment I have marked by the letters a, and there were three points a_0, a_1 and a_2. In the lower right-hand corner of the sheet I indicated the page in the notes from which these points were taken, and I have also indicated the pressures at which the current values were taken.

If we look at the pressure values in the "a" experiment, we find that the pressure decreases, and this first point is the one about which I made my exception. For this point a_0, the current was fluctuating at least immediately before it was fluctuating. On Plaintiff's Exhibit No. 163, it is the point right—at the bottom of this zig-zag line. As I say, with that exception, for every other point that I have plotted here, whenever the pressure decreased, the current decreased. For instance, a_1 to a_2, the pressure decreased from .366 to .336, and as you notice the current has dropped from 5 to 4.5. In the b experiment, when the pressure dropped from .536 to .430, the current dropped from 3.2 to 3.0 milliamperes.

In the c experiment there are three points recorded. For the first one, the pressure is not recorded, but immediately before that point the pressure is .71, and after that, it was .51, so that for c_1, the pressure was somewhere between those two values.

Then as it dropped to .544, the current dropped from 3.1 to 3.0, and as the pressure dropped still further to .430, the current dropped to 2.9.

In the d experiment, there is only one point recorded.

In the e experiment, the pressure changed from .522 microns to .298 microns and the current dropped from 5 to 4.

Unfortunately, or at least, unfortunately for the purpose of testing whether or not the current would have dropped still further with a further decrease of pressure, there are no further decreases in pressure recorded at which current values were taken.

From my experience in these fields, I should say that the reason why the current stayed as constant as it did, was not because it would not have changed with a further change in pressure, but because the pressure did not go down any lower. An equilibrium value is reached in which there is just as much gas liberated from the walls as there is gas cleaned up, so that the pressure stays constant and consequently the current stays approximately constant.

If the pressures had been further decreased by pumping out gas, then I am confident that in this experiment the currents would have kept on decreasing for a considerable time until the pressure would have gotten so low that subsequent decreases in pressure would no longer have caused decreases in current.

The Court: Is this a suitable place for recess now?

Mr. Richmond: The diagram just referred to by the witness is offered in evidence as "Becker diagram for low current values of Sweetser, Auguest, 1912, notes."

(Received in evidence and marked "Defendant's Exhibit No. 295." *See Volume VI, Defendant's, Exhibits, page 1202.*)

Mr. Richmond: Your Honor, I will mention that this exhibit incorporates all the data in Exhibit J for Identification and other data.

By Mr. Richmond:

Q. 13. Dr. Becker, will you please go on and explain what you have recorded on that exhibit sheet, so far as you have not already done so in your explanation?

A. I have recorded all the space charge points that are to be found in Plaintiff's Exhibit No. 99. These are all of the points. There are no more in plaintiff's Exhibit No. 99.

Then I have enclosed a region in which I say:

> "If discharge had been substantially unaffected by positive ionization, the characteristic would have been within these bounds."

That means that if the current had actually been unaffected by the presence of gas, the points, instead of being where they actually are, would be somewhere between those two lines, the exact place can not be located, because I do not know what the exact distance between the filaments was, and the exact place would depend upon the distance between the filaments.

Q. 14. If there had been a pure electron discharge in this tube, with the recorded current values, would the current have fluctuated with changes in gas pressure?

A. You mean after the drop?

Q. 15. Yes, after the drop.

A. If, after the drop, the discharge had been a pure electron discharge, then the current should have remained constant as the gas pressure changed, and the very fact that it did not remain constant, shows that it was affected by positive ionization, because if there were no gas present, you could not have any positive ions.

Q. 16. Can you make some kind of an estimate of the values to which the current would have dropped further, with further improvement of the vacuum?

A. I think I have already given my estimate, and that is, it would have gone down to one-half to one-third in values that the current had at about four-tenths of a micron; that would depend somewhat upon the voltage and my estimates are based on the 250 volt value.

Q. 17. Then, when the current got down to that value, an improved vacuum, what would have happened with further improvement of the vacuum?

A. You mean after the pressure had gotten so low that the discharge would have been a pure electron discharge?

Q. 18. Yes.

A. Then a further decrease in the pressure would have no effect on the current.

Q. 19. Will you please give us the reasons for your estimate of the value that the current would have attained with further improvement in the vacuum?

A. Aside from the Sweetser note evidence, which I have given, and aside from my general experience with such types of discharge, I have specifically repeated this particular experiment, that is, I have duplicated as near as I could from the description given in the notes, the bulb which was used in August, 1912, and your Honor may be interested in seeing just how—this is as close a duplicate as I could make from the description in the notes (indicating to Court).

Q. 20. Describe the internal structure, Dr. Becker, so that it can easily be recognized.

A. In this particular case, the filaments are one-half inch apart and the plane of the filaments are parallel. The distance between the legs of the filament in this particular tube is a quarter of an inch. I have carefully examined the notes of Exhibit 99 to see whether there was anything said about the distance between the filaments or the distance between the legs of the filaments, and I can say positively that there is nothing mentioned in these notes concerning those distances. Consequently, of course, I could not duplicate the tube in that respect.

The first intimation I received of what that actual distance had been, was when Dr. Langmuir said that according to his recollection it was about half an inch. Now, it so happens that with this particular tube, the filaments are very close to one-half inch apart.

This bulb was put on a system very much the same as the system described here. The system consisted of liquid air trap, then a McLeod gauge to measure the pressures, and beyond that a mercury cut-off to disconnect the system from the pumps. Then I even went to the extent of blackening the bulb just as recorded in the notes; that is, whenever you send a discharge through nitrogen, after the discharge has run for some time, the bulb becomes discolored by a brown deposit. With this bulb, I first tried to see whether I could repeat as much of the experiment as is recorded that is, I introduced—after blackening the bulb—I introduced nitrogen gas—I should say that this system also had a means for introducing certain amounts of nitrogen, and the pressure could be adjusted by lowering the trap connecting it to the pump, pumping it out a little if necessary, and connecting it to the pump for a short time. In that way you could adjust the pressure to any desired value.

I adjusted the pressure of the nitrogen to five microns of pressure and I applied 250 volts between the two filaments, and I raised the filament temperature of the cathode—one of the filaments—to such a value that the current was about eighteen milliamperes. Then I watched to see what would happen, and just as they found, I found that the whole bulb was filled with a purple glow, and I also found that the pressure in the system decreased, and after a certain time when the pressure was in the neighborhood of four-tenths of a micron, the blue glow disappeared, and at the same time—the same instant—the current in the instrument which recorded the current, or which measured the current, would drop suddenly from perhaps sixteen or seventeen milliamperes down to, I think, in this case, down to four or five milliamperes. I have forgotten the exact amount.

Then, subsequent to that in some experiments, the pressure would keep on decreasing, and when the pressure decreased, the current decreased. In some other experiments, it sometimes happened that the pressure would increase, because that depended on the exact condition of the walls, just as it did in the exhibit. Sometimes under certain conditions, when the discharge was taking place, the pressure would increase; but in my case, whenever the pressure did increase, the current also increased. Then, after allowing the experiment to run for a certain time, it was approximately the same length of time—which was taken in Plaintiff's Exhibit No. 163, after the drop, after the drop, I went further than that, and I decreased the pressure by pumping the gas out. As soon as the pumps took hold—as soon as the mercury trap connecting the system to the pumps was lowered, so that I felt sure that the pressure was being decreased, just as soon as that happened, my instrument which recorded the current would drop, and then I would raise my mercury trap again, because I did not want to pump all the gas out at one shot. The current would stay quite steady, but there was a slow drift upward, the current would increase again, and when I measured my pressure, I found my pressure had increased. So after waiting for perhaps five to ten minutes for things to get about as steady as they were going to get, I connected my system to the pumps again and lowered the pressure still further, and repeated the same process. Then I plotted the value of the current in milliamperes against the pressure in microns, keeping the voltage between the filaments constant at 250 volts, and observed the points here plotted, and put in circles. You will notice that the points are in pairs. The lower one of these represents the condition of current versus pressure soon after the pumps had taken hold. Then, as the pressure increased, after the system had been shut off again from the pumps, it is to be noted that in every instance the current increased also.

Now, by connecting all of the points or as many of the points as possible by a smooth curve, one can see quite readily that at pressures in the neighborhood as low as even three-tenths of a micron, the currents were still at least twice as great as they were when the pressure was reduced to five one-hundredths of a micron, at which value the currents are quite approximately independent of the pressure.

Now, if the pressure had been higher than three-tenths of a micron, the currents would have been quite appreciably greater than they were at three-tenths, because in the neighborhood of three-tenths of a micron, the current is going up quite rapidly.

It is on this evidence among others, that I base my estimate of this factor of 2 to 3, as shown on the previous curve I presented, that is, Defendant's Exhibit No. 295. As I took a point at about 4.5 milliamperes and half of that would be about 2.25, it would be within the region there specified.

Mr. Richmond: The tube or bulb produced by the witness is offered in evidence as "Becker Approximate Duplicate of Sweetser's tube of August, 1912."

(Received in evidence and marked "Defendant's Exhibit No. 296." *See Volume VI, Defendant's Exhibits, page 1203.*)

Mr. Richmond: The diagram last produced by the witness is offered in evidence as "Becker Diagram for current pressure relation in tube Exhibit No. 296."

(Received in evidence and marked "Defendant's Exhibit No. 297." *See Volume VI, Defendant's Exhibits, page 1204.*)

Q. 20a. I notice that this tube, Defendant's Exhibit No. 296, has two little short wires in the glass on opposite sides. Please tell about those.

A. Those are two platinum wires sealed into the glass so as to make contact with this film on the inside. The purpose of those was to be able to determine the potential of the wall and it is on the basis of measurements made on those that I gave my previous description of changes in wall potential in the course of experiments, such as those on Plaintiff's Exhibit

No. 163. Now, during other tests, these were left floating. They were disconnected and they produced no result whatsoever different from what would happen if they were not there when they were disconnected; and even when you do have them connected in a circuit, if the potential that you apply to them is the same that they already have, it makes no difference. It is only when you apply different potentials that it changes the character of the results at all, and in most cases they were simply left floating.

Q. 21. Now, referring to that last current pressure diagram, Defendant's Exhibit No. 297, did you see any blue glow during the points that you have recorded on that diagram?

A. No. I did not see any blue glow.

Q. 22. Is that in accordance with your general experience?

A. It is with tungsten filaments. That is, tubes containing tungsten filaments. It is my experience that with currents of that magnitude and voltages of that magnitude and pressures of that magnitude, you can not see the blue glow.

Q. 23. Well, apart from what you saw, what is your belief as to the presence of blue glow at that time?

A. I am quite certain that there was some blue glow present.

Q. 24. How do you reconcile that with not seeing it?

A. Oh, very simply. It merely means that the eye is not sensitive enough as a detector; since whenever you have ionization in a tube, you must have the blue glow present, but the only reason that you do not see it is because your eye is not a sensitive enough detector, and also if the filament had been made of an oxide coated filament, such that the temperature had been a good deal lower, then, I am quite sure that even under those circumstances I could have seen blue glow.

You see the eye can not see a faint blue glow when it is contrasted with a very bright light. But you might very easily see that blue glow under other circumstances where there was no bright light around it, and I am quite sure that the amount of ionization under these circumstances would have been sufficient to have been visible had it not been for the bright tungsten filament.

However, I should say that if this experiment had been repeated with an oxide coated filament, the amount of blue glow right at the break would have been greatly diminished. Before the break there would have been a lot of blue glow, and after the break there would still have been some blue glow, but its amount would have been quite diminished, because there is a great deal less current than there was before, and consequently there is a great deal less ionization after the break than there was before the break.

Q. 25. Now, referring to these changes in current that occur after the break, what significance is there in a comparison of those changes with the magnitude of the change that you have referred to as the second stage of Defendant's Exhibit No. 163?

A. I think it is quite erroneous and misleading to compare changes in the third stage with the magnitude of the break of the second, because they are two different things. As I have explained before, the magnitude of the change during the second stage can be made large or small merely by changing the temperature; but the magnitude of the changes in the third stage depend on the changes in gas pressure, and do not in general depend on the temperature. So I think it is quite erroneous and misleading to try to compare these two things.

For example, in run No. 2, if the pressure had been decreased a lot, the change subsequent to the drop would have been of the same order, or perhaps even greater than the actual drop itself; whereas, in run No. 1, where the temperature was high, the subsequent changes after the drop, would not have been so very great, compared with the magnitude of the drop; and in another experiment, if the temperature of the filament in a run similar to run 1 had been even higher, the magnitude of the drop could have been made 100 times the changes subsequent to the drop.

Q. 26-27. To what extent are you familiar with Plaintiff's Exhibit No. 100, these Sweetser notes of November and December, 1912?

A. I have also carefully looked over these pages and have also familiarized myself with what they contain, and the type of experiments which they record, and the results derived therefrom.

Q. 28. Do you find any data in those notes exhibiting the dependence of the current on the cathode temperature in a two-electrode thermionic tube, and can you exhibit such data graphically?

A. Yes, I find very many curves showing the dependence of the current on the temperature of the cathode in fact.

Q. 29. You mean you find the curves, Dr. Becker?

A. No, I do not find curves in there, but I have plotted some curves, of which these are fairly representative.

Q. 30. You mean that you find the numerical data from which you have made these plots?

A. Yes, that is correct. I have only selected those temperatures which show the flat-topped region and have drawn just a sufficient amount of the region where the current is dependent upon the temperature to clearly indicate that at this stage, the currents were flat topped.

Now, this is a fairly representative compilation of flat-topped current temperature curves in Plaintiff's Exhibit No. 100 for hydrogen. I have been very careful to pick only such values or such experiments in which it was quite evident that the distance between the filaments was not changing, due to the application of a magnet, which Dr. Langmuir spoke about the other day. For all of the curves indicated here, the distance between the filaments is about 3 millimeters as recorded in those notes, so that they are all to be compared one with the other.

Now, when the current has the value representative of a flat-topped curve, that is, when the current say for the uppermost curve has this value or these values, the current is limited by space charge. In the region preceding that, the current is either limited by emission from the filament, or else it is in a transition region from about here to here (indicating), where it is neither limited by one alone or by the other, but limited to some extent by both. But in the flat-top part of the curve, the current is actually limited by space charge. Now that does not mean a pure electron space charge, that is a space charge composed solely of electrons, but it is composed of a mixed space charge. That is, there are electrons present and some positive ions. The positive ions that are present partially neutralize the negative electron space charge and as a result of that neutralization or partial neutralization of the space charge, the currents can be a good deal higher than they are in a vacuum. Of course, when the current is limited by space charge in these curves, the net result is still a negative space charge, but it does not have the value that it would have if the positive ions were not present.

Mr. Richmond: The diagram just produced by the witness is offered in evidence as "Becker current temperature diagrams for Hydrogen from Sweetser's notes for November and December, 1912."

(Received in evidence and marked "Defendant's Exhibit No. 298." *See Volume VI, Defendant's Exhibits, page 1205.*)

Q. 31. Referring to those diagrams, will you please tell us just how Richardson's law comes in there?

A. Why Richardson's law states how the current from the filament varies with the temperature of the filament and on these diagrams it hardly shows up at all. It would show up away to the left of these diagrams, away beyond at lower temperatures than here recorded. There as the temperature is lowered, the current keeps on decreasing. Actually due to the fact of the poisoning of the filament due to small amounts of water vapor, or oxygen, or some other gas, which would not be sufficient to affect the current in the space charge region, the currents in the region where they are limited by emission, are affected by these small quantities of impurities, and that is the reason why there is no regularity in this region, whereas there is perfect regularity in this region (indicates); that is, in the space charge region whenever the pressure increases, the current increases despite the fact that the voltage decreases.

The Court: Will you tell me that again?

The Witness: In the region where the currents are limited by space charge——

Q. 32. Dr. Becker, can you indicate the region in some way so that it can be identified when you speak of this region or that region?

A. In the flat-topped region, the current increases regularly as the pressure increases, despite the fact that the voltage is decreasing. If the pressure were constant and the voltage were decreasing, the current should decrease.

Q. 33. How do you get the bottom line of that diagram?

A. That lowest line of this diagram, the one that is dotted, is computed and shows what the current would have been if the voltage for curve No. 1, the lowest solid line curve, instead of being 180 volts, had been 99 volts.

Now, for the purpose of this computation, I have assumed that the 3/2 power law holds, and I have made a correction for the filament drop voltage; that is, in making this computation, I measured or computed my voltage from the middle of the cathode filament instead of from the negative end. In other words, I made the filament drop correction, which is perfectly well known, largely for accuracy. On the basis of that, I find that the current instead of being 66 units of current at 180 volts, would have been 26 units of current at 99 volts, when the pressure was one-tenth of a micron.

I think it is interesting to compare this value of the flat-topped current with the value of the flat-topped current for curve No. 6, which is also for 99 volts. The only difference between these two curves is the fact that for the higher one, the pressure is 7.2 microns; for the lowest one, the pressure is one-tenth of a micron, and yet the upper one is just as good a flat-topped curve as the lower one. But the current is 134 over 26 or 5.15 times as high as the current in a vacuum and still there is just as good a flat top as there was in a vacuum.

I might even state that, if, instead of having two filaments for cathode and anode, if the anode encloses the cathode, then even larger ratios are possible, and still the flat-topped emission curve is just as good for the high values of current and the high pressures of gas as it is in a perfect vacuum. In fact, all that is necessary to get a flat-topped curve is to have the current limited by space charge. That can be a mixed space charge, and does not have to be a pure electron space charge.

Q. 34. What is your opinion of the significance of such flat-topped current temperature curves, as tests for a pure electron discharge?

A. Well, I can hardly say that it is a good test. It is a very, very poor test. In fact, I would hardly give it the name of a test at all. It is in the same class as is the saying "all that glitters is not gold," in this sense, that while a pure electron discharge shows a flat-topped curve, you could have a discharge which is nothing like a pure electron discharge and still get a flat-topped curve. The flat-topped curve is a necessary condition for a pure electron discharge, but it is not at all a sufficient condition. That is, a pure electron discharge shows a flat-topped curve, but not every flat-topped curve discharge is a pure electron discharge, so that in answer to your question I would say if it is to be considered a test at all, it is certainly a very poor test.

Q. 35. I direct your attention to the flat-topped current temperature curves on pages 133 and 134 of Langmuir's Notebook 413, which is now Defendant's Exhibit No. 101. These notes were taken in the latter half of November, 1912. Do these flat tops give any indication of the purity of the electron discharge, when the corresponding readings were taken?

A. Just from the fact that they are flat topped, I can not draw any conclusion whatsoever as to whether the discharge was a pure electron discharge or not.

Q. 36. Referring to Exhibit No. 298 for hydrogen, which you produced recently, I notice that for each curve, there are two variables. The pressures vary from curve to curve, and the voltages vary from curve to curve. Can you make any comparison of these data on the basis of constant voltage, so that we can see the direct effect of pressure changes?

A. Yes. I think it is quite possible to do it. Just as before in getting curve 1a from curve 1, I assumed for the purposes of computation that the 3/2 power law held, and on the basis of that, computed what the current would have been at 99 volts. So here we can reduce all of these voltages to a common basis, and to be as accurate as possible, it is best to choose a value somewhere between the actual values; that is, between the values 99 and 180, such that if using the 3/2 power correction, there is some slight error in applying that law—as there will be, especially for the higher pressures—then the error will be quite small since the correction itself is small; that is, I chose a common voltage such that in no case will the correction be very large, and if there is a percentage error in the correction, the total error will be quite small. Thus, if the error in the correction is 10 per cent., let us say, and the correction itself amounts to 50 per cent., then the error in the result will only be a 5 per cent. error, that is, 10 per cent. of 50 per cent.

So that I have chosen 150 volts as a good intermediate value to which to reduce all the voltages, and for that voltage I have plotted the values of the current readings for hydrogen from these flat-topped curves.

Mr. Davis: May I interrupt? This from Exhibit No. 298?

Mr. Richmond: That is right, 298.

The Witness: This is 298. I have computed the values on the common basis of 150 volts for the current readings at various pressures, and I believe the scale on this new curve is so chosen that some of the points are left off. I think the highest ones are left off. The two highest curves on 298 are not plotted on the next curve, and also besides plotting these points, I have taken other points from the notes, which I could not plot on 298 without making 298 too mixed up. I have plotted them in the same way on the next curve. In other words, I have taken all the points for hydrogen that I could find in these notes, where I was sure that the distance between the filaments remain constant at about three millimeters, and have reduced all the current readings to what they would have been if the voltage had been 150 volts, and I then get the resultant curve marked: "Hydrogen: H_2."

Mr. Richmond: The curve just produced by the witness is offered in evidence as "Becker diagram for current pressure data in Exhibit No. 298, reduced to common voltage."

(Received in evidence and marked "Defendant's Exhibit No. 299." *See Volume VI, Defendant's Exhibits, page 1206.*)

The Witness: If I may, I should like to state that for all these points for hydrogen, the current is limited by space charge, but at the very low pressures this space charge is practically a pure electron space charge; that is, there are so few positive ions present that they do not affect substantially the current; but for the higher pressures the space charge was mixed, consisting of electrons and positives, and there the current is quite considerably affected by the presence of these positive ions. One can see from this curve that with this structure and a distance of three millimeters between the filaments and hydrogen gas present, one would have to reduce the pressure to perhaps six-tenths to eight-tenths of a micron before you get to the stage where a further decrease in pressure would no longer change the value of the current.

Q. 37. Your explanation so far for that sheet is related to the hydrogen curve, is it not, Dr. Becker? A. Yes, sir.

Q. 38. Please tell us about the curve marked "Nitrogen."

A. I proceeded in a similar manner for the data in Exhibit No. 100, in which nitrogen was present in the tube. There again I selected all the points for which I felt quite certain, first, that the current was actually limited by space charge; second, that the separation of the filaments was the same, namely, about three millimeters, and third, that there was nothing which would indicate that the data was suspicious or was not correct.

Q. 39. Why is the nitrogen curve steeper than the hydrogen curve?

A. There are several reasons, but the chief one is, as I think Dr. Langmuir has explained before, that the nitrogen is so much heavier than hydrogen that it moves much more slowly, and it traverses the space charge region around the cathode so much more slowly and stays there so much longer that its influence is felt for a longer time; and consequently its effect in neutralizing the electron space charge is considerably greater than that for hydrogen. In fact, it is readily seen that to get the same amount of neutralization of the space charge, it requires about five times as much hydrogen as it does nitrogen.

Q. 40. But have you purposely omitted any data in compiling the curve for nitrogen?

A. Oh, yes. There were two points which were purposely omitted, and the reason for those is apparent, when one looks at the pages on which the data for those two points occur. These are on pages 1403 in Plaintiff's Exhibit No. 100 down near the lower part of the page where appear these words: "Results doubtful plotted poorly."

I omitted the data in that neighborhood and did not plot the point which I could have gotten from that data on the curve sheet. These points would have corresponded to a reading of approximately seventy units of current, because when the temperature of the filament had gotten to the temperature corresponding to 9.7 volts, which I believe is 2325 degrees, the current did not increase when the voltage was increased to 10.5, which would correspond to a great deal higher temperature. So that the value of the current would have corresponded to seventy units, and the pressure which would have gone with that is .11; but I did not plot that because of the fact of this notation "Results doubtful."

Then, on the next page, on page 1404, there appears a similar notation, "Results doubtful," and I omitted that point for the same reason. Now, those are the only two points for which I found such a notation in this connection, so that those are the only two points which I purposely omitted. There might have been some other points which I overlooked but I am somewhat in doubt about that, as I was fairly careful to get all points which fulfilled all the conditions necessary to be a representative point.

Q. 41. I direct your attention to page 1565 in the Interference record, and ask you whether the data there shown are dependent on those pages of notes that are marked "Results doubtful"?

A. On the bottom of the page to which you have referred, that is, page 1565, there is a table in which the pressure in the first column is compared with, or at least is associated with the current readings, reduced to a common voltage of 100, just as I reduced it to 150.

The data here was reduced to 100, and the lowest two points in that table, that is, the ones that are most significant, are those very two points which I have pointed out in the notes, for which there appears the notation, "Results doubtful."

I might say that I think the choosing of 150 volts is a good deal better than the choosing of 100 volts, because of the error—the necessary errors that are known to exist at the higher gas pressures at which the 3/2 law does not hold. So by reducing to a common voltage, it is known you produce an error; but the larger the correction, the bigger the error will be, and the more likely you are to deduce erroneous conclusions from the data. So I think 150 volts which is an intermediate value, is a good deal better than 100 volts.

Q. 42. Please compare the electrode spacing for the Sweetser tube of November and December, 1912, with the spacing for the Sweetser tube of August, 1912.

A. In the Sweetser tube for November and December, 1912, the spacings vary, as Dr. Langmuir has pointed out, and it is quite obvious from looking through the notes that the distance between those filaments sometimes had one value and sometimes another value. I have found specifically mentioned values like 8 millimeters, another time 2½ millimeters; another time 3½ millimeters; but for the values which I have chosen, and the values for which most of the data in the notes was taken, it was about 3 millimeters.

So much for the distance in the November notes. In the August notes, I have very carefully examined those to find out what that distance was, and it is not mentioned.

As I said before, Dr. Langmuir I believe has testified that as far as he can remember, or from his recollection, that distance was about half an inch, and judging from my general experience I think that is not far from correct. That is, judging from the way the experiments went and the values of the currents—half an inch is not far from correct for the August work; whereas, most of the work in December had a filament separation of three millimeters.

Now, when that separation is specified as three millimeters, I think that probably that must refer to the tip or the loop of the filaments, actually very likely at the fastened end of the filaments the separation was probably half an inch, that is, judging from the fact that Dr. Langmuir testified that it was common practice to mount them on a common stem, and that distance was half an inch. Probably as I interpret the notes, when they say the distance is three millimeters, it means of the loop, and of course that would be the most determining region, that is, that would be the region where most of the electrons would come from, because it is the hottest part of the filament, and there is little emission from the cold region of the filament near the point where the filament is attached to the cold stem; so that three millimeters separation probably means a somewhat larger average separation, although not very much greater than three millimeters.

Q. 43. Now, this different spacing for the electrodes in the two tubes, causes what difference in the effect of the gas on the discharge currents?

A. Well, other things being the same, the bigger the distance between the filaments, the greater is the amount of gas, which is susceptible to ionization. Consequently, the greater the number of ions produced; consequently, the greater will be the reduction in the space charge; so that for a given pressure—for the same pressure—the further the filaments are apart, the greater will be the effect of gas.

Q. 44. Then, for a certain effect at a certain pressure in the December tube, what would be the comparative effect of the same pressure in the August tube?

A. If we take the figures to be three millimeters separation in the December experiments—at least for the parts to which I have referred—and twelve millimeters as the separation in the August experiments, then to a first approximation, the pressure should be divided by four to reduce the December pressures to equivalent pressures in August. To be specific, I refer to this last curve, Exhibit No. 299 for nitrogen, we see that with a separation in December of three millimeters, the pressure had to be reduced to something like, oh, let us say, 2/10 of a micron before it was substantially independent of the pressure.

Now, if that same pressure had been present in the August experiment, where the separation was four times as large, the number of ions produced, would have been approximately four times as great, or if we had wanted to get the same number of ions, we would have to reduce our pressure by a factor of four; and instead of having a pressure of 2/10 of a micron, we would have had four or five, one-hundredths of a micron before the current would have been substantially unaffected by changes in pressure. That figure of five one-hundredths of a micron agrees very well with what I actually found with the tube I have exhibited, for the value at which the current becomes substantially unaffected by positive ions; so that I can say that approximately the results from my tube with a separation of half an inch or twelve millimeters—half an inch is 12.5 millimeters—agrees with what one deduces from the December notes for the pressure below which further changes in pressure have no effect on the current. In both cases, the conclusion is that it is only when the pressure has been reduced to approximately five one-hundredths of a micron with a separation of half an inch between the filament that the current becomes substantially unaffected by positive ions.

Mr. Richmond: Direct examination closed.

U. S. District Court, Wilmington, Del.,
Thursday, 11th November, 1926,
10 o'clock A. M.

TWENTIETH DAY.

Before:
Hon. Hugh M. Morris,
U. S. District Judge.

Appearances as before.

Mr. Lunt: If the Court please, I would like to offer certain pages of the book by Richardson on the Emission of Electricity from Hot Bodies, published in 1916. This was the book referred to yesterday, and I offer in evidence pages 13 to 15 inclusive; pages 20 to 23 inclusive; pages 61 to 68 inclusive; pages 91 and 92; pages 117 and 118, and pages 128 to 138.

These are either referred to directly or indirectly in the testimony given by Professor Richardson on behalf of Arnold, and by Langmuir.

The Court: Have you inspected these pages?

Mr. Haight: No, sir, we have not.

The Court: Suppose they be admitted with leave to you to move to strike out any portions if you feel inclined to do so.

Mr. Haight: Your Honor would you rather have that course than their acceptance held in abeyance until we have had a chance to examine them?

The Court: It is not material. I was thinking the other way would get our exhibit numbers more nearly right, but probably not.

Mr. Haight: If it makes no difference to you I think I would rather adopt the latter course.

The Court: All right.

Mr. Lunt: I would also like to offer in evidence the patent to Langmuir, No. 1,558,437, of October 20, 1925. This appears as a part of Defendant's Exhibit No. 300, which was offered yesterday.

(Received in evidence and marked "Plaintiff's Exhibit No. 215." *See Volume IV, Plaintiff's Exhibits, page 313.*)

The Court: Now, the twenty patents, Mr. Richmond.

Mr. Richmond: Your Honor, twenty-two patents. In the first place, your Honor, if our opponents care to withdraw from the argument they have advanced heretofore that non-mention of high vacuum in Western Electric patents is significant, then I do not care to offer these twenty-two patents; but if they insist on that argument, based on the patents they have put in before, then I do ask to put in these twenty-two patents.

The Court: I have concluded that the slight confusion under which one or possibly two or more patents were put in in your case in chief in your defense, should not bar you from presenting your mass of evidence on this minor issue, and that in the exercise of discretion I shall permit you to present any evidence which might be deemed material to that issue. Consequently your patents are admitted, if they bear upon this issue.

Mr. Richmond: Very well, your Honor. Here is a list of the patent names and numbers. There are twenty-two of them; the exhibit numbers will run consecutively over them.

The Court: They will be admitted, but if counsel should later deem it advisable to withdraw from the record these patents, and there will be a withdrawal on the other side, either can do that at any time.

Mr. Davis: I merely make the objection that they are immaterial, the point being that each of them, so far as I have been able to examine them, speaks of an electron discharge apparatus. Whether we are right or wrong in thinking that be a proper term to explain this phenomenon is a matter of judgment in this case.

(The patent to E. F. W. Alexanderson, dated July 7, 1914, being No. 1,102,628, was received in evidence and marked "Defendant's Exhibit No. 302." *See Volume VI, Defendant's Exhibits, page 1233.*)

(The patent to W. C. White, dated August 22, 1916, No. 1,195,632, was received in evidence and marked "Defendant's Exhibit No. 303." *See Volume VI, Defendant's Exhibits, page 1241.*)

(The patent to I. Langmuir, dated July 23, 1918, No. 1,273,627, was received in evidence and marked "Defendant's Exhibit No. 304." *See Volume VI, Defendant's Exhibits, page 1246.*)

(The patent to W. C. White, dated March 25, 1919, No. 1,298,613, was received in evidence and marked "Defendant's Exhibit No. 305." *See Volume VI, Defendant's Exhibits, page 1251.*)

(The patent to I. Langmuir, dated April 22, 1919, being No. 1,301,279, was received in evidence and marked "Defendant's Exhibit No. 306." *See Volume VI, Defendant's Exhibits, page 1257.*)

(The patent to E. F. W. Alexanderson, dated August 12, 1919, being No. 1,313,042, was received in evidence and marked "Defendant's Exhibit No. 307." *See Volume VI, Defendant's Exhibits, page 1263.*)

(The patent to I. Langmuir, dated August 12, 1919, being No. Re 15,495, was received in evidence and marked "Defendant's Exhibit No. 308." *See Volume VI, Defendant's Exhibits, page 1267.*)

(The patent to A. N. Goldsmith, dated December 2, 1919, being No. 1,323,759, was received in evidence and marked "Defendant's Exhibit No. 309." *See Volume VI, Defendant's Exhibits, page 1271.*)

(The patent to A. N. Goldsmith, *et al.*, dated March 16, 1920, being No. 1,334,687, was received in evidence and marked "Defendant's Exhibit No. 310." *See Volume VI, Defendant's Exhibits, page 1276.*)

(The patent to E. F. W. Alexanderson, dated May 11, 1920, being No. 1,340,101, was received in evidence and marked "Defendant's Exhibit No. 311." *See Volume VI, Defendant's Exhibits, page 1280.*)

(The patent to E. F. W. Alexanderson, dated April 5, 1912, being No. 1,373,931, was received in evidence and marked "Defendant's Exhibit No. 312." *See Volume VI, Defendant's Exhibits, page 1285.*)

(The patent to J. H. Payne, Jr., dated December 13, 1921, being No. 1,400,235, was received in evidence and marked "Defendant's Exhibit No. 313." *See Volume VI, Defendant's Exhibits, page 1289.*)

(The patent to B. Bradbury, dated October 3, 1922, being No. 1,430,883, was received in evidence and marked "Defendant's Exhibit No. 314." *See Volume VI, Defendant's Exhibits, page 1293.*)

(The patent to H. H. Beverage, dated November 7, 1922, being No. 1,434,984, was received in evidence and marked "Defendant's Exhibit No. 315." *See Volume VI, Defendant's Exhibits, page 1297.*)

(The patent to H. H. Beverage, dated November 7, 1922, being No. 1,434,985, was received in evidence and marked "Defendant's Exhibit No. 316." *See Volume VI, Defendant's Exhibits, page 1303.*)

(The patent to B. Bradbury, dated January 23, 1923, being No. 1,443,209, was received in evidence and marked "Defendant's Exhibit No. 317." *See Volume VI, Defendant's Exhibits, page 1314.*)

(The patent to W. R. G. Baker, dated May 15, 1923, being No. 1,455,099, was received in evidence and marked "Defendant's Exhibit No. 318." (*See Volume VI, Defendant's Exhibits, page 131*[illegible])

(The patent to E. F. W. Alexanderson, dated August 28, 1923, being No. 1,466,263, was received in evidence and marked "Defendant's Exhibit No. 319." *See Volume VI, Defendant's Exhibits, page 1321.*)

(The patent to O. C. Traver, dated October 9, 1923, being No. 1,470,582, was received in evidence and marked "Defendant's Exhibit No. 320." *See Volume VI, Defendant's Exhibits, page 1325.*)

(The patent to E. F. W. Alexanderson, dated April 22, 1923, being No. 1,491,372, was received in evidence and marked "Defendant's Exhibit No. 321." *See Volume VI, Defendant's Exhibits, page 1331.*)

(The patent to W. C. White, dated June 30, 1925, being No. 1,544,202, was received in evidence and marked "Defendant's Exhibit No. 322." *See Volume VI, Defendant's Exhibits, page 1337.*)

(The patent to A. W. Hull, dated July 21, 1925, being No. 1,547,153, was received in evidence and marked "Defendant's Exhibit No. 323." *See Volume VI, Defendant's Exhibits, page 1341.*)

JOSEPH A. BECKER, resumes the stand.

CROSS-EXAMINATION.

By MR. DAVIS:

XQ. 45. In the first stage, using the language, Doctor, which you used yesterday, of the phenomenon which was observed by Dr. Langmuir and Mr. Sweetser in August, 1912, you remember you divided that into three stages. I am thinking now of the first stage. I understood you to testify that in that stage the current was limited only by the emission from the cathode and that the bulb was full of blue glow; is that correct?

A. I believe I made a slight provision. I did not say that it "was limited only," I said "practically," and that it is correct.

XQ. 46. As a practical matter it is limited only by emission?

A. Yes. I want to make sure that I am not misinterpreted.

XQ. 47. The other factors were negligible in your judgment?

A. Yes, and the bulb was filled with blue glow.

XQ. 48. What part of the bulb was filled with blue glow?

A. At the pressures of approximately five microns or down to three microns practically the whole bulb. Then as the pressure gets down lower——

XQ. 49. We are talking about the first stage.

A. Yes, I am talking about the first stage.

XQ. 50. All right.

A. In the beginning of that stage the whole bulb is filled with blue glow. Then as you approach near to the second stage, where the glow is going to drop in, you can actually see that the glow is disappearing. I can illustrate that if I may have the bulb. I have now Defendant's Exhibit 297. When the pressures are fairly high the whole bulb, including from the top of the bulb to the lower part of the bulb, is filled with a blue or purple glow. Then just before, say perhaps a minute or two before the glow is going to drop in you can actually see the glow disappearing from the upper portion of the bulb and also at the same time you can begin to see that it is less pronounced in the neighborhood of the glass walls. Then all of a sudden it disappears as far as the eye is concerned.

XQ. 51. That is, you get a dark space around the walls?

A. At first there is quite an appreciable dark space up in this partial portion, the portion of the bulb containing the stem and you can also see it separate to some extent from the walls of the glass, although that is not very pronounced. It might be partly an illusion, because in looking through the middle of the bulb you have a deeper path but it is quite pronounced in the stem portion that the blue glow is certainly much fainter.

XQ. 52. And in that first stage the space charge is completely neutralized throughout the whole bulb?

A. I do not know just what you would mean by the space charge being in certain parts of the bulb, I do not think it is correct to differentiate space charge in this part of the bulb. If you mean the density of charge in different places then I can talk about it.

XQ. 53. I mean the density of charge established by Poisson's equation?

A. If you mean to say that there is no space charge in any portion of the bulb, in other words, that every little portion of the bulb is electrically neutral, I do not know that I would agree with you perfectly. I do not know that I have any evidence of that. What is true is that the current is not limited in any sense by space charge.

XQ. 54. Is it not true that all of the gas in the bulb is at substantially the same potential in that stage?

A. I am not so sure that that is true. I think it is pretty nearly correct. I have never personally measured what the potential is in all parts of the bulb.

XQ. 55. But you know from a consideration of the matter that that statement is substantially true?

A. I think so.

XQ. 56. So that there is no field of any magnitude anywhere in the bulb?

A. Oh, no. Of course not. There is quite a big field in the neighborhood of the cathode. In certain stages there is a big field in the neighborhood of the anode and there is probably a field to some extent in the neighborhood of the glass walls.

XQ. 57. Let us take these one at a time. Of course there is a field in the neighborhood of the anode?

A. I think under some cases there is, yes.

XQ. 58. Is there a field in the neighborhood of the cathode?

A. Oh, yes, there is always an intense field in the neighborhood of the cathode.

XQ. 59. How far out does that extend?

A. Not very far.

XQ. 60. It is a matter of millimeters?

A. Oh, I do not know.

XQ. 61. I am talking about these high pressures.

A. My impression is that it is less than a millimeter.

XQ. 62. So that the substantial drop of potential in that tube is concentrated in a very small volume outside of the cathode?

A. Will you please say that again?

XQ. 63. The substantial drop of potential in the tube is concentrated in a very small volume surrounding the cathode?

A. Yes. Quite a considerable proportion of the difference of potential between the two filaments takes place in the immediate neighborhood of the cathode.

XQ. 64. That is the old-fashioned cathode drop, is it not?

A. It is analogous to it.

XQ. 65. I do not want to be too accurate or too scientific, but that is a rough way of looking at it and a fairly accurate way?

A. Yes.

XQ. 66. As a matter of practice all the potential is in the cathode drop?

A. I did not say so.

XQ. 67. I am asking you.

A. I think under some circumstances there is quite an anode drop.

XQ. 68. Under what circumstances?

A. I do not know that I can tell you exactly, Mr. Davis, but I know that sometimes there is quite an appreciable anode drop too, I mean right in the neighborhood of the anode there will be a drop.

XQ. 69. That would be very close to the anode?

A. I am under the impression that it is, yes.

XQ. 70. So that the bulk of the tube is electrically pretty neutral?

A. If interpreted electrically pretty neutral in the sense that the difference of potential——

XQ. 71. From point to point?

A. From point to point where your points are not near the anode or cathode, or too near to the glass walls, then I will agree in that sense. I should modify that to this extent, that when your pressures get down low——

XQ. 72. We are talking about ten or fifteen microns.

A. Then I will agree with you.

XQ. 73. Let us take the simple thing first. The walls of that stage are at anode potential?

A. Pretty nearly.

XQ. 74. Not quite?

A. I do not know. At ten or fifteen microns I do not know how much difference there would be but they would be very close to anode potential.

XQ. 75. How do you know that?

A. I know that because in working with pressures of five microns and in this bulb I have measured that potential on the glass walls and I found that it is not very far different from the anode potential.

XQ. 76. Which way does it differ?

A. It is less in the case in which I measured it, less than the anode potential.

XQ. 77. In five microns the wall is slightly negative with respect to the anode?

A. Yes, if the cathode is at zero the bulb might be at 145 volts positive.

XQ. 78. Now, an electron emerging from the cathode has to pass through this steep potential gradient surrounding the cathode?

A. Yes, sir.

XQ. 79. And when it has gotten through that it shoots through it, does it not, like a projectile?

A. Shoots through what?

XQ. 80. Through this space surrounding the cathode?

A. It does not shoot through it after it has gotten through.

XQ. 81. Perhaps I did not make my question clear. I am trying to see what would happen to an electron that was active enough to get through this cathode space. It would shoot out in straight lines, would it not? You need not answer that question because I do not think it is very well framed. How did the electrons get through this cathode space? Let us begin from the beginning.

A. If an electron is once liberated from the hot filament, that means if it gets to a distance of one-one hundred thousandths of a centimeter away from the surface of the tungsten filament, it is then practically free from the surface. It is then subjected to this intense field which surrounds the filament and is accelerated by that field.

XQ. 82. And that field is a very large part of the 100 or 200 volts that is on the tube?

A. That is the thing I have answered before. Under some circumstances it is a large part.

XQ. 83. I want to make it clear that here you have in this kind of a discharge a little shell surrounding the cathode which the witness says is only a millimeter thick and in that shell is concentrated most of the potential of the tube. The electron shoots through that, is that right?

A. I would like to put things in my own way, Mr. Davis.

XQ. 84. Please do.

A. I said that when the electron is liberated from the filament it is accelerated by this field. If you want to call that shooting through the field, well and good. Then it gets into this region where there is practically no field and when there is no field there is no force acting on it and it keeps on moving until it hits something or until it goes into a region where the fields again act upon it. So that now at these high pressures after it has gone through this cathode drop, the chances are it will hit something before it gets to the glass wall.

XQ. 85. When it comes out of this narrow space, this thin space around the cathode, it comes out at a pretty high velocity?

A. Yes, at a velocity corresponding to the equivalent voltage drop.

XQ. 86. And that means it comes out considerably above the velocity corresponding to ionization?

A. If that drop is greater than the ionization potential, yes.

XQ. 87. It is in the case we are talking about?

A. It is in case you have 150 volts on the other filament.

XQ. 88. So that this electron can ionize almost anywhere in its path, can it not?

A. Provided it hits something.

XQ. 89. It has velocity enough to ionize?

A. It has energy enough, yes.

XQ. 90. So that any collision between that electron and a molecule is capable of producing ionization unless the collision occurs in that thin space around the cathode; is that right?

A. I should say that even in that thin space around the cathode there are parts of that thin space where it has sufficient energy.

XQ. 91. What happens to these ions when they are formed?

A. That depends on a good many circumstances.

XQ. 92. They are not in a very strong field, are they?

A. No, and that is just why it depends on a good many circumstances, on just accidental velocities that they happen to have at the instant at which they are ionized.

XQ. 93. There is nothing that amounts to anything to pull them away?

A. I would not say that there is nothing that amounts to anything. The forces are small.

XQ. 94. The forces acting to pull them away are small?

A. Yes.

XQ. 95. And therefore they sort of lie around until something happens to them?

A. I would not say that.

XQ. 96. What do they do?

A. Remember that atoms even at room temperature are far from lying around, they are travelling with speeds of the order of a mile a second.

XQ. 97. I might say wandering around.

A. If you want to say that speeds corresponding to a mile a second are wandering around then they do wander around, yes.

XQ. 98. They are very slow in getting out of the space, are they not, as compared to what they would be in a high vacuum tube?

A. I would not say that at all.

XQ. 99. Why would you not say that?

A. It depends entirely on the fields acting on it. In a high vacuum tube they might have very strong field pulling them one way or the other and if they have strong fields pulling them they move pretty rapidly.

XQ. 100. That is what I was trying to get at. In the high vacuum tube there is a tendency to remove the ions which pulls them toward the cathode?

A. Provided there is a strong field which pulls the ion toward the cathode.

XQ. 101. There is generally in a high vacuum tube?

A. Not always. It might pull them towards something else.

XQ. 102. But the distribution of potential in the two cases is different, in one case you have a distribution potential in the high vacuum tube across the tube from anode to cathode with a relatively smooth drop of potential, whereas, in the case of the tubes we are considering the drop is around the cathode?

A. I do not like the term you used in a high vacuum tube. You can have this different potential distribution even though your tube is not a high vacuum tube, as for example, after the drop, I would not call the tube a high vacuum tube, but yet the potential distribution is different from what it was before the drop.

XQ. 103. What actually does happen in this first stage with these ions that are formed?

A. They move and as I said the exact thing that happens to them depends on circumstances. If for example you take this standard as one filament, and that standard as the other filament, and this room as a bulb, and if the ion happens to be here, if it happens to go in that direction, it would keep on going in that direction until it got to some region where these small forces which are not entirely negligible would deviate it from its path.

XQ. 104. It can go to the glass walls?

A. Provided that the glass walls are at a potential which will not repel them.

XQ. 105. And it can go to the anode?

A. No, it cannot go to the anode.

XQ. 106. It can go to the cathode?

A. Yes, sir, it can go to the cathode.

XQ. 107. Does the charge on the walls of the bulb in this first stage substantially influence the flow of current through the tube?

A. Do you mean by that that if I could change the potential of the walls——

XQ. 108. Let us ask if the actual charge does seriously influence it. You said the walls I think were about anode potential perhaps five volts negative. Does that fact substantially influence the flow of current through this tube?

A. If by that you mean the current from the cathode to the anode I should say not. I could change the wall potential from let us say 135 volts which it might have to 125 and that would vary little if at all change the current from the cathode to the anode.

XQ. 109. And if you should put a grid in the tube, the grid would be ineffective, would it not?

A. Not unless it were placed in a very peculiar position; not unless it were placed very close to the cathode or in a critical region. If the grid were placed at considerable distance from either the cathode or the anode and not right straight in between them, then what you say is true.

XQ. 110. That is, it would be ineffective?

A. Quite ineffective. All this I take it is limited to quite high pressures.

XQ. 111. We are talking about this first stage.

A. But there are parts of the first stage, towards the end of the first stage, for which not everything that I have answered to your questions is quite true.

XQ. 112. I understood you to be talking about something like ten microns.

A. Yes, then everything I said is true.

XQ. 113. Are these things true at five microns what we have been talking about?

A. Yes, at five microns it is still all quite true.

XQ. 114. Now, let us turn our attention to what you call stage 3. In that stage there is space charge all through the bulb, modified, as you put it, the other day, by positive ions; is that your view?

A. I do not like the expression "space charge in all parts of the bulb" because I have not studied it and I do not know whether very many people have studied just what the density of charge is in all parts of a bulb like this. The current is limited by space charge.

XQ. 115. So that there must be space charge somewhere between the anode and cathode anyway?

A. Yes.

XQ. 116. You said that in this stage, if I understood you correctly, the distance between the anode and the cathode had an effect on the current although such distance did not have such substantial effect in the first stage. Will you explain why it has an effect in the third stage, that is why the distance from anode to cathode affects the current?

A. The reason is very similar to the reason why distance between the plates in a parallel plate case has an effect on the current. It is for quite exactly similar reasons.

XQ. 117. In this stage you said that there was a charge on the bulb of a few volts minus with respect to the negative end of the filament; is that right?

A. Are you sure I said that?

XQ. 118. I am not sure. I forget what you did say.

A. If I remember correctly I did not say that. I said immediately after the drop when the pressures were of the order of .5 microns that the potential of the walls of the bulb were several volts positive with respect to the negative end of the filament.

XQ. 119. Thank you, Doctor. I beg your pardon. Did you ascertain that by experiment?

A. Yes, sir.

XQ. 120. How did you do it?

A. Very simple. By means of these platinum lead-in wires.

The Court: You are referring now to what exhibit?

The Witness: Thank you. I am referring to Defendant's Exhibit 297.

A. (Continued.) By means of platinum lead-in wires on the sides of the bulb I can apply various potentials to the inside wall. Now, if the potential applied to those wires is different than the potential at which the wires are, or tend to be, then a current will flow in this subsidiary circuit or auxiliary circuit. If, however, I applied a potential with respect to the negative end of the filament which is the same potential as these points are with respect to the negative end of the filament, then nothing happens at all in this auxiliary circuit.

So that I merely vary the potential applied to these as measured from the negative end of the filament until no current flows in that circuit. That is one way of telling what the potential of those points is when they are floating.

Another criterion is to see whether or not when you apply a potential there is a change in the current flowing from the cathode to the anode. When you apply a potential to this wall which is just equal to the potential, at which it tends to be by itself, then there is no change. This second method is not as sensitive and not as convenient as the first. I actually applied both methods and found the first one to be more convenient and used it.

XQ. 121. And you did find that applying potential to the walls of the bulb different from the potential at which they happened to be at the time, changed the current flowing in the main circuit of the tube?

A. Yes, sir. If I changed that potential sufficiently I could change the current flowing from the cathode to the anode.

XQ. 122. That was sort of a grid action?

A. Something like a grid action.

XQ. 123. I suppose you could have put a grid into that tube at this stage and varied the current?

A. Certainly.

XQ. 124. Have you any quantitative data as to the effect of these various potentials applied to the walls on the flow of current?

A. When I did the experiment I had quantitative data.

XQ. 125. You have not it here?

A. No, sir.

XQ. 126. Perhaps you could remember in a general way what the order of magnitude of the effect was?

A. I think in a general way I can, yes.

XQ. 127. Suppose you give it to us?

A. Just what?

XQ. 128. I want to see——

A. Can you tell me more definitely what you want me to give?

By Mr. Davis:

XQ. 129. Let us assume a current of four milliamperes in a tube. Is that reasonable?

A. Yes.

XQ. 130. At the beginning of stage 3?

A. You mean right after the drop or soon after the drop?

XQ. 131. Soon after the drop.

A. All right.

XQ. 132. And there you have the walls charged to about plus 4 normally?

A. Yes.

XQ. 133. Suppose you change that to zero, what would happen?

A. In that case the current between the cathode and anode might change to something like 3½ to 3 from 4. I take it you assumed a potential between filament and grid of something like 200.

XQ. 134. Yes, that is what I mean.

A. That would make a difference.

XQ. 135. I was trying to make the conditions as near as we can to the experiments that Dr. Langmuir carried out. There were 200 to 250 volts across the tube in these experiments, as I remember it, and if you made the wall potential plus 8, instead of plus 4, it would roughly do what to the current?

A. A very interesting thing would happen when you do that, Mr. Davis, if I may change your plus 8 a little bit, will that be convenient?

XQ. 136. If you will.

A. If in that stage you suddenly change the wall potential from plus 4, let us say to plus 16, it can then happen that the blue glow will come right out again, thus showing that the blue glow is dependent upon the wall potential. I have done an experiment just similar to that, in fact, I did an experiment something like this: I had my potential at such a value that the blue glow was not present, then I suddenly increased the potential on the wall to something like 12 volts, and my blue glow appeared.

XQ. 137. And this thing happened about 16 volts, did it?

A. Which thing?

XQ. 138. This phenomenon you have mentioned, the reappearance of blue glow?

A. The thing I remember clearly is that I suddenly changed the potential by 12 volts. Now, if I changed it by more than 12 volts, the same thing would have happened. If I changed it at only four volts I doubt very much whether the blue glow would have appeared.

XQ. 139. And when you get it into this condition by putting this plus—was the tube or not back in stage one, as a practical matter?

A. If the blue glow appeared, or when the blue glow appeared, the current from cathode to anode went up and the current was limited by the filament temperature, yes, so that I should say it had all the characteristics present in stage one.

XQ. 140. Now, in this stage three, the distribution of potential around the cathode is what? That is, you had a very heavy accelerating field around the cathode in stage one?

A. Yes.

XQ. 141. What did you have in stage three?

A. There is still quite an accelerating potential in stage 3. It is not as intense as in stage 1, since it is not so concentrated, but the biggest part of the potential drop is still at the cathode.

XQ. 142. Then why does not the tube saturate immediately?

A. Have you finished your question?

XQ. 143. Yes.

A. Why does not the tube saturate immediately?

XQ. 144. Yes.

A. Do you mean by that why is not the current limited by the filament temperature?

XQ. 145. Yes.

A. Because it is limited by space charge.

XQ. 146. But you have an accelerating field tending to pull these electrons out, and why don't they come out?

A. I beg your pardon, Mr. Davis. When the current is limited by space charge, right at the cathode, right at the very surface of the cathode——

XQ. 147. That is what I was inquiring about.

A. There the field is very small and probably is in the negative direction; that is, it tends to drive electrons back into the filament right at the cathode. By that I mean something like one-hundredth of a centimeter or perhaps even less. Then as soon as you get outside of that region—and that was what I was referring to before—my statement is correct; only I want to modify it to take account of what you evidently had in mind.

XQ. 148. I was thinking of the space immediately surrounding the cathode, Doctor, and there you have a retarding field rather than an accelerating?

A. That is defining "immediately" to be something of the order of one-hundredths or thousandths of a centimeter.

XQ. 149. Well, I was thinking perhaps inaccurately, but to the best of the ability I had, of this same space which in the experiment No. 1 was a strong accelerating field, which I think you said was something less than a millimeter. Now, this same space, or part of it at least, has become the retarding field, when you change conditions to those of No. 3?

A. That is, that part which is very close to the cathode, yes, but a considerable part of that, the remainder of it, still has quite an accelerating field.

XQ. 150. How do the electrons get through this retarding field?

A. Chiefly because of initial velocity due to the fact that the filament is at a high temperature.

XQ. 151. So it is only the more energetic and active ones that manage to get through, is that it?

A. Yes, but remember these retarding fields you are now speaking of are very small. They are fractions of a volt.

XQ. 152. So are the initial velocities, are they not?

A. The initial velocities are also small, so that the things are comparable. They do not need very much energy to overcome the opposing field.

XQ. 153. Now, let us imagine an electron which is active enough to get through this field. What does it do?

A. After it passes through the opposing field, it enters the accelerating field and is accelerated, and moves faster and faster. It does what any body subjected to force does.

XQ. 154. I was thinking of the shape of the path, Doctor. I think you told us that in the first stage, the No. 1 phenomena, the electrons when they got through this space, this dark space, shot out normally into straight lines?

A. I said a little more than that.

XQ. 155. What did you say?

A. I said a little more than that.

XQ. 156. Well, you said that much; you said also that they might hit something; but I mean until they hit something, you gave us the impression they shot out into straight lines?

A. Or until they came to a region where they were subjected to other forces.

XQ. 157. I quite agree, Doctor, you said that very carefully, but I was trying to shorten it, that is all.

A. All right.

XQ. 158. In this third stage, do they shoot out in straight lines after they get through this first field?

A. It depends. If they are not subjected to forces which are perpendicular to the direction of motion, they keep right on moving in a straight line; but when they get to a region where those forces are not in the direction of motion, then they change their path.

XQ. 159. Let us think of an electron which is active enough to get through this first space, and which is going to form part of the current that flows across the tube, which I suppose means it is going to get to the anode. What is the typical path of such an electron?

A. About the simplest way to say it, is the typical path is a curved path.

XQ. 160. What kind of a curve?

A. It depends on so many different things. I can say one path is a spiral, a sort of spiral.

XQ. 161. A sort of spiral around the anode?

A. I would not say that that was necessarily always so.

XQ. 162. Oh, no, but the typical case?

A, It depends on the gas pressure to some extent, if it hits a gas molecule and ionizes it, its velocity is considerably decreased, and perhaps brought to a very small value, and then it starts to follow the lines of force from there on, and its chance of hitting the anode is somewhat greater.

XQ. 163. But it is a matter of chance hitting the anode first time, is it not?

A. At the first time, I think so.

XQ. 164. And if it misses the anode the first time, what would it do?

A. That depends on circumstances again. It depends on just what region of this third stage you are talking about.

XQ. 165. It is something like a comet coming into the solar system, is it not?

A. Well, if you do not stress the "something like," too much, I will agree with you.

XQ. 166. That comet may be trapped and rotate in an orbit around the sun, may it not?

A. Not unless its energy is changed.

XQ. 167. That may well happen, may it not?

A. It may or may not. I would not say. It may well happen if it hits something or there are resisting forces which decrease the energy. As a matter of fact, most comets, I think come in and go out, and I think it is a rather rare occasion——

XQ. 168. They go back, don't they?

A. Some do and some don't. Those that do, already have lost some of their original energy, and unless they lose their energy, they keep on going.

XQ. 169. And most comets do not hit the sun?

A. I am not well versed enough in cosmology to say whether they do or do not.

XQ. 170. Most electrons do not hit the anode the first time?

A. Most of those that start from the cathode?

XQ. 171. Yes.

A. I do not think so.

XQ. 172. I do not think the answer is quite clear. Do you mean you agree or disagree?

A. I am inclined to agree with you. I have not analyzed that. I have not thought of that specific question before.

XQ. 173. And those that do not hit the anode the first time will either be thrown out of the field of the anode, or will circulate around the anode in some sort of complex way; is not that right?

A. They will certainly not circulate indefinitely.

XQ. 174. No, but for a while?

A. For a while, yes.

XQ. 175. And ultimately they will fall into the anode, will they?

A. Some will and some won't.

XQ. 176. So that there will be a pretty strong field around that anode, won't there?

A. Will you read that? (Question repeated as recorded.) I do not see how you can draw that conclusion from what has gone before. If you ask me whether there is or not, that is a different matter.

XQ. 177. I will ask you whether there is, Doctor?

A. Yes, there is a field and a strong field, and especially—that depends on the shape of the anode—if it is in the form of a filament, there will a strong field. There again, it depends on circumstances.

XQ. 178. We are talking about a typical case, Doctor, of course, I understand.

A. There are so many typical cases. If you have a high vacuum, such that, there are no ion effects, and if your anode is in the form of a filament, there is a high potential gradient in the neighborhood of the anode.

XQ. 179. There is quite a high potential in the neighborhood of the anode in what you call the third stage, is there not?

A. Certainly in a high vacuum stage, and very likely also throughout the whole stage.

XQ. 180. Now, these electrons coming out of the cathode which describe these paths, which we have been trying to analyze a little, start out rather slowly, don't they, as compared, for instance, to the way they come out of the cathode space in the first stage?

A. If you mean that when they are at a distance of one millimeter from the cathode, their velocity is smaller than it was in the first stage, then I would say yes; but that velocity is not so terribly small, even when they are only one millimeter away.

XQ. 181. In the first stage, when they are one millimeter away from the cathode, they had a velocity corresponding to a very substantial fraction of the voltage across the tube, don't they?

A. Yes.

XQ. 182. In this third stage, they have no such velocity as that, have they?

A. I would say they had quite a substantial, yes. When they are one millimeter away, my estimate would be that they would have perhaps one-quarter of the velocity corresponding to the total drop.

XQ. 183. They have been through a retarding field?

A. Yes, but that retarding field, as I said before, is present only in a small region very close to the filament, and beyond that you soon get into an accelerating field and——

XQ. 184. But you are going to get a quarter of the whole voltage on the tube in a millimeter?

A. Without further calculations, yes, I think that is quite right.

XQ. 185. In spite of the fact you have a good deal of a drop around the anode?

A. Remember, I did not say that you had a very large part of the total drop around the anode. You have a considerable, as most of the drop is still concentrated in the neighborhood of the two filaments.

XQ. 186. In your answer to Q. 10, Doctor, you said on page 1795, that with a very special structure of tube, it might be possible to have the walls of the tube become negative immediately after the drop, corresponding to the second stage. Please tell me what kind of structure you had in mind when you referred to this special structure?

A. Could I see that, please?

XQ. 187. Surely (handing volume of testimony).

A. Did you say page 1795? I do not see that particular reference on that page, Mr. Davis.

XQ. 188. Perhaps you can find the place better than I can, Doctor.

A. I would rather prefer to put it the way I did, exactly in the exact way I put it, if you do not mind.

XQ. 189. Please do. I may have summarized it wrong.

A. What I actually said on page 1796 was:

> "If you modify the type of structure sufficient to bring out just certain points, I would not dare say that it was impossible to have the wall negative immediately after the drop, but from my experience I should say that one would have to take a very special structure to do that. And in general the walls are positive, slightly positive, immediately after the drop, and they do not become negative until the pressure is decreased considerably. But the most important thing I think is that just before and just after the occurrence of the sudden drop, the wall potentials undergo a sudden change."

I do not think when I said that, I had any special one in mind. I just wanted to make clear that the general thing was that the walls were positive immediately after the drop.

XQ. 190. Now, on the next page 1796, in answer to Q. 11a, you said something about reducing the current or the pressure rather by a factor of 8 or 10, or it might be 5, in the particular type of structure, and the current being two or three times lower than the value in stage 3, if I understood you correctly, Doctor?

A. What is your question, Mr. Davis?

XQ. 191. Whether I understood you correctly, that is all.

A. I think the best thing if you want me to, is to repeat substantially what I said then.

XQ. 192. I do not want to trouble you to do that. Did you speak of this reduction of potential as being necessary to transform the conditions of stage three into a condition of pure electron discharge, in which the positive ions were playing a non-substantial part, did you not?

A. What I said was that immediately after the drop, the currents had a certain value; that if you then changed the pressure by a factor of, let us say, 8, the value of the current would then decrease to one-half or one-third the value that it had soon after the drop.

XQ. 193. You distinguish, at least I understood you to distinguish, between the conditions in stage 3, which you define as a condition in which the current is limited by space charge, substantially affected by ionization, and the condition which would arise if you had this still higher vacuum, which I understood you to say was the condition where the current was limited by space charge, not substantially affected by ionization; is that true?

A. That is the general characterization of stage 3. The current is limited by space charge, but this space charge may be a mixed space charge, and it is only when the pressure has been decreased considerably, that you arrive at the place where the space charge is substantially unaffected by positive ionization.

XQ. 194. What do you mean by "space charge substantially unaffected by positive ionization"?

A. I mean that the space charge is a pure electron space charge in the sense that the number of positive ions which are inevitably present—unless you have a perfect vacuum, which it is impossible to get—that these positive ions play an unsubstantial part; their number is so small that they do not affect substantially the current flow.

XQ. 195. It is the effect rather than the number you are interested in, is it not?

A. Well, I think what I said, speaks for itself.

XQ. 196. Now, if you have a tube containing gas and pass current through it, you get light, a glow in the tube there frequently, don't you?

A. Oh, I would like to be more definite, Mr. Davis——

XQ. 197. I am just trying to get at this thing, what we call blue glow. If the gas pressure is pretty heavy, the blue glow is apt to be purple, is it not?

A. It depends on the gas.

XQ. 198. With nitrogen, it is purple. Now, if you reduce the pressure, continuing to pass the current through the tube, that purple turns into a blue, does it not?

A. I do not know that I would say that. That depends on your exact shade.

XQ. 199. It changes color?

A. I do not know that I would even say, that it changes color.

XQ. 200. I see so many references to pale blue haze, and in tubes of a higher current, I see so many references to red and purple haze, I thought there was a tendency to change color?

A. I do not see what difference it makes, whether the exact tint is blue or purple; I think it would depend on the person looking at it, on his judgment.

THE COURT: May we take our recess today at eleven o'clock.

(After a short recess.)

By MR. DAVIS:

XQ. 201. Now, in your testimony on direct you testified about some blue haze that you could not see, for instance, at Q. 24, do you remember that?

A. I remember about it.

XQ. 202. What color was that blue haze?

A. If you could not see it you could not very well say what color it was.

Mr. Davis: That is all, if your Honor please.

Re-Direct Examination.

By Mr. Richmond:

RDQ. 203. If directly after the drop of the current, which you have referred to as the second stage, you had then without changing the pressure, imposed a change on the voltage of the wall so as to bring it down to the voltage corresponding to extreme high vacuum, how would that imposed change on the wall voltage have affected the current at that stage?

A. I think it would have had a grid action effect or I think that action would have been quite small—this is just an estimate—I think it might have made one-tenth the change that actually took place by reducing the pressure to such a stage that the wall potentials came to minus 2.

Mr. Richmond: That is all.

Re-Cross-Examination.

By Mr. Davis:

RXQ. 204. How do you know that?

A. I base my answer on this: I do not think I ever did what Mr. Richmond's question implied, but I did this, after the pressure was reduced and after the wall had come to a slightly negative potential with respect to the negative end of the filament, I then applied purposely more negative potentials and as I remember it I applied negative potentials fully as great as the difference between the wall potential at the initial part of stage 3, that is, the beginning of stage 3, and the wall potential at the end of stage 3 in the high vacuum, and found that changing the wall by that amount produced changes in the discharge current; that is, this grid action effect was much smaller than the pressure change effect.

Mr. Davis: Thank you, Doctor. That is all.

(Witness excused.)

IRVING LANGMUIR.

Irving Langmuir was called as a witness on behalf of the defendant in sur-rebuttal, and having been previously sworn, testifies as follows:

The Court: He is made your witness for the purpose of sur-rebuttal then?

Mr. Haight: Yes.

Direct Examination.

By **Mr. Haight:**

Q. 1. Dr. Langmuir, I show you what purports to be a certified copy of a petition to the Commissioner of Patents, purporting to have been signed by you, and the accompanying specification and claims and drawings, which eventuated in a patent to you known as No. 1,558,437, and ask you if you recognize your signature to these papers?

Mr. Davis: May I ask, if your Honor please, to reserve objection until we see whether it is sur-rebuttal?

A. I recognize my signature to these papers which you have put before me.

Mr. Haight: I have not offered them.

Mr. Davis: I reserve objection until I know what it is.

The Witness: I recognize my signature to these papers which you have just shown me.

Mr. Haight: I offer the petition, specification, claims and oath and drawing in evidence, the same being dated October 27, 1913.

Mr. Davis: I object if your Honor please. I have not been shown it is sur-rebuttal.

The Court: To meet what, Judge Haight?

Mr. Haight: The purpose of it will be shown in just a moment.

Mr. Davis: I reserve my objection.

By Mr. Haight:

Q. 2. And Mr. Davis was your attorney in the prosecution of that application, was he not; it seems, to have been signed by him?

A. Yes.

Mr. Haight: This standing alone, of course, shows nothing; but I offer also in evidence a certified copy of a communication to the Commissioner of Patents, signed by Mr. Davis as attorney for Dr. Langmuir and dated November 27, 1915. The purpose of the two papers is this: Your Honor will recall that while Mr. Colpitts was on the stand there was exhibited to him a patent which had been granted to him and the claims in which referred to an "ionized stream," I think that was the expression that was used. The patent was one of those patents that was in the Interference record. The purpose of this offer is to show that Dr. Langmuir in an application for a patent for a device, which he states "consists essentially of an electron emitting cathode and one or more anodes thoroughly freed from gas, located in an envelop evacuated to such a high degree that an electron discharge can take place . . . without causing appreciable gas ionization by collision with residual gas molecules."

The purpose is to show that on November 27, 1915, he asked the Commissioner of Patents to declare an Interference between this application and the Colpitts patent to which I have referred, and copied into his application the claims of the Colpitts patent.

The Court: Then the Colpitts patent was put in evidence by the plaintiff?

Mr. Haight: Yes, sir.

The Court: And this is to meet the Colpitts patent?

Mr. Haight: To meet any inference that may be drawn by the plaintiff from the Colpitts patent.

The Court: In so far as this would serve that purpose?

Mr. Haight: Yes, sir.

Mr. Davis: I object to this on its face as immaterial, for this reason, and if necessary, I will call a witness to prove the practice of the Patent Office in that respect, but I do not think it is necessary. It seems to me it is apparent on its face. A man is issued a patent in this case, Mr. Colpitts, containing claims in a certain form, the form may be very bad and objectionable, but there they are. The only way in which an Interference can be had with a patent containing that claim, so far as that claim is concerned, is by copying the claim.

The Court: Does not that go to the weight?

Mr. Davis: I think not; I think it goes to the materiality. I suggest that for your Honor's consideration, it is a perfectly automatic thing. Here is a man who gets a patent, and I do not care what language he uses, if you want the Interference you must copy the claim in those words and every comma must be there, and any suggestion of the General Electric or Dr. Langmuir that they were doing anything by copying the language of these Colpitts claims is perfectly ridiculous, and nobody would think otherwise. If, for instance, he knew the Patent Office practice, and I am prepared to call an expert on the Patent Office practice, if necessary.

The Court: I will hear you, Judge Haight.

Mr. Haight: Mr. Ballard tells me that Mr. Davis is possibly in error in his idea of the Patent Office practice, but I do not think that makes any difference. The point is that in a patent or an application for a patent——

The Court: I have your point, and I think Mr. Davis' objection goes probably to weight, and whether it reduces the weight to approximately zero or not, is a question that is not determinable now. I think this is admissible, but what weight should be given to it, is another matter, assuming the Patent Office practice to be as stated by Mr. Davis.

Mr. Haight: All right, sir.

(The petition and specification and drawings were received in evidence and marked "Defendant's Exhibit No. 300." *See Volume VI, Defendant's Exhibits, page 1207.*)

(The certified copy of the communication was received in evidence and marked "Defendant's Exhibit No. 301." *See Volume VI, Defendant's Exhibits, page 1228.*)

Mr. Haight: That is all.

Mr. Davis: I think I would like to ask one question in re-direct examination.

By Mr. Davis:

Q. 3. Did you know anything about this letter to the Patent Office in which Mr. Colpitts' claims were copied at the time at which it was written?

A. I have no present recollection of the matter at all.

Mr. Davis: Thank you.

Mr. Richmond: Just a moment, please.

By Mr. Haight:

Q. 4. Do you recall, Doctor, whether or not you executed and swore to a preliminary statement?

A. I have no recollection at all concerning the procedure in connection with this patent.

Mr. Haight: That is all.

(Witness excused.)

(Whereupon at 5.30 P. M. adjournment was taken until Thursday, 11th November, 1926, at 10 o'clock A. M.)

GEORGE E. FOLK.

George E. Folk, was called as a witness in surrebuttal on behalf of the defendants, having been duly sworn, testified as follows:

Direct Examination.

By Mr. Haight:

Q. 1. Mr. Folk, you are the general patent attorney of the American Telephone & Telegraph Company?

A. I am.

Q. 2. You have been connected with the Patent Department of the Telephone Company for how many years?

A. Since 1915.

Q. 3. I show you a letter purporting to have been written by Charles Neave to H. B. Thayer on October 10, 1913, and ask you if you got that from the files of the American Telephone & Telegraph Company?

A. I did.

Q. 4. Who was Mr. Thayer?

A. Mr. Thayer in 1913 was president of the Western Electric Company, if I remember correctly.

Q. 5. And Mr. Neave?

A. Mr. Neave was the patent attorney at that time and did patent work for the Telephone Company and for the Western Electric Company.

Mr. Haight: I offer this letter and the accompanying report in evidence, the purpose of it being to show that at the date of the letter Mr. Neave advised the Telephone Company that Mr. Hewitt was then claiming that the audion came within his patents. Of course, the purpose of this is to show the reason why the Telephone Company exercised the option that the Hewitt agreement gave them——

The Court: One of the reasons for the license.

Mr. Haight: Yes.

Mr. Davis: The only point occurs to me is whether that is in rebuttal of anything.

Mr. Haight: You put in the Hewitt contract.

Mr. Davis: We put that in at our last session?

Mr. Haight: Yes, sir.

Mr. Davis: Then I have no objection.

Mr. Haight: This is the original, and if counsel are agreeable I will have a photostatic copy made and put in the record and have that marked and let them have a copy.

Mr. Davis: I have no objection to the letter.

(Received in evidence and marked "Defendant's Exhibit No. 324." *See Volume VI, Defendant's Exhibits, page 1349.)*

By Mr. Haight:

Q. 6. Do you know whether suit was brought by Hewitt on the agreement with the Telephone Company entered into with him?

A. There was.

Q. 7. And it was a suit for royalties which he claimed to be due from the Telephone Company by virtue of that agreement on account of the Telephone Company's use of the audion?

A. That is right.

Q. 8. And he was defeated in that suit?

A. That is correct.

Q. 9. It appears in the evidence that sometime in the early part of April, 1915, the Telephone officials or some of them at least learned that Dr. Langmuir had filed an application for a patent of the high vacuum audion. And it also appears that it was because of the filing of that patent that the Telephone Company determined to file an application for a patent on the same thing on behalf of Dr. Arnold, and also it appears that Arnold's application was not filed until November, 1915. Can you tell us the reason for the delay in the filing of the Arnold application between the time in April that I have referred to and the time that it was actually filed in November?

A. Perhaps I can do that best by telling the circumstances.

Q. 10. All right.

A. In the latter part of April, 1915, I received a letter from Mr. Thomas D. Lockwood, the general patent attorney of the American Telephone & Telegraph Company stating that a number of important questions had come up concerning the audion and asking me if I could not come on from Chicago where I was then practicing law, and help them out in the solution of the questions that had arisen.

He said the matter was very urgent and asked me if I would not telegraph when I could come. I telegraphed that I would be in New York on May 5th. I was there and met Mr. Lockwood and he explained the situation to me and stated a number of matters in which it was necessary to determine what should be done. One of them was the particular matter that you have referred to, that is the question of the high vacuum audion.

I immediately began investigation in these matters and found that there was so much involved that I advised them that I could not see that there was any particular hurry in filing that application in view of the facts as I understood them and suggested that they had better get someone to take charge of these matters and look into them thoroughly and he could devote his whole time to it.

The upshot of the whole thing was I was asked whether I would not enter the employ of the company and do that thing myself. They made me a proposition on Wednesday, the latter part of May, and I accepted it the next day, and telegraphed my wife that I was coming to New York and be ready to leave the following Monday and I went back to Chicago and was in New York again on the first of June, that is, within a week after the offer had been made to me I was on the job and I had several assistants looking up this matter and a number of others and I came to the conclusion that there was no special hurry about filing the application because we had never abandoned the invention and the only reason that I could see for rushing—I could see no reason for rushing it in the office because I could not see that there had been any statutory prior use of the invention, and there was no concern about it and I was very anxious to take the right step and I felt it was very important that we look into the matter and ascertain just what the facts were, what our company had done and what the prior art was so that I could discover whether there was an invention and if so what it was.

Within four or five months after I came to the company I had determined what should be done and had an application filed.

Meanwhile I had given a very careful consideration of a number of other matters which I considered were more urgent than that.

Q. 11. Will you mention some of these?

A. I made a memorandum of those that occurred to me and I checked them up to see that they did occur during that interval. One of the matters which I took up even before I came to the company on the first of June, that is, during that interval in May, was the Hewitt situation. Hewitt at that time was claiming royalties and it was up to us to determine whether royalties were due him or not and I remember I went into the whole situation very thoroughly during that summer, that was something that had to be taken up at once. If royalties were due to him he should be paid and if not we should tell him that. Within a year he brought suit against the company.

Another thing that was very urgent was the De-Forest-Marconi suit to which some reference has been made in this case. At that time there was a suit pending between the DeForest Company and the Marconi Company. The DeForest Company being sued on the Fleming valve patent and the Marconi Company, I believe, being sued on one of the DeForest patents. We were licensees under the DeForest and our interests were involved. Mr. DeForest was infringing the Fleming valve patent, and what about the Telephone Company, and it was very urgent to determine what we should do and so we looked into that situation.

I finally determined that we could do nothing but let the matter alone, but I did go into it very thoroughly.

Another matter that came up during that summer of 1915, was the Grisinger situation. We were using a repeater circuit that Grisinger claimed. We knew what it was and while there was an interference there were still some claims that bothered us. Finally, within a year after considerable negotiations we settled the matter with Grisinger by paying him a very large sum of money for the rights under his patent.

Another matter that engaged my attention during the summer of 1915 was the oscillating audion situation. I found that our company was developing a carrier current system that involved the feedback oscillating audion, and we did not have any patent application covering that broadly, and we were aware of the fact that there were other pending applications on the matter and I was looking into that to see whom that invention belonged to and what to do about it. I believe that matter is still unsettled.

That gives you some idea of the work I had to do that summer. In addition to the oscillating audion situation we had the whole carrier current patent situation before us and to find out just what patents we might need in order to be free of infringement and I looked that up carefully.

Then another matter that was very urgent and I believe was really the first thing that I did was to file a patent application on a wave filament. We had had an application pending for a number of years on what we considered a very important invention, but it had been finally rejected and abandoned in the Patent Office. There had been publications of this, the time to refile was short and that matter was so urgent that I personally prepared this application and had it filed on July 15, 1915.

The original application did not give the mathematical equations involved and I found considerable difficulty in presenting that because it was a purely mathematical equation, in such a way to have the Patent Office understand it. This we consider one of the most important patents we have taken out in a number of years. That gives you some idea of a few of the things that engaged my attention that summer, and I think you will appreciate that the responsibility of those things turned over on me, was great.

Q. 12. I take it then that you had a very busy summer?

A. Very busy summer.

Q. 13. And you took up this Arnold situation and filed it as soon as you could reasonably get to it?

A. As soon as I could get the information and data that enabled me to do what I considered best.

Q. 14. There has been offered in evidence the file wrapper of a patent No. 1,297,309, issued to Dr. Arnold on or about March 18, 1919, Plaintiff's Exhibit 170. Do the files of the Western Electric Company show how the subject matter of this patent or the question of applying for a patent covering the subject matter of the patent was brought up?

A. They do.

Q. 15. I show you what purports to be a letter written by Mr. Scribner to Mr. Tanner under date of February 10, 1915, enclosing a memorandum from H. D. Arnold, dated February 8, 1915, and ask you if those are papers in your file which show how these matters were brought out?

A. These papers are on file with the Western Electric Company.

Q. 16. And who is Mr. Scribner?

A. He was the chief engineer of the Western Electric Company in 1915.

Q. 17. And who is Mr. Tanner?

A. He was the general patent attorney for the Western Electric Company.

Q. 18. And who is H. D. Arnold?

A. H. D. Arnold is the Arnold who had filed an application for a high vacuum tube in interference with the Langmuir application.

Mr. Haight: I offer this letter of Mr. Scribner's and the enclosed report of Dr. Arnold in evidence, for the purpose of showing how the idea of applying for a patent, the patent in question, initiated and I am going to ask for consent of counsel that photostat copies be put in rather than the original.

Mr. Davis: I have no objection and will consent to the substitution.

(Received in evidence and marked "Defendant's Exhibit No. 325." *See Volume VI, Defendant's Exhibits, page 1358.*)

By Mr. Haight:

Q. 18a. Now, Mr. Folk, it appears that in the prosecution of this patent application the office rejected certain of the claims upon certain patents which had been issued to Dr. Coolidge and it also appears that no effort was made to take the Arnold invention back of the Coolidge filing dates, but that the claims of the Arnold application were amended so as to avoid the Coolidge references. Did you have charge of the prosecution of this application and do you know the circumstances and reason why no effort was made to take the Arnold invention back to Coolidge?

A. I had general responsibility for the prosecution of that application and I do know the reason why the action that was taken was taken.

Q. 19. Without asking you to quote from the correspondence on file I will ask you to look at the file if you need it to refresh your recollection and just state the circumstances and I will make the file available to the other side.

A. After the Arnold application had been filed for about a year, my attention was called to the fact that a Coolidge patent had been issued containing claims which might be made in the Arnold application. That means that although the two cases had been pending contemporaneously in the Patent Office, the Patent Office had inadvertently issued a patent to Coolidge without declaring an interference as should have been done.

The question was up to us as to what we should do and I had a report made on the patent in order that I might get the facts to enable me to reach a conclusion as to just what we should do.

I find a report in my files as dated December 8, 1916, signed by P. I. Wold that discussed the various claims of the Coolidge patent, stating that these claims describe substantially what Arnold had done broadly and that the broadest of the claims, Claims 25 to 28, might be made in the Arnold application, but that in view of the prior art mentioned in this report in the writer's opinion the claims were not patentable and the interference should not be sought for something which he considered was unpatentable.

I reached that conclusion myself after investigating it and determined that we should simply ignore that patent instead of asking for an interference on a claim which in our view was clearly unpatentable.

In other words, although we were convinced that we could antedate the filing date of Coolidge without any difficulty, that it would be unnecessary and unwise to do that in view of the situation as thus stated.

Q. 20. Just to make that clear, in view of the fact that the Coolidge patent had issued and an interference had not been declared, what would have been the effect so far as you are concerned, if you had gone into interference with the Coolidge patent and had prevailed?

A. We would be getting the patent for claims that we did not consider should be allowed to anybody.

Q. 21. If you had gotten that patent?

A. Then we would, if we wanted to, we might have brought suit under 4918 for the cancellation of the Coolidge patent, but I did not consider the matter of sufficient importance to waste our time and energy in fighting something that we decided we should ignore.

THE COURT: What was the Coolidge patent for?

MR. HAIGHT: It was this bombardment.

MR. RICHMOND: It was the Coolidge X-ray tube.

THE WITNESS: It was the Coolidge Patent No. 1,120,349 of October 31, 1916.

MR. HAIGHT: There were three of them mentioned—cited, but one of them is the Coolidge X-ray patent.

MR. DAVIS: There were some claims of clean-up in the Coolidge X-ray tube patent.

A. (Continued.) My attention was next called to this matter some time later by a letter from Mr. Tanner the general patent attorney of the Western Electric Company, asking for my advice as to what should be done after the Coolidge patent had been cited for a reference. This was some two years after the original investigation. Mr. Tanner says: "Attached is a copy of a memorandum from Mr. Beatty," and asking for my advice as to what we should do under the circumstances.

By MR. HAIGHT:

Q. 22. Who was Mr. Beatty?

A. He was the young man who had the actual charge of the prosecution of the Arnold application.

Q. 23. In the Patent Department of the Western Electric Company?

A. Yes. Mr. Tanner undoubtedly sent that to me on this date because in Mr. Beatty's memorandum was a statement that he was informed by one of my assistants, Mr. Rose, that the question of the interference between the Arnold application and the Coolidge patent had already been given consideration by me and I wrote to Mr. Tanner telling him that that was a fact and since the claim seemed to be unpatentable, advising that we not make them, but that we cancel all the claims except those that we consider as clearly patentable over the prior art, not merely the Coolidge patent, but the prior art in general.

Q. 24. Then am I correct in understanding that the reason why no effort was made after the Coolidge patents were cited against the Arnold applications, to take the Arnold date of invention back of the Coolidge filing date, was because you considered that the claims of the Coolidge patent, which conflicted with the Arnold claims were unpatentable?

A. Yes, absolutely. The records bear that out.

Mr. Haight: You may cross-examine.

Mr. Davis: I understand that if plaintiff desires any of these papers this file will be offered.

Mr. Haight: Yes.

Mr. Davis: And that I may postpone that decision until I have a chance to look them over.

Mr. Haight: Yes.

Cross-Examination.

By Mr. Davis:

XQ. 25. You spoke, Mr. Folk, of a suit which Dr. Hewitt brought against the telephone company to collect royalties which he claimed were due him under the license agreement?

A. Yes.

XQ. 26. The articles which you had made with respect to which that claim was made by Dr. Hewitt, were these three-electrode repeater tubes which you used in your telephone circuits?

A. That is correct.

XQ. 27. And those were the tubes of the type described in the Arnold application which was involved in the interference with Dr. Langmuir?

A. That is correct.

XQ. 28. And that suit was Hewitt against the American Telephone & Telegraph Company, Judge Mayer's decision, in 272 Federal Reporter, 1914?

A. That is correct.

XQ. 29. The Court of Appeals decision is in the same volume at page 392. It was written by Judge Hough?

A. Yes.

XQ. 30. The situation in this suit was that the only question which could be debated was the question of infringement, was it not?

A. It was hardly the question of infringement.

XQ. 31. The question was whether the claims of the Hewitt patent properly construed covered the device which you used?

A. That is correct.

XQ. 32. You had admitted the validity of the patent substantially by taking the license?

A. We never denied the validity of it. We questioned whether it covered the high vacuum device.

XQ. 33. And the Hewitt device was a mercury device?

A. That is correct.

XQ. 34. And therefore a device operating at relatively high gas pressures?

A. Yes, except that Hewitt was contending at that time and had contended at that time his invention was based on and covered a high vacuum or low vacuum or any kind of vacuum, any means of getting electrons from the cathode to the anode.

By Mr. Davis:

XQ. 35. And that was the real contention of the suit, was it not?

A. That was practically the contention.

XQ. 36. And you defended that suit on the ground that these devices which you are saying operated on entirely different principles to Dr. Hewitt's device?

A. That was correct.

XQ. 37. Because your devices had a very high vacuum, and were independent of the presence of gas in the tube?

A. That is correct.

XQ. 38. Do you remember the summary which Judge Mayer made of the contentions from the brief of Defendant's counsel which he accepted, on page 199 of the Federal Reporter (handing book)?

A. I find that there is such a summary.

XQ. 39-40. Judge Mayer says:

> "On the point that this minute amount of gas does not take any part in the operation of defendant's devices, I accept the summary of facts in the brief of defendant's counsel.
>
> "(1) The pressure does not rise when the device is heated as it would if an appreciable amount of gas were present.
>
> "(2) No appreciable amount of current flows between filament and grid and such current would flow if gas or vapor took any part in the operation of the device. There is a small leakage current there, amounting between filament and plate, but it is ineffective for any purpose and does not figure in the operation.
>
> "(3) The device works no differently, if even less gas or vapor is present; it is merely useless and uneconomical to reduce the pressure to a lower point.

"(4) The space inside of the defendant's tubes does not glow, as it would if gas were taking part in the operation.

"(5) During operation, the temperature of defendant's filament does not change as it would if appreciable gas were present.

"(6) If, during operation, the temperature of the filament is intentionally increased, the current blow between filament and plate is not altered as it would be if gas took part in the operation of the device.

"(7) If gas or mercury is introduced into the defendant's tube while the device is operating, the usefulness of the tube is ended, as its amplifying qualities were destroyed."

Was that a substantially correct summary of the position taken by your company in that suit?

A. I do not recall; I dare say it is. I know I never questioned that summary.

XQ. 41. You did not question the summary?

A. No, I do not question that summary. I do not pose as an expert on that subject matter; I simply accepted that Court's view of the testimony.

XQ. 42. And you were in touch with the suit, of course?

A. I was.

XQ. 43. Do you remember that when this so-called Langmuir Interference was argued before the Examiner of Interferences in the Patent Office, that you took part?

A. On the question of priority, yes.

XQ. 44. And at the beginning of your argument, near the beginning of your argument, you very frankly stated that you were going a little outside of the record and then proceeded to say something about these matters, about which you have testified this morning. I will read from the record as I have it here.

MR. HAIGHT: I would rather you show it to him.

XQ. 44a. Have you any doubt that this is the record of the argument, Mr. Folk?

A. I remember something of that kind. I dare say that is a correct report of what I said.

XQ. 45. Then you said, did you not——

MR. HAIGHT: What is that?

XQ. 46. You said, did you not, in that argument: "When the Telephone Company in April, 1913, heard of this claim of the General Electric Company"——

THE WITNESS: 1913?

XQ. 47. "1915." I beg your pardon.

> "When the Telephone Company in April, 1915, heard of this claim of the General Electric Company, claiming that it made a higher vacuum tube, the record refers to the fact that the company realized that they had that tube in commercial operation in the trans-continental lines, and in other commercial circuits, it never occurred to them that this was not their development work, and when they understood the General Electric Company was claiming that which might be work resulting from their laboratory work, they naturally became excited.
>
> "I was practicing law in Chicago at that time and got a very urgent telegram to come to New York. That was responsible for my giving up my business in Chicago, and I never worked so hard in my life as I did to get this application filed, and I filed it as quickly as I could."

Is that a correct report?

A. It is substantially correct. I find the telegram was the other way. The request was that I myself telegraph, and I did so. What I got was a letter, was a request, that I should send a telegram.

MR. DAVIS: That closes the cross-examination subject to these papers we have not had time to locate.

RE-DIRECT EXAMINATION.

By MR. HAIGHT:

RDQ. 48. At the time you were arguing this matter in the Patent Office, did you make a thorough examination of your records and files, and whatnot, as you did preparatory to testifying here?

A. I did not. I did not expect to say a word only I possibly felt that some unfair things had been said about Dr. Arnold and in the heat of the moment, I got up and made that reply.

RDQ. 49. I presume there was firmly fixed in your mind the idea of working very hard in New York in the hot summer months, and you did not attempt to differentiate whether you worked on Hewitt against the Telephone Company or Arnold vs. Langmuir?

A. I was working on all of them. I might say I was keeping them all going.

MR. HAIGHT: That is all. Now, Dr. Arnold.

HAROLD D. ARNOLD.

HAROLD D. ARNOLD, was recalled as a witness on behalf of the defendants:

DIRECT EXAMINATION.

By MR. HAIGHT:

Q. 1. Doctor, referring to your notebook about which you were cross-examined, I notice that from June 3, 1912, to October 2d, and including October 28, 1912, there were only seven entries, and those entries covered pages 134 to 136; is that correct?

A. That is correct.

Q. 2. Will you just give us the dates of the various entries in that period of time?

A. The dates are June 3d, June 6th, August 15th, August 23d, August 24th, August 26th, October 28th.

Q. 3. Now then, am I correct in stating that from October 28th, 1912, on to January 2d, 1917, nearly five years, there were in that book only ten entries?

A. I count eleven, but perhaps I am mistaken in my count. Just a moment. Unless I am mistaken in my count, there are twelve entries, but perhaps I had better give the dates; then it will appear how many there are.

Q. 4. Please give the dates.

A. December 23, 1912; February 3, 1913; May 1, 1913; November 29, 1913; March 4, 1914; March 7, 1914; May 21, 1915; September 1, 1915; September 2, 1915; November 1, 1915; December 7, 1915; January 2, 1917.

Q. 5. You are right; there are twelve. I had left out two that I apparently had lost. Now, those entries cover from pages 137 to 148 inclusive; is that right?

A. That is correct.

Q. 6. I notice that one of these entries, that of December 7, 1915, reads as follows: "Whole month has been consumed in planning winter's work and in fussing about patents." Is that correct?

A. That is correct.

Q. 7. I notice that some of the other pages refer to various scientific formulæ, and other drawings upon them; is that correct?

A. That is correct.

Q. 8. Now, you did not seem to be very regular in the entries that you made in this book from June of 1912, and the subjects which you selected for entry were not governed by any particular standard, is that correct?

A. That is correct.

Q. 9. Will you please tell us what your method was of making entries in the notebook; I mean by that, what kind of entries did you make; did you have any fixed plan, or what?

A. No. There is no plan of entries used in our keeping of notebooks in our laboratory. The books are furnished to the members of the laboratory, in order, if possible, to avoid their using loose sheets of paper for taking data, which loose sheets of paper might be lost; but there is no requirement whatever as to how entries shall be made, or when entries shall be made, or what type of entries shall be made; that is, it is entirely at the discretion of the person who is using the book, and in many cases—and I think this is rather common practice—whenever I personally took the observations of instruments, and had my own book handy, I would write those down. That relates to the early part of my work when I was working in direct experimentation; but aside from that, there was no regularity whatever in my method of keeping my book.

Q. 10. I notice that before August, 1912, there seems to be entered in the book a great many readings and things of that kind; is that so, and that after that time there were very few, if any?

A. Yes, sir. My book up until October 28, 1912, and that comprises 136 pages, out of the 148 that have records on them—was devoted almost exclusively to the record of my own observations in connection with the mercury arc work, or other minor problems I might be engaged upon. As I have already testified, I think, on October 28th, or between October 28 and November first, the type of my employment changed in this respect; that whereas I had been working with the mercury arc at the laboratory bench, and making observations myself prior to November first, that on November first my duties were broadened by the addition of other problems, specifically the problem of the development of the high vacuum audion, and by the addition of other employees; so that from that time on, I personally did very little work at the laboratory bench myself, and that was largely, I presume, the reason that from then on, there were so very few entries in my book.

Q. 11. Now, I do not know whether you testified as to exactly what Mr. Nicolson's duties were or not. If you did not, will you please state them in a general way?

A. Mr. Nicolson, who came with us in November, 1912, had assigned to him the general problem of developing the process of making Wehnelt oxide filaments. His work on that subject was interrupted by the necessity of his taking observations on the Von Lieben-Reisz-Strauss repeater during the early part of 1913, but from then on during the year 1913, his orders were to do the best he could to develop the process of the manufacture of the Wehnelt oxide filaments, and that was the only problem that was assigned to him during the year 1913 and 1914.

Q. 12. Did you direct the details of his work in that respect?

A. Not at all.

Q. 13. Did you acquaint yourself with the details of his work?

A. From time to time. Mr. Nicolson would tell me of interesting things that he had discovered. Occasionally he would ask me to go into his laboratory room to see things that he thought might interest me, and from time to time I would drop into the room, quite uninvited, in the course of inspection of the laboratory.

Q. 14. Did you instruct him to interest himself in the construction of audions other than the filaments; did you instruct him to study the methods of pumping audions, or preparing them to hold their vacuum?

A. No. That was quite out of his field. If he did any such work, it was entirely on his own volition.

Q. 15. Now, referring to the entries and notebooks of those working under you, were those entries brought to your attention with any regularity or in accordance with any settled system or practice?

A. Not at all. It is very rare indeed for a supervisor to see any entries in an employee's notebook. The book is kept entirely for the employee's own personal convenience.

Q. 16. Dr. Arnold, Dr. Langmuir has testified in this case in reference to a conversation that he had with you at a meeting of the Physical Society, held at Columbia University on October 13th, and has recited that conversation as follows:

> "A. There was considerable discussion after the meeting, mostly by Dr. Arnold. He pointed out to me——"

THE COURT: On what?

MR. HAIGHT: On the record, page 1235.

THE COURT: I am wondering whether you could give the number of the question, so that it can be identified in the printed record as well.

MR. HAIGHT: In answer to Q. No. 198.

Q. 17. I will now read it:

> "A. There was considerable discussion after the meeting, mostly by Dr. Arnold. He pointed out to me that the 3/2 power law had been previously published by Child in 1911, and that was for the case of parallel plane electrodes. In my paper I had also given the derivation of electrodes in the form of a wire as the center in the axis of a cylinder. Dr. Arnold also stated that he felt that it was very doubtful if I had really obtained currents of such voltages as I had spoken of, 250 volts, that were free from blue glow and ioniza-

> tion effects. After the meeting, I had a longer talk with Dr. Arnold, and he told me that they had been working on electric discharges in evacuated tubes from hot cathodes and had used the Wehnelt cathode, and said that they were particularly interested in low voltages, much lower voltages than those I had been talking about. I think that he spoke of voltages of 20 to 30 volts as being the voltages that he intended to use in operation."

Does his recital of that conversation correspond with your recollection of it?

A. No. A part of his recollection corresponds with mine but a part of it is quite different.

Q. 18. Please state the part that corresponds with your recollection and state wherein your recollection differs from his?

A. I remember distinctly speaking after Dr. Langmuir had completed his talk, as is customarily done in the meetings of the American Physical Society, by those who desire to comment upon the speaker's words, and in my comments I said that Lilienfeld had obtained the 3/2 power law experimentally and that Child had derived the 3/2 power law mathematically and also remarked that I had worked it out myself prior to the time I had found Child's work. To that extent my recollection is I think in line with Dr. Langmuir's recollection of the matter.

The difference between our recollections as to what I said immediately after the completion of his talk is as to my doubt of his having obtained a discharge free of blue haze at 250 volts. I remember quite well what I intended to say, although, of course, I cannot remember the words that I used and what I intended to say, and what I think I did convey was this, that if one is looking for blue haze in a tube that is brilliantly lighted with a tungsten filament, then he is apt to be misled by the brilliance of the filament into thinking there is no blue haze when there may be blue haze; that this had been very distinctly brought home to me in my work where I had been using Wehnelt oxide filaments which are very dull and so did not conceal the blue haze much and even with those I had found that if I covered my head and the tube with a black cloth, as a photographer does when he is preparing to take a picture, that then blue haze would sometimes become apparent, that had not been apparent in open daylight.

I had intended to offer a word of warning to those who might be experimenting with brightly lighted tungsten filament, but I did not doubt at that time or had no reason to doubt that Dr. Langmuir had gotten discharges at 250 volts free of blue haze.

Even if I had doubted it I think I should not have mentioned it in my comments on his paper, but I certainly did not doubt it because I myself had had such discharges in the laboratory during the preceding months and was quite familiar with the discharges up to 200 volts or more in which there was no blue haze present even if the utmost precautions were taken to see it.

So on that point I think that Dr. Langmuir has either not remembered what I said at the time or had placed a construction upon it that was quite foreign to what I had in mind.

Q. 19. Did you tell him that you and the Telephone Company had intended to use twenty and thirty volts in operation?

A. No, I could not have told him that. After the formal part of the meeting was over, Dr. Langmuir came to me and asked for the reference to Child's paper and we had a few moments' conversation. I cannot recall what we talked about at that time now, but I could not have told him that we were planning to use voltages of the order of twenty or thirty volts on the plate circuit for vacuum tubes.

Q. 20. Why?

A. Because at that time our plans were all made for using higher voltages than that. We were using higher voltages than that and we were starting to engineer our equipment on the basis of 120 volts on the plate circuit, that being one of the voltages available in the telephone plant.

Whatever misunderstanding there is about this may possibly have arisen from the fact that we were using, as we now are, too, the twenty-four volts storage battery service of the telephone office for the filament current in our vacuum tubes and I can think of no other way in which such a voltage as twenty-four or twenty to thirty volts could have been mentioned except in that connection.

Q. 21. There has been a lot of talk in this case about blue haze and it has occurred to us that it might be interesting to his Honor to see blue haze in a tube and to point out the difference between the visibility of blue haze in a tube employing a tungsten filament and one employing a Wehnelt oxide filament. Are you prepared to demonstrate blue haze and the differences of which I have spoken?

A. I have a tube prepared for that purpose and if we have no misfortune in making the demonstration, I think that can be done very quickly.

Mr. Haight: Would your Honor like to see it?

The Court: How long does it take?

The Witness: About five minutes.

The Court: If it can be demonstrated in five minutes then we can do it now or at two o'clock, because I have an engagement. Suppose you do it at two o'clock.

AFTER RECESS.

MR. HAIGHT: Dr. Arnold is going to make the demonstration for the Court.

By **MR. HAIGHT:**

Q. 22. The last question was with respect to the demonstration and you stated you were prepared to make it. Will you please do so?

A. The tube is on the side table and I think we may go to the table.

THE COURT: All exhibits which have been offered and admitted but which have not actually been delivered to the clerk are to be delivered to him not later than the twenty-second day of the present month.

(Here the demonstration was made and the following took place.)

THE WITNESS: The tube which I have here is equipped with two filaments, one of them is a Wehnelt oxide filament of our standard type of the size that we use, set into the tubes, and the other filament is a tungsten filament of about 3/1000 of an inch diameter. The currents which are to be supplied to those filaments are those which would normally be used in operation giving the Wehnelt oxide filament a temperature of between a thousand and eleven hundred degrees K. and the tungsten filament has a temperature of about 2500 degrees K. This tungsten filament is of course operated as a tungsten filament and not as a thoriated tungsten filament. If it were operated as a thoriated tungsten filament, the temperature of operation would be somewhat lower.

The tube is also provided with a plate to which the electrons may be drawn and the tube is evacuated to a pressure of about eight microns of argon gas. Argon is used in order that the blue haze may not change its character too rapidly during the demonstration and is particularly good for this purpose because the color of the haze in argon is rather similar to that obtained in nitrogen which is the normal residue of an exhaust from air.

Now, we will apply to the Wehnelt oxide filament its normal current and the tube is so arranged that the wires can be rather easily short-circuited so that we better not touch the tube very much. This gives an idea of the brightness to which the Wehnelt oxide filament is normally operated. In fact, this is somewhat brighter than the filament that we use in the telephone plant at present.

Now, we will apply between the negative terminal of this filament and the plate a voltage of about sixty-six volts and the tube shows blue haze of a color that is quite customarily seen in exhaust process and of a magnitude that is quite customarily seen.

I want to make quite clear that it is much easier to see blue haze under these conditions than it is with a bright tungsten filament.

We will now light the tungsten filament with its normal current and it is better not to look too fixedly at the filament.

By The Court:

Q. 23. There is no blue haze there now?

A. No blue haze at present. The filament is lighted. We will now apply to the plate the same voltage that we had in the previous case and there is blue haze in the tube. It will be difficult to see it. In fact you would have to very carefully shield your eyes and look past the edges of the plate to see it. We can make it more apparent by increasing the temperature of the filament slightly which will increase the electron emission and thereby increase the blue haze.

Can you touch the connection on and off and see if we cannot discover a little flash of blue haze in there?

Q. 24. Is there as much blue haze in there now, in fact, as there was with your other filament?

A. Very approximately the same under these conditions. It probably is a little less but not very much less. I am told that the change in plate current caused by the blue haze in our laboratory test were in the ratio of four to three, so that would be roughly the ratio of the amount of ionization under those two conditions.

We can go back to the Wehnelt oxide filament and show that the condition of the tube has not appreciably changed. If the tube had been filled with nitrogen then a clean-up would have occurred during this test, but being filled with argon the clean-up is very much less because the argon is a very difficult gas to clean-up with this process.

I want to correct my previous statement about the results in the laboratory. The fact is that the ratio of the current to the plate was four to three, four being from the Wehnelt oxide and three from the tungsten filament. So it is not fair to deduce that the ratio of the blue haze would be exactly in that same ratio.

The Court: Are there any questions which the other side may bring out by cross-examination while the experiment is going on?

The Witness: Now, we see that the blue haze is again visible with the Wehnelt oxide filament lighted and in order that we may be quite sure of our test, without disturbing the connection of the B-battery to the plate, we will change the filament connection so that we light the other filament in order that we may be quite sure that the plate is at the same potential in both experiments.

THE COURT: Judge Haight, you were examining Dr. Arnold.

MR. HAIGHT: I am finished.

THE COURT: Mr. Davis, do you wish to cross-examine with respect to the experiment, while we are here?

CROSS-EXAMINATION.

By MR. DAVIS:

XQ. 25. What was the current in the plate?

A. We have no meter in the plate circuit at present and perhaps I can find out what the value was in the laboratory. I am told that with sixty-six volts on the plate in the laboratory, which is approximately the voltage that we have here now, the current to the plate with the Wehnelt oxide filament was about twenty milliamperes and with the tungsten filament was about fifteen milliamperes.

XQ. 26. Have you the diameter of the tungsten filament?

A. It is approximately 3 mil. wire.

XQ. 27. And the current in the filament?

A. The current in the filament was 1.14 amperes. There are two strands in this filament but the two strands are in parallel, one lead to the filament going to the top of the hairpin and the other lead going to both legs of the hairpin.

XQ. 28. So that you get 0.557?

A. 2.28 total amperes.

XQ. 29. And each of these three mil. filaments carries 1.14 amperes?

A. That is correct, and the power in the tungsten filament is thirteen watts.

XQ. 30. And the drop in each separate tungsten filament?

A. 5.7 volts.

XQ. 31. Can I have that information on the Wehnelt?

A. Yes, sir. On the Wehnelt oxide filament the current is about three amperes, the voltage is four volts and the power is twelve watts.

XQ. 32. That is a single filament?

A. That is a single filament. The reason for using the two legs of the tungsten filament in parallel in this experiment was simply for constructional purposes in order that we might get the same power dissipated in both filaments at about the same voltage applied and of course tungsten would be of much higher resistance than the Wehnelt oxide filament and we put the legs in parallel.

(The witness thereupon resumed the stand.)

By Mr. Davis:

XQ. 33. These figures you gave me, Doctor, were the figures on currents actually used in the room?

A. The currents from the filament as you saw the tube first were those that I have given you; but in order to emphasize the blue haze, and with the tungsten filament at the latter part of the experiment, we increased the current through the tungsten filament to a somewhat higher value.

XQ. 34. Now, did you say this morning, referring to Mr. Nicolson, that his orders were to make filaments?

A. That is correct.

XQ. 35. And that was all his orders were, to make, is that it?

A. That is correct.

XQ. 36. He was not supposed to make tubes?

A. Except as he might care to make them in testing under his own control the goodness or badness of the filaments he might make.

XQ. 37. If he did make any tubes, who exhausted them?

A. They were exhausted in our small glass working shop, either by Mr. Trimble or one of Mr. Trimble's assistants.

XQ. 38. So that really there was not much difference between a tube which Mr. Nicolson had exhausted, and any one else's tube, so far as the exhaust was concerned?

A. There might be a very great deal of difference, because as I think I have explained, with the great variety of Wehnelt coatings that Mr. Nicolson used, peculiar pump procedures were sometimes necessary to, in our slang terminology, "open-up" the emission of the filament.

XQ. 39. You were not opening up filaments in those days, were you?

A. Oh, yes. That procedure was found to be necessary with almost the first Wehnelt oxide filaments that we made, it was found necessary or desirable to operate them in the presence of blue haze for some little time.

XQ. 40. What was that for?

A. In order to get the electron emission from them started, it apparently makes a chemical change in the surface of the filament that was not understood at the time. As a matter of fact, I think it is not now very completely understood.

XQ. 41. Now, the object of this filament which Mr. Nicolson was making, of course, was to make tubes ultimately, rather than filaments, was it not?

A. That is correct.

XQ. 42. And you were desirous, were you not, of having filaments which would work in a tube?

A. That is correct.

XQ. 43. And would work in a good tube?

A. That is right.

XQ. 44. And of course the bombardment, if there is any bombardment, does change the emission of the Wehnelt filament, does it not? Suppose the cathode is heated by ion bombardment, does not that change the emission?

A. If the bombardment is sufficient to change the temperature, then the emission changes. I think that aside from that the bombardment produces comparatively little effect on the emission.

XQ. 45. The Wehnelt filament is rather more sensitive to temperature changes, is it not?

A. Well, I think it is not much more sensitive to temperature changes than any other filaments. All filaments obey the same general law of emission, but it happens that the Wehnelt oxide filament emits more electrons at a given temperature than the other filaments do. Perhaps I may say that the same number of degrees temperature change at the working temperature of the Wehnelt cathode, will change its emission more than that number of degrees change in temperature at the working temperature of a tungsten filament would change the emission in a tungsten filament.

XQ. 46. So that in order for Nicolson to know whether he was succeeding or not, it was necessary those filaments should be mounted in good tubes, and the tubes tested, was it not?

A. Well, the tubes had to be of a sort suitable for him to draw his conclusions from. The tubes need not have been tubes that would be satisfactory for any commercial use. It was understood particularly in the temperature emission characteristic of the filaments.

XQ. 47. Suppose one of his filaments was mounted in a tube that had a bad vacuum. Would you consider the data obtained from that tube would be very helpful to you in considering whether that was a good filament?

A. Yes, I think it would be very helpful indeed as indicating the emission from the filament, because you see the emission from the filament is just as readily measured in the presence of a poor vacuum as a good.

XQ. 48. Maybe just as readily measured, but it may not be the same, may it?

A. It would not be the same if the filament were very much affected by the presence of gas; it happens that the Wehnelt oxide is not very much affected by the presence of gas.

XQ. 49. You did not know as much in those days as you know now about these things?

A. No, sir; not nearly as much.

XQ. 50. And you were trying to develop, as I understand your testimony, a tube for use in this transcontinental circuit, among other things?

A. Yes, that was the general aim of our work.

XQ. 51. And is it at all probable that you would have let Nicholson, who was responsible for making the filaments, carry on his tests ordinarily under conditions which were different from the conditions from which the tube would be used in as important a matter as vacuum?

A. Oh, yes, indeed.

XQ. 52. Why would you have done that?

A. Because in the first place, Nicolson was his own master as to the nature of his tests.

XQ. 53. You were very close to his work, were you not?

A. I knew in a general way about the conduct of his work.

XQ. 54. Actually were you not very close to his work?

A. I think I can only explain that by stating again, as I did this morning that Nicolson called to my attention the parts of his work that he thought were very interesting to me, and that from time to time I dropped into his laboratory, either at his request or on my own volition, to see what was going on, but I presume, according to my present recollection, I was not familiar with 10 per cent. of the work that he did. That 10 per cent., however, was probably the most important part of the work that he did, at least he thought so.

XQ. 55. Please do not misunderstand me, I can appreciate that you may have deliberately put a filament in a bad vacuum, to see what it would do in a bad vacuum. That would be a perfectly legitimate test, and I am not setting a trap in connection with some use of that notebook in the slightest degree. I am simply asking you whether as a scientist and research engineer, knowing these tubes, or believing these tubes, as you say you did, were to be used on this transcontinental line, were to be used with a high vacuum, you would have had them tested as a general proposition in any other kind of a vacuum?

A. Yes, I think I ought to explain that thing quite fully in view of your question. There are two things to be carefully distinguished; one is the number of electrons that will come out from the filament, and the other is how a tube will behave in a high vacuum. The number of electrons that will come out from the filament, particularly in the case of the Wehnelt oxide filament, is not much influenced by the vacuum, so that a test in a poor vacuum is easy, quick and entirely indicative of the number of electrons that will come out, but the operation of a high vacuum tube as a repeater can not be thoroughly investigated, nor would the results from it be truly indicative, unless it were operated in a high vacuum, because its operation takes place in the presence of space charge, and does not depend upon the total number of electrons from the filament.

XQ. 56. That means, does it not, that you might let Nicolson make a rough test in a vacuum, an easily pumped vacuum, but before you had passed that filament, you would make him put it in a good vacuum?

A. Oh, no. No. These tests as to the filament, would be quite conclusive in a poor vacuum.

XQ. 57. Although changes in the vacuum would affect the saturation part of the curve, would it not?

A. Somewhat, but not very much, in the case of Wehnelt oxide filament, as a rule.

XQ. 58. Are you familiar with Dr. Van der Bijl's testimony on that subject in the Interference case?

Mr. Haight: I object.

Mr. Davis: I ask if he is familiar.

Mr. Haight: That does not make any difference.

The Court: I can not tell until the next question. It may be wrong, but I will overrule the objection to this question without prejudice to any objection that may be made to the next question.

The Witness: What is the question?

(XQ. 58 repeated.)

A. No. I have not seen that testimony for a good many years.

XQ. 59. You do not remember what he said about them?

A. I do not remember what he said.

XQ. 60. Now, I understood you to say, and correct me if I am wrong, that the only reason why Nicolson should ever make any tubes or have any tubes made, was to test those filaments; is that right?

A. Unless of his own volition he wanted to conduct experiments along inventive lines of his own.

XQ. 61. Do you remember the tube N-2, the adjustable audion?

A. I remember there was such a tube.

XQ. 62. What was the purpose of that experiment?

A. As I recall that tube, it had an adjustable element, moved by a magnet on the outside with which Nicolson was investigating how the current through the tube varied with the change in spacing.

XQ. 63. That was an experiment that you knew about at the time, was it not?

A. Yes, I knew about that at the time.

XQ. 64. That had nothing to do with filaments, had it?

A. Comparatively little to do with filaments, nor was it an experiment that I initiated.

XQ. 65. And all those N-tubes were Nicolson's tubes?

A. I can not answer as to that.

XQ. 66. This N-2 was Nicolson's tube, the one we have been talking about?

A. The N-2 tube was a tube designed by Nicolson.

XQ. 67. You do not remember whether the letter N stood for Nicolson?

A. Whether the letter N stood for Nicolson, and whether Nicolson designed all the tubes in the record which show a letter N, I do not know.

Mr. Davis: I think that is all, if your Honor please.

Mr. Haight: No re-direct.

(Witness excused.)

Mr. Richmond: I would like to offer a few exhibits and things that were marked for identification. I would like to offer Exhibit M for identification which is the abstract of Langmuir's talk before the Physical Society in October, 1913, as this abstract is printed in the official publication of the American Physical Society for November, 1913.

(Received in evidence and marked "Defendant's Exhibit No. 326." *See Volume VI, Defendant's Exhibits, page 1361.*)

Mr. Richmond: L for identification, which is a page of the Interference record with some points indicated by crosses on it that was produced by the witness——

Mr. Davis: It was shown to Dr. Langmuir during his cross-examination.

Mr. Richmond: Oh, yes, it was shown to Dr. Langmuir during his cross-examination. It is page 1176 of the Interference record.

The Court: Is this one of the exhibits?

Mr. Richmond: It is one of the exhibits modified. Some markings were superposed upon it.

The Court: I see.

(Received in evidence and marked "Defendant's Exhibit No. 327." *See Volume VI, Defendant's Exhibits, page 1363.*)

Mr. Richmond: In response to a request, I am not sure at the moment whether it was made in cross-examination or informally, but in response to a request from our opponents, I furnished to them and marked for identification N some data sheets about the nitrogen filled tube and also on the helium filled tube which is an exhibit and these were furnished to our opponents and they were marked for identification N and I would like to offer those in evidence.

Mr. Davis: I was under the impression that we put them in. I certainly think that they should be in. They should be in as having been furnished by the witness Kelly in response to our request and testified to by him as correct. Is that what you want?

Mr. Richmond: Yes.

(Received in evidence and marked "Defendant's Exhibit No. 328." *See Volume VI, Defendant's Exhibits, page 1364.*)

Mr. Darby: Mr. Howson offered in evidence a copy of the DeForest Patent 879,532, the grid audion patent. I have no objection to that. He also offered in evidence copy of DeForest Patent 1,201,273, applied for December 28, 1915, and issued October 17, 1916, and I object to that as being wholly without any relevancy to any issue in the case. The early DeForest patent was put in evidence, was received in evidence, but the later patent, the one which I object to was not received at the session.

(Discussion.)

The Court: I will overrule the objection. While I do not see it I think if counsel can find in it anything that they deem to negative the effect of some of your testimony then it should be available to them wherever they may want to use it.

Mr. Darby: I was merely trying to keep a large record down.

(Received in evidence and marked "Plaintiff's Exhibit No. 217." *See Volume IV, Plaintiff's Exhibits, page 328.*)

Mr. Darby: Do I understand that the plaintiff's rebuttal case is closed?

Mr. Edmonds: We are not through yet. We have another one because of your absence yesterday. We offer in evidence the file wrapper and contents of the DeForest Patent 1,507,017, applied for March 20, 1914, and granted September 22, 1924. That is for the same purppose.

Mr. Darby: I object to it for the same reason. My recollection is that this patent, the file wrapper and contents of this patent, which is one of the patents involved in the 4915 case before your Honor, according to my recollection is an exceedingly long thing, something like——

THE COURT: I remember it.

MR. DARBY: It is an enormous thing about three or four inches, to offer the file wrapper and contents of that patent in this case.

MR. EDMONDS: Nothing short of the file wrapper and contents will make our point. I will state our purpose in sixty words. Here is an original specification of an application filed in March, 1914, and it reads in this fashion: "By reason of the arrangement above described and the ionizing of the gas in the bulb due to the heated filament."

Several years later than that, to wit, November 13, 1916, that sentence was stricken out of the specification and the patent issued without it. By that time Mr. DeForest had found gas ionization was not to be used in the practical tube of the future, and he struck that out entirely. We want the benefit of that fact in this case.

THE COURT: I am wondering whether we can not get along without printing that. You may have the benefit of those statements, but use copies without enlarging the record.

MR. DARBY: Why cannot Mr. Edmonds' statement just as he has made it here be accepted without putting the file wrapper in?

MR. EDMONDS: That will answer the purpose.

MR. DARBY: Fine.

MR. EDMONDS: Do you agree to that?

MR. DARBY: I agree to having the statement go in.

THE COURT: I will overrule the objection. You have nothing else in the patent and if there is any other quotation from the patent that you want a record of made, you may do so.

Mr. Darby: My whole point is that Dr. DeForest in 1914, had the theory that all tubes operated by gas ionization and subsequently found his theory was wrong and that does not affect the fact at all. Now do I understand that the plaintiff's rebuttal case is closed?

Mr. Edmonds: There are two exhibits offered in evidence but the exhibits were not produced and we did not have an opportunity to examine a witness concerning them.

Mr. Darby: There were two exhibits, 83 and 84, which were physical exhibits that your Honor will recall we mentioned once before. The Clerk of the Court in Brooklyn assures me that he has never received those exhibits. They were mailed to him directly from California by the notary public. I sent two long telegrams to the notary public in California but thus far have been unable to get any response to them. I asked him to look up and send back to me the registered receipts of the exhibits. The only information I could get from him at all was to the effect that he mailed them to the Clerk of the Court in Brooklyn.

One of them was a DeForest audion structure, the sole function of which was to have the witnesses identify the tubes that Lamont had pumped were similar in appearance to this structure, and that structure is identical in appearance with this tube we have referred to as 7-A in the interference, that is, the tube that was left with Dr. Arnold when Dr. DeForest made the demonstration. That serves the sole purpose in the California deposition.

Exhibit 84 was a Jahnke tube which I might characterize as being a three-electrode tube of a rather freakish shape and because of the fact that it was referred to and one was available we secured one of them. If under those circumstances your Honor will permit me to withdraw those two exhibits from the case and it is acceptable to Mr. Edmonds I will do so, because they serve no useful purpose in the case and I offered them only because they were part of the deposition.

MR. EDMONDS: That is satisfactory.

THE COURT: Let them be withdrawn by agreement.

MR. DARBY: Now, does that close the case?

MR. HAIGHT: We have gone over the parts of Richardson's book that the plaintiff desires to be marked in evidence. We have no objection to the receiving in evidence of pages 13 to 15, 20 to 23; 61 to 68; 128 to 130. We do object to the admission of pages 91 to 92 and 117 to 118. The reasons why we object to those latter are these: Mr. Davis tells me that the first was read in but I do not know whether that makes it evidence. Who was it read in by?

MR. DAVIS: I read it in myself or I had one of your witnesses read it. I do not see why we need to trouble about that, Mr. Edmonds.

MR. HAIGHT: The reference in the interference record from which the offer of pages 117 to 118 is based is found on page 1259 of the interference record and is in the testimony of Dr. Langmuir. He says this: "On page 118 of Richardson's book entitled the emission of electron from hot bodies, he refers to my published results that argon"—and so forth, and then he quotes. I do not see any justification for offering any more of Richardson's book than that which is already there.

THE COURT: What have you to say, Mr. Davis?

Mr. Davis: I understand it is simply a question of getting the context, that is all, to make it clear what the situation was. It is not put in to prove anything.

The Court: Dr. Langmuir used the portions upon which he relied. Do you withdraw your offer as to——

Mr. Davis: Yes, because for the reason stated, and I understand that this book will be treated as a physical exhibit and that the only parts that are in evidence are pages that are agreed to.

The Court: The book may be used as a book of reference for those pages but no other pages are a part of the record in this case.

Mr. Davis: That is right.

(Received in evidence and marked "Plaintiff's Exhibit No. 218." *See Volume IV, Plaintiff's Exhibits, page 332.*)

Mr. Davis: In response to Mr. Darby's question as to whether we close our rebuttal, the answer is that we have closed this morning.

Mr. Darby: We have the Alexanderson patent marked for identification. I do not care about putting it in evidence unless Mr. Davis wants me to put it in.

Mr. Davis: I think it will only encumber the record.

Mr. Darby: I would like to offer in evidence as a physical exhibit the book on high vacuum by Dr. Saul Dushman, production and measurement of high vacuum.

Mr. Davis: I object.

Mr. Darby: I believe that this book should be in as a physical exhibit because your Honor will recall I cross-examined Mr. Hogan in connection with certain passages in the book and Mr. Hogan qualified his answer, or at least mentioned in his answer as to whether or not he agreed with the statement or the statements contained in the book, that he would have to know what particular state of facts, or what particular instance Dr. Dushman was talking about, in the particular case that Dr. Dushman was talking about in making that statement and my purpose of putting the book in is to establish just what particular circumstances and instances Dr. Dushman was talking about.

Mr. Davis: It seems to me highly objectionable on the same basis that I cannot put the whole Richardson book in. You cannot make a book evidence by asking a witness a question about it, of course.

Mr. Haight: I suggested to Mr. Darby that he read the argument and ruling yesterday.

The Court: I think the objection is well taken, but if there are any portions of it that are directly pertinent or material, probably your purposes will be served by following the same course that was followed with respect to the Richardson book.

Mr. Darby: Yes, sir.

Mr. Davis: I refer to your Honor's ruling just now and I may assume that Mr. Darby read to the witness the portions he regarded as important.

Mr. Darby: I read to the witness the portions I considered important.

The Court: My impression is that you are limited by that but if you think you are not I will hear you, but I should think we went through this field reasonably well yesterday and in view of that if you have not conferred with your colleagues about it——

Mr. Darby: I will not press it.

Mr. Haight: Defendant offers in evidence the tube that was demonstrated this afternoon by Dr. Arnold.

(Received in evidence and marked "Defendant's Exhibit No. 329.")

FREDERICK L. HUNTER.

Frederick L. Hunter, was called as a witness in sur-rebuttal, on behalf of the defendants, and being first duly sworn, testified as follows:

Direct Examination.

By Mr. Darby:

Q. 1. What is your age, residence and occupation, Mr. Hunter?

A. Age, thirty-one; residence, Towaco, New Jersey; employed as Engineer in charge of the Audion Division of the DeForest Radio Company.

Q. 2. You graduated from Stevens Institute?

A. Massachusetts Institute of Technology.

Q. 3. What year and what degree?

A. Class of 1919, Bachelor of Science, in the Department of Electro-Chemical Engineering.

Q. 4. You served with the staff of instructors at M. I. T.?

A. I did.

Q. 5. And then you were employed by the Western Electric Company?

A. I was.

Q. 6. In vacuum tube work?

A. Yes.

Q. 7. For how long?

A. Until 1923.

Q. 8. How long was that?

A. Approximately three years, slightly over.

Q. 9. For how long have you been with the DeForest Company?

A. Somewhat over three years.

Q. 10. All in vacuum tube work?

A. Yes.

Q. 11. In manufacturing the type of receiving tubes charged as infringements of the Langmuir patent in suit, do you use an automatic exhaust machine?

Mr. Davis: I object. This question of infringement has been covered by a stipulation. At the beginning of the case defendants stipulated that they infringed all of the claims of the first patent and certain numbered claims of the second, third and fourth patents. Our experts have not discussed infringement in any way, shape or manner and have kept away from it. It seems to me that in sur-rebuttal, whichever it is, it is too late to go into that question.

Mr. Darby: I am not going into that question. This testimony is related strictly to rebutting the testimony of the witness Hogan.

The Court: Won't you have the question read? It leads us to think that it is directed specifically to infringement.

Mr. Darby: If the question has carried that impression I will reframe it.

By Mr. Darby:

Q. 12. In the manufacture of the type of DeForest receiving tubes before the Court as infringement of the Langmuir patent No. 1 in suit, do you use an automatic exhaust machine?

Mr. Davis: Same objection.

The Court: I miss the point, Mr. Darby, because it looks to me—although the form is changed—as if it bears on the issue of infringement and could bear on the issue of infringement only.

Mr. Darby: I was merely using the word infringement to identify the tubes.

The Court: Will you tell me what your purpose is?

Mr. Darby: My purpose is to have the witness——

The Court: Let me ask you first: What is the testimony of Mr. Hogan which you are attempting to meet by this testimony?

Mr. Darby: The testimony of Mr. Hogan has two points. One is in connection with the automatic exhaust machine and his consideration of the prior art where he states, at least as I understand in effect, that you could not obtain a sufficiently high degree of vacuum——

The Court: All right. You may move to strike it out if it appears to be not relevant. I will overrule the objection with leave to move to strike out after the answer is taken.

(Question repeated.)

A. We do.

Q. 13. Will you very briefly describe the automatic exhaust machine and state the process employed in producing these tubes in their consecutive steps and the degree of vacuum obtained by the respective steps?

The Court: It being understood that this question, like the other, is not to elicit evidence touching or bearing upon the question of infringement.

Mr. Davis: I further object for this reason: The testimony of the witness Hogan as far as I remember it and as far as he remembers it was something like this. Mr. Darby asked him certain questions about automatic exhaust machines and he said he did not know.

THE COURT: Then, Mr. Darby, you will have to examine the record.

MR. DARBY: I am not confining this in any sense to a consideration of the automatic exhaust machines. I am advancing it on this proposition or this theory and I am not in any way attempting to retract from the stipulation.

THE COURT: I have that now.

MR. DARBY: Mr. Hogan has testified in one instance that blue glow, for example, would be absolutely fatal to a thoriated tungsten filament, and wipe off this layer one atom deep. He has also testified of the extreme care and pains that must be taken in considering prior art patents, to get the highest degree of vacuum where you use a thoriated tungsten filament. I want to prove by this witness in connection with my admission, that these claims are not infringements of our structure, that Mr. Hogan's consideration of this prior art is, as I view it, rather far-fetched, in view of the fact that this process in making the infringing tube is admitted to be an infringement.

MR. DAVIS: Your Honor please, all that from our point of view, is absolutely immaterial, for these reasons: In the first place, if during the manipulation of the tube in the exhaust machine, the atomic film would be burned off, that would be re-formed. You have this reactivation. In the second place, it has been brought out and brought out to the utmost degree, that where you are using those powerful keepers like magnesium that the exhaust precautions which were necessary in order to secure the result first obtained in the prior art become relatively unnecessary. I do not mean that they do not have to be taken, but you may use a preparation of the anode which would be inadequate without a keeper. It seems to me that to prove that the DeForest Company exhaust their tubes very quickly, because they take advantage of all of Dr. Langmuir's inventions, it is not a defense in suit.

Mr. Darby: But Mr. Davis is overlooking—pardon me.

The Court: I think, Mr. Davis, that will be your argument which might be advanced by you to meet this, but it does not appeal to me at the moment as an argument which denies to this testimony, admissibility; and it may be advanced to negative this fact, but it is admissible to meet the testimony of Mr. Hogan, if it will.

By Mr. Darby:

Q. 14. Will you answer the question?

Mr. Davis: I think there ought to be specific questions asked and directed to the particular point.

The Court: Yes, if it is not a specific question. Will you read the question, Mr. Smart?

(Question repeated.)

Mr. Davis: The specific process.

The Court: Let that question be withdrawn, Mr. Darby, and re-put it.

Mr. Darby: Are you referring to the automatic machine, you want a specific question as to the process employed?

Q. 15. Will you briefly state the successive steps of processing these tubes, these receiving tubes?

Mr. Davis: The same objection. If there is any merit in that question, it is to show some qualification of what Mr. Hogan said with respect to some specific steps of the process and I see no reason to go through the whole process.

Mr. Darby: It is the whole of the processes entirely, and if your Honor would care to hear me further on it.

MR. DAVIS: We would like to see the place in the record about it.

MR. DARBY: Take Mr. Hogan's testimony where he speaks of the prior art and says that this patent shows that you can produce vacua down to two to ten microns, and that is incandescent lamp vacuum, and of course that was impossible to get the vacuum necessary in these tubes. I intend to prove by this witness that we produce the tubes by the pumps down to five microns.

THE COURT: Why not direct his attention and be as near to leading questions as seem proper?

MR. DARBY: Very well.

THE COURT: Put a series of questions rather than asking him to narrate the process as a whole.

By MR. DARBY:

Q. 16. Have you got a device or tube in the form in which it is put on the automatic exhaust machine?

A. I have (producing same).

MR. DAVIS: I object. I do not see that that has anything to do with that question at all, the details of exhaust. If Mr. Darby wants to ask the witness a question to what vacuum the tube is pumped, I have no objection to that.

THE COURT: I have gathered the impression, not only from the exhibits of the prior art, but also from the mass of testimony in here, that the form in which it was put upon the exhaust machine, might be quite material as to the quality of the vacuum in the tube, upon its being sealed, and for that reason I think the objection is not well taken.

Q. 17. Is the electrode structure——

THE COURT: He has not answered the previous question.

MR. DARBY: Yes—"I have."

Q. 18. Is the electrode structure freed from gas before it is assembled in this tube?

A. It is not.

Q. 19. Are any pains taken in assembling the tube to prevent contamination of the electrodes by handling or otherwise?

A. None.

MR. DAVIS: Your Honor understands that this is all subject to this objection?

THE COURT: Yes.

Q. 20. As I understand it, this tube in the form that you have produced it, is inserted in a sleeve or receptacle with the open end of the tubular tube leading into it, is that correct?

A. That is right.

Q. 21. What is the material in which it is inserted?

A. Rubber.

Q. 22. Is it coated with any oil or material of that kind?

A. Castor oil.

Q. 23. As I understand it, it is then exhausted by a rough exhaust pump?

A. It is.

Q. 24. It is likewise enclosed in a heated oven?

A. It is, during a portion of the exhaust.

Q. 25. How long is it maintained in the heated oven?

A. Three minutes and about thirty-six seconds.

Q. 26. And throughout what portion of that three minutes and about thirty-six seconds is it connected to a pump?

A. For approximately nine seconds it is connected to a rough exhaust pump—no, approximately 1½ minutes it is connected to an exhaust pump.

Q. 27. And at any time while it is in this heated oven, is it connected to a finer pump; that is, one that can get a higher degree of vacuum than your rough pump?

A. Yes.

Q. 28. For how long?

A. For about approximately thirty-six seconds.

Q. 29. Then is anything done to remove any oil vapor that may have gotten into the tube?

A. Nothing.

Q. 30. While the tube is in the heated oven, is air allowed to pass into the tube, or deliberately fed into the tube?

A. Yes, for approximately—for at intervals which total about one and one-half minutes.

Q. 31. Is that what you call "air washing"?

A. It is.

Q. 32. And what is the purpose of the air washing?

A. The air fed into the tube is dried very carefully by means of sulphuric acid, caustic potash and phosphorus pentoxide——

Q. 33. Any means taken——

THE COURT: He has not finished.

A. (Continuing.) The purpose of that very dry air is two-fold. It takes up water vapor like a sponge, and also communicates heat from the bulb to the structure.

Q. 34. Through conduction—through the gas particles?

A. Yes.

Q. 35. Are any means thereafter taken to exclude from the bulb any gases that might result from the presence of phosphorus pentoxide?

A. No.

MR. DARBY: I offer the tube in evidence.

(Tube received in evidence and marked "Defendant's Exhibit No. 330.")

Q. 36. As I understand it then, the tube is sealed off from the exhaust pump, is that correct?

A. That is right.

Q. 37. And is the tube that I now show you, the condition of the tube? Does that illustrate the condition of the tube after it is sealed off from the pump?

A. It does.

Q. 38. And what is the order of magnitude of pressure in the tube when it is sealed off?

A. From one to eight microns.

Q. 39. I call your attention to two little white spots, one on each side of the plate electrode, in both the Exhibit No. 330 and the tube in my hand. What is that?

A. Magnesium.

Q. 40. After the tube is taken off of the automatic exhaust machine, as I understand it, you then put the tube on a base; is that correct?

A. That is correct.

Mr. Darby: I offer in evidence the tube illustrating its condition as it comes off of the machine.

(Received in evidence and marked "Defendant's Exhibit No. 331.")

Q. 41. And does the tube that I now show you show the condition of the tube after it is based?

A. It does.

Q. 42. Then I understand that you put this tube in what you call a rotary flashing machine; is that correct?

A. It is.

Q. 43. And current is supplied, or at least heat is supplied through an induction coil on this flashing machine, which heats the magnesium to a point where it volatilizes; is that correct?

A. It is.

Mr. Darby: I offer in evidence the tube based prior to volatilization of the magnesium.

(Received in evidence and marked "Defendant's Exhibit No. 332.")

Q. 44. And it is the volatilizing of the magnesium which causes the mirror-appearance to the glass of the vessel, is that correct?

A. That is true.

Q. 45. As is shown in the tube which I now have in my hand?

A. Yes.

Q. 46. Then as I understand it, you thereafter use heat treatment of the filament, and apply voltage on the plate electrode——

Mr. Davis: Now, if your Honor please, that part of it certainly can not refer to the exhaust; that must refer——

Mr. Darby: That is my last question, as I understand it, the next thing they do is heat the filament, give the filament heat treatment.

The Court: I will take your answer to that question. I think it is material. Now, then, whether it must be eliminated in weighing the issue for reasons which are obvious to both of you, is a question I will have to consider later, but I think that question is admissible, because whether that clean-up is the result of one thing or another thing, is a matter which I should not now determine.

Mr. Darby: I will defer my question.

Q. 47. Then, as I understand it, you flash the filament agent, and apply a voltage on the plate; is that correct?

A. That is.

Q. 48. And does blue glow appear when you apply a voltage on the plate?

A. Nearly always.

Q. 49. Then as I understand it, a tube is tested for its operating characteristics and it is in a condition for sale?

A. That is right.

Q. 50. After it passes the tests?

A. That is right.

Mr. Darby: I offer in evidence the tube in its completed form.

(Received in evidence and marked "Defendant's Exhibit No. 333.")

Q. 51. Have you a photograph of the automatic exhaust machine?

A. I have.

Mr. Davis: The same objection.

Q. 52. And an enlarged sectional drawing showing its structure?

A. I have.

Mr. Darby: In view of the permitted leading nature of the examination, I do not care to offer this in evidence unless opposing counsel should care to have them go in evidence. I had intended to have the witness describe the machine to permit a more complete understanding of its operation; but in view of the permitted leading nature of the questions, I do not believe it is necessary, unless you want it.

Mr. Davis: No.

Q. 53. Prior to the flashing, what was the order of magnitude of the pressure in the tube?

A. From 1 to 8 microns, depending upon the condition of the pumps.

Q. 54. And after the flashing, what was the order of magnitude of the pressure; that is, in its completed form, in the completed form of the tube, the last exhibit, after it has passed the test?

Mr. Davis: Of course it is understood these objections continue. Here is a question that goes right straight at one of the features of the patent after he has admitted infringement.

The Court: Then I made my ruling not specific or clear. These questions as I understand it are directed not at all to infringement. They pertain not at all to infringement any more than if these tubes had been manufactured by John Smith in Australia; but here are tubes manufactured in Australia, let us say, which are charged by the plaintiff to infringe the patent. These questions are all directed as it seems to me, and the evidence pertains to a denial of the effect and substance of certain portions of your expert testimony, by the production of a fact witness, and they go, as I see it, and they are neither excluded nor admitted, by reason of the fact that it happens to be the process employed by the defendant here, that has got nothing to do with it; but here are tubes produced in a certain way, alleged to infringe, which tend or do not tend, according as I take the respective contentions, to meet the testimony of an expert witness by fact, and for that reason, and not at all as bearing upon infringement, but solely as indicating the degree of vacuum that is in fact obtained and had, by a process employed by some one who happened in this case to be the defendant. Now, then, how that last production is brought about and what brings it about, is another question, which I will not pass on now.

Mr. Darby: I am not going into any theory at all.

The Court: That is how I understand your question, and I think the last question—it might under other issues, and under a different state of issues—have a bearing upon infringement, but here it has no bearing upon that. It has merely a bearing as to how the vacuum—as to whether the theory of the plaintiff's witnesses is correct, or whether it is incorrect.

The Witness: The answer to that last question was, approximately one one-thousandth of a micron.

Q. 55-56. One one-thousandth of a micron?

A. Yes.

Mr. Darby: You may cross-examine.

Cross-Examination.

By Mr. Davis:

XQ. 57. Where did you get this induction coil you speak of?

A. I do not understand the question.

XQ. 58. Where did you get this induction coil you speak of?

A. Made it.

XQ. 59. What are the dimensions of it?

A. It is just sufficient to slide over the bulb.

XQ. 60. That is, it has a coil that surrounds the bulb on the outside, is that right?

A. That is right.

XQ. 61. That is mounted on the machine?

A. That is on the mechanism on the machine.

XQ. 62. At a certain stage, the tube passes into this coil and remains there for a certain time; is that right?

A. That is right.

XQ. 63. Now, what is the magnitude of the current you send through that coil?

A. We did not measure it.

XQ. 64. What is the voltage?

A. I have no way of knowing.

XQ. 65. What is the frequency?

A. It is approximately 900 meters.

XQ. 66. That is, it is a very high frequency current?

A. Yes.

XQ. 67. Not an ordinary alternating current at all?

Mr. Darby: Mr. Davis, is that material to this case or are you trying to establish evidence in connection with the Northrak patent?

Mr. Davis: I am not interested in that patent. We are not exclusive licensees, and we have paid our royalty. I am very much interested in the fact that this thing casually referred to as an induction coil, turns out to be a high frequency electric furnace, and that I brought out.

Mr. Darby: No objection.

XQ. 68. Now how much does this high frequency furnace heat the anode?

A. That depends on the amount of gas in the tube; it varies.

XQ. 69. Let us have some limits; is it five degrees C.?

A. When the vacuum is very good, the magnesium goes off, and the plate gets a dull red.

XQ. 70. And when it is poor?

A. When it is poor, the plate gets bright red.

XQ. 71. That is, this heat is generated in the plate by currents induced in the plate by this high frequency coil on the outside?

A. That is true.

XQ. 72. And at the same time, it vaporizes the magnesium?

A. Yes, sir.

MR. DAVIS: That is all.

RE-DIRECT-EXAMINATION.

By MR. DARBY:

RDQ. 73. How long is the heat of the induction coil applied to the plate, in order to raise it to the proper degree of temperature to flash the magnesium?

A. Since the machine is automatic, it must get up to the temperature in four seconds.

RDQ. 74. And the heat is not maintained on the plate thereafter?

A. It is not.

MR. DARBY: That is all.

RE-CROSS-EXAMINATION.

By MR. DAVIS:

RXQ. 75. Where did you get your authority for calling that an induction coil; did you ever hear any one call it an induction coil?

A. I did not call it an induction coil.

RXQ. 76. I beg your pardon, you have adopted Mr. Darby's characterization.

A. I answered Mr. Darby's question.

RXQ. 77. Did you ever hear it called an induction coil, except by Mr. Darby?

A. Yes.

RXQ. 78. When?

A. It is a common terminology.

RXQ. 78a. To call it an induction coil?

A. It is a coil which operates an induction furnace.

RXQ. 79. You call that an induction furnace round the factory?

A. It has been referred to more than once.

RXQ. 80. Who did that?

A. Various members of the plant.

RXQ. 81. You know the term "induction coil" has a perfectly definite meaning in the art, don't you?

A. Yes, I know that.

RXQ. 82. Which is entirely different from this meaning, is it not?

A. I am aware of that, yes, sir.

RXQ. 83. Where did you get this 900 meter current you pass through this coil?

A. We have an oscillator.

RXQ. 84. That is a vacuum tube oscillator?

A. A vacuum tube oscillator.

RXQ. 85. Can not you give us some idea of the amount of energy?

A. We use 250 watt tubes, four of them in parallel, applying 3,000 volts on the plate.

RXQ. 86. In this oscillator?

A. Yes, sir.

Mr. Davis: That is all, Mr. Darby.

Mr. Darby: That is all, Mr. Hunter.

(Witness excused.)

Mr. Darby: I would like to offer in evidence and agree not to have it reproduced unless Mr. Davis wants to have it reproduced, the list of references which were referred to in the Interference proceeding, but concerning which no evidence has been put in here, the sole purpose of this evidence or these references is to enable your Honor to have before you the references that were testified about in the Interference proceeding in support of the motion to dissolve the Interference on the ground of patentability, and that is its sole function, to have it before your Honor.

THE COURT: Do you know whether it was before the Patent Office tribunals?

MR. DARBY: The one tribunal, the Law Examiner, that is the only tribunal who passes on the question of patentability, and that is not including the Armstrong article. Mr. Davis has somewhere in the record made reference to the fact that Mr. Hogan has not testified to these references because we have not put them in, but we have no intention of putting them in except for that one purpose.

MR. DAVIS: If your Honor please, it is a little unusual, and I rather dislike to admit a lot of references that even yet we have not seen, we have seen extracts from them.

(Discussion.)

MR. DARBY: I am perfectly willing to withdraw them.

MR. DAVIS: I do not know what is in them. I ought to know because I ought to have known years ago and maybe I may be blamed for not knowing, but I dislike to have them gone in after our expert has gone off the stand.

THE COURT: Then they are withdrawn.

MR. DARBY: Yes. That completes our case.

MR. DAVIS: Then I have two witnesses in rebuttal.

PLAINTIFF'S SUR-REBUTTAL PROOFS.

FAIRFAX BAYARD.

Fairfax Bayard, was called as a witness in surrebuttal on behalf of the plaintiff, having been duly sworn, testified as follows:

Direct Examination.

By Mr. Davis:

Q. 1. You are an attorney connected with the Patent Department of the General Electric Company?

A. I am.

Q. 2. And you were in the United States Patent Office?

A. I was.

Q. 3. For how long?

A. About twenty-five years.

Q. 4. And when you left what position did you occupy there?

A. Examiner in Chief, member of the Board of Examiners in Chief.

Q. 5. For how long?

A. Ten years.

Q. 6. And prior to that time you had been what?

A. I had been Examiner of Interferences for three years and Law Clerk assisting the Commissioner for three years.

Q. 7. That is sufficient, I think. When a man has an application in the Patent Office and a patent issues to another with claims which seem to the applicant to cover his invention or to be capable of being construed to cover his invention, what is the remedy which the applicant has, what is it the practice in the Patent Office that he should do?

A. He should copy the claims of the patent which he considers to interfere and ask for an interference proceeding.

Q. 8. By copy you mean introduce them into his application?

A. I mean he should file an amendment to his application directing the insertion of these claims which he embodies in his amendment, copied from the patent.

Q. 9. Suppose he thinks they are badly expressed or unscientifically expressed, what is his remedy?

A. There is no direct remedy at that time. He copies the claims anyhow and gets the Interference.

Q. 10. That is what I want. He copies the claims to get the interference. How long has that been the practice?

A. For about twenty-five years. It was inaugurated about 1900.

Mr. Davis: That is all.

Cross-Examination.

By Mr. Ballard:

XQ. 11. Don't you know that the Patent Office decisions of the Commissioner, in control of the office, and the practice provide for interferences between applicants and patentees where the applicant cannot copy the exact language of the claims of the patent?

A. I am not aware of any rule bearing on that subject. As to decisions, I remember that there was a decision, *ex parte* Card & Card, in which the question was discussed, a good many years ago, in an interference in those cases where the patent is limited to some detail of invention which the applicant has not disclosed and therefore cannot properly claim. I remember that there was some discussion about that.

XQ. 12. Do you remember the decision in *ex parte* Thompson?

A. No, I do not recall the decision in *ex parte* Thompson.

XQ. 13. You do not think there is anything in the Patent Office rules or practice that requires any applicant to copy any claim that does not properly describe his invention?

A. I do not think that any applicant is required to copy a claim which in his opinion cannot be construed to cover his invention.

Mr. Ballard: That is all.

Mr. Davis: That is all.

(Witness excused.)

IRVING LANGMUIR.

Irving Langmuir, was called as a witness in surrebuttal on behalf of the plaintiff, and having been previously sworn, testified further as follows:

Direct Examination.

By Mr. Davis:

Q. 1. You have just heard, have you not, described certain operations of pumping a vacuum in a tube as practiced by the DeForest Company?

A. Yes.

Q. 2. Will you please explain how it happened, what the physical causes were, that that vacuum which was testified at one time, when the tube was sealed off from the pump, was several microns, was reduced to one one-thousandth of a micron and how that could be under the circumstances, and describe how that could be in the presence of stop-cock greases and so forth?

A. It is made possible by the effectiveness of magnesium in producing and maintaining high vacuum and by the effectiveness of the very useful method of heating electrodes which has become possible by high frequency currents applied by induction coils, currents induced in the metal parts of the electrodes.

By placing a coil around the tube and passing a very heavy high frequency through it, in this case from a high frequency generator of about one kilowatt, and a frequency of about 30,000 cycles per second, a radio frequency, and large currents, it is possible to heat the objects placed in that coil almost instantly to red heat. For instance a coin or a pen held in the hand and inserted into this coil almost immediately becomes red hot by the currents set up in the metal part by the induced voltages from these high frequency currents.

That I think is used today for practically all vacuum tube exhaust because it has this enormous advantage that you can heat the plate to a red heat or white heat almost instantly and keep it there as long as desired and drive the gas out very rapidly out of the red hot plates without at the same time injuring the filament in the slightest degree.

By the old methods that were necessary, before that method was possible, in order to heat the plates red hot it was necessary to proceed by an extremely laborious process. The plates contained gas and you had a relatively small filament, and you would light the filament and put voltage on the plate and you would get a few milliamperes of current but you could not safely use very high voltages because the first gas that would come out would be ionized by the electron current and would produce positive ion bombardment of the filaments. That would injure the filaments unless you applied only a little voltage and a little current at first and waited for the pump to pump out that gas. This process had to be repeated again and again and again and probably in the older days it was a matter of hundreds of times, applying voltages and each time a little higher current and waiting for the pump to remove the gas.

That was necessary because if you heated the plate all at once at any time you got such a large amount of gas. In order to heat the plate you would have to have large currents and high voltages, both were necessary for even on small tubes it was a question of ten watts or so, of energy that needed to be liberated on the surface of the anode.

If you should get all that gas out at once you would get such severe positive ion bombardment that it would destroy your filaments in a few seconds or minutes. Thus unless you used great care the life of the filament was practically gone.

By this new method we get all that gas out without calling on the filament to emit any electrons at all. You can drive it all out of the electrodes at once in a very short time and if the device is still connected to the pump it could be pumped out. This is usually done with the larger tubes, the process being applied while the tube is on the pump and then you get rid of the gas in the electrodes in one operation and after that you can get the gas out of the filament and out of the grid.

But in this case the tube had been sealed off from the pumping system, before this process was carried on; and there was one to eight microns of gas left in the tube. The tube had been heated to get moisture out of the glass but only for a short time and the degree to which the walls were denuded from water vapor and carbon dioxide and nitrogen was nowhere near what would have been necessary in the old days, because now magnesium would take care of any slight traces of water vapor or carbon dioxide that might come off subsequently from the walls. Thus it was unnecessary to go to extreme methods of exhaust. In this case there was a little residual gas. That gas at eight microns pressure was probably hardly 1 per cent. of the gas that would come out of the electrodes during heating. It did not make any difference whether it was one or eight microns left in the tube. It would not have been material. It was just a little more gas that would be taken care of by the magnesium anyway.

Then in this particular case that we are referring to the plates were heated to very high temperature by this induction method and the gas was driven out and at the same time the magnesium was also heated by the same induction and was vaporized at the same time. All of those gases that come off from the plate are gases that can combine with magnesium under the conditions where the magnesium is in the form of a vapor.

Then the magnesium forms a film over the surface of that bulb which is and remains extremely active during the whole life of the tube in cleaning up and removing any further traces of gas that may come off the electrodes or may come from underneath the deposits of magnesium, as for example, from the glass.

Those are the two methods combined in this case that have made it possible to accomplish in a few minutes an exhaust which would otherwise in 1912 have taken days. To have exhausted a tube like that, in 1912 would have taken say two or three days and then we would have had to know how to do it even then; I do not know that anybody knew how to exhaust a tube of that character in 1912.

I did not know and I did not learn it until very late in 1913, how to get metal plates of that size and character free from gas by the bombardment of the plates. And then, as a practical matter, it only became possible to do that by the use of the very rapidly acting pumps that we then had, by the Gaede molecular pumps—with the old pumps we had to pump by hand—and I may say the Gaede molecular pumps operated about thirty times as fast as the old Gaede rotary pump.

This makes it possible to cut down the time of the exhaust manifold (under these conditions where you are getting gases off the electrodes and have to wait for the gas to come out before you can apply the voltage again), as compared with the Toepler pump. The Toepler pump pumped fifteen or twenty cubic centimeters per second. It was a hand-operating pump. With the Gaede molecular pump you got 3000 cubic centimeters per second. Think of that ratio. It was 200 to one. of that order of magnitude.

Q. 3. Coming now to Dr. Becker, do you agree with Dr. Becker in the statement which he made about the conditions in what he called the first stage of the tube of August, 1912?

A. Yes, substantially.

Q. 4. Do you wish to add anything to the statements he made? Can you add anything to the statements that he made about it that is important to this case?

A. In the first stage the current is limited by the emission from the filament and as Dr. Becker said the whole potential difference between the cathode and the anode at the higher gas pressures, at least, is concentrated in a thin layer of gas very close to the surface of the cathode in which there is a positive ion space charge; whereas, in high vacuum tubes we have an electron space charge.

There is a positive ion space charge within the distance of a few tenths of a millimeter from the cathode under the conditions that he is speaking of, and then the gas through probably 99 per cent. of the volume of the bulb, or 95 per cent. of the volume of the bulb at least at the higher gas pressures, the space is very nearly free from electric field, that is, there is very little potential gradient.

The space is nearly all at the same voltage and at about the same potential as the anode. It may differ by a few volts.

The walls of the tube are always negatively charged with respect to the bulk of the gas. There is a little thin layer close to the surface of the walls where there is also a little positive ion space charge and that causes a little drop in potential, five volts in the case that Dr. Becker spoke of, but as the pressure is lowered the supply of positive ions decreases, there being less gas to ionize, and the positive ions are no longer able to keep the walls from charging negatively.

The reason the walls charge negatively is because the electrons. All through the space, in this field free space, there are equal numbers of electrons and positive ions per unit volume and there is thus no space charge, but the electrons are moving very fast and the positive ions are moving slowly so that the electrons carry a much bigger current.

More electrons per second tend to strike the walls than the positive ions and that electron current is compensated for by the supply of positives. If that is no longer sufficient then the walls become more and more negative and as Dr. Becker said, they went down to fifteen volts at the end of stage 1, just before the stage 2 starts.

So we have in the tube no space charge through most of the gas, and a thin layer of positive space charge surrounding the cathode and surrounding all surfaces of the glass.

There is one other point, and that is that in this case the electrons acquire nearly all their speed in passing through this little thin layer on the surface of the cathode and they then have their full energy corresponding to 250 volts or 245 volts, if there is 250 volts on the anode, and they travel in straight lines until they are stopped by something, either by collisions or by coming close to the glass walls in this little region where there is a strong field.

The electrons striking the glass walls will be reflected, a good many of them, and thrown back into the gas and they travel around in the gas until they ionize, in general, gas molecules. The electrons then lose energy and new electrons are produced and those scondary electrons, those lower velocity electrons are the ones which ultimately reach the anode and carry the current. The energy of the discharge is not liberated on the surface of the anode in this type of a discharge, but it is liberated on the walls of the tube.

The positive ions that are formed are formed in a region where there is very little electric field and although they move at velocities of many miles a second they move at velocities that are almost negligible as compared with the velocity of the electrons. The result is they are very effective in eliminating space charge. Those positive ions ultimately, practically all of them go to the walls.

In this particular device where the cathode was so small compared to the walls only a very minute fraction of them would strike the surface of the cathode. Most of them go to the walls of the tube and they are neutralized by electrons that also strike the walls. Practically none of the positive ions combine with the electrons at these pressures in the space. There is no appreciable amount of recombination of ions at pressures of a few microns in tubes of this character.

Q. 5. Now, will you consider what Dr. Becker called the third stage and stage your view of the phenomenon which goes on in that stage?

A. The main characteristic of the discharge is the third stage is that the currents are limited by space charge. There is no cathode drop, there is a slight retarding field in the surface of the cathode and the main characteristic of this type of discharge is that practically throughout the whole space in the bulb there are electric fields, very strong electric fields in general.

That is due to the fact that there are electric charges due to the space charge which set up those fields and the fields are due to the electric charges in the space in accordance with Poisson's equation.

Now I would like to discuss the distribution of this potential between the anode and the cathode. In this device we are dealing with cathodes and anodes that are geometrically alike. They are both filaments of the same size, symmetrically placed within the bulb and you can analyze the problem in this way. First of all you can consider what the distribution of potential would be if you had say 250 volts on one of these electrodes, say the anode and zero volts on the cathode, but the cathode is cold, so that it is emitting no electrons. Let us consider that we are dealing with a cold cathode and anode at 250 volts and we put the wall of the tube at the potential half-way between, that is 125 volts. Then the geometrical similarity of the two electrodes tells us that the field of the anode and cathode will be alike; that is in this case where we have no space charge. Now, if we then lower the wall potential to say plus four volts, which is the potential that Dr. Becker found in the beginning of the second stage——

Q. 6. You are in the third stage, Doctor.

A. (Continuing): —beginning at the third stage, I beg your pardon, if we change the potential of the walls from 125 volts to four volts positive, the effect of that change is to greatly increase the field around the anode and greatly decrease the field around the cathode.

Now, then, I have neglected to take into account the effect of space change. In general, if we have a symmetrical structure, as for instance, two parallel plates with the field between them, the effect of the space-charge is to give a high field at the anode, and decrease the field at the cathode, and this effect will take place in this tube. The effect of the space charge will be in general to still further increase the field near the anode and decrease it near the cathode.

This space charge effect is in this case furthermore exaggerated because of the fact that the electrons from the cathode are accelerated outward as soon as they get a little distance out past this small retarding field at the cathode, and travel out for short distances in nearly straight lines, and therefore rapidly get out of the field of the cathode what field there is. But then, in approaching the anode, they follow very crooked paths, more complicated than that of a comet coming into the solar system. They will describe orbits around these anode wires, and they may pass probably ten to fifty times around the wires, before they finally hit them by accident. They may circulate relatively long distances, and many times, before they finally strike the anode. Thus an electron may come almost to the anode, and then be thrown out into the outer regions of the bulb, and drift around relatively slowly and again come back and go very fast as it approaches the anode and is thrown out again by the field, somewhat as the comet approaches the sun.

The effect of that is that the electrons have great difficulty in getting towards the anode, but have no difficulty in getting away from the cathode. That exaggerates still further the space charge near the anode. Thus all these factors combine or act in the same direction, and I know no factor that would compensate for them. So that I conclude that in a device of this character, the field near the anode is many times stronger than the field near the cathode, and even at distances of several millimeters, or a few millimeters from the cathode and anode, that comparison holds.

Now, the walls of the tube tend to be negatively charged by the electrons from the filament and if there were no positive ions they would always charge up to a potential negative with respect to the cathode, but if there are some positive ions, these will tend to raise that potential until a balance is reached between the number of positive ions and the number of electrons that strike the walls.

Let us consider what the paths of the electrons are. The electron starts out from the cathode, moving very slowly, is accelerated by a relatively weak field, comes out into the larger volume of the bulb, and by that time probably has only a relatively small fraction of energy that it will have by the time that it gets to the anode. The result is there will be practically no ionization. I believe, in a tube of this character, when the current is limited by space charge in what is called the third stage, that throughout probably over 95 per cent. of the volume of the bulb there is no ionization whatever; that is, no ions are being produced by impact of electrons and gas molecules. There are certain numbers of positive ions in the space, but these are produced by collisions that take place relatively close to the anode.

Now, when they are produced close to the anode, they are produced in a region where there is the strongest field in the whole tube, and they are accelerated radially outwards from the anode, and are thrown out as quickly as possible from the region of the anode, and they are projected outward into a region where there is a relatively weak field, and thrown against the bulb. They are not directed towards the cathode, they are directed away from the anode, and only a few are headed towards the cathode.

The result is that of these positive ions that are thus formed, relatively few or only a negligible fraction of them get into the region close to the cathode.

Now, the effect of positive ions on space charge is most marked near the cathode. That is, if equal numbers of positive ions were introduced near the cathode or anode, other things being similar, the effect of positive ions in modifying current limited to space charge, is much greater where the electrons are near the cathode than it is when they are near the anode.

So that in this case, the fact that the positive ions are drawn on to the walls of the tube and in general, away from the cathode, means that the structure of a tube of this kind is particularly favorable. In fact, I can not think of a tube that would be more favorable in its design for suppressing the effect of positive ions in neutralizing space charge, than a tube of this character.

By Mr. Davis:

Q. 7. Can you compare the conditions in that respect, Doctor, in this tube, with the conditions in the ordinary radio tubes, and if you will, you might mention in that connection any other tubes you know of in which the reverse effect occurs in an exaggerated degree, for illustration.

Mr. Haight: I do not see how that will be rebuttal of anything that Dr. Becker has talked about; maybe I am wrong.

The Court: I will hear you, Mr. Davis, on your impression after discussion.

(Discussion.)

The Court: Will you read the question, Mr. Smart? (Question repeated as recorded.) I think, Mr. Davis, that is going back into your rebuttal.

Mr. Davis: I will withdraw the question, if your Honor please.

The Witness: I have not quite finished the last answer.

MR. DAVIS: I am sorry, Dr. Langmuir, if I interrupted you. I withdraw the question and ask the witness to finish his last answer.

THE WITNESS (continuing): I was speaking of the effect of this charge on the bulb with four volts, and it was stated by Dr. Becker that as the vacuum got better that changed gradually to a potential of something negative with respect to the negative end of the filament.

It is my opinion that the greater part, if not practically all of the reduction in current that takes place between the end of the second stage, and the lowest pressures or that would have taken place if the pressure had gone down to practically nothing, was due not to the effect of positive ions on the space charge in the tube, for I think that the positive ions are altogether too effectively removed by these fields that I have spoken of, to contribute appreciably to the space charge.

I think that the effect is probably almost entirely due to the changes in the bulb potential that result from the decreased supply of positive ions, as the pressure goes down. That has an amplifying effect and the small changes in the potential of the walls due to the change in the supply of positive ions will react back on the discharge between the anode and cathode and modify it.

Q. 8. I think you have a copy there, Doctor, of
2 Defendant's Exhibit No. 295. Will you please refer
to that copy and tell me whether or not you agree with
the statement, and if you disagree, please give your
reasons, which statement is printed or lettered on this
Exhibit No. 295:

> "If discharge had been substantially unaffected by positive ionization, the characteristic would have been within these bounds."

A. I have analyzed the experimental results in Experiment 291, which I think is in Plaintiff's Exhibit No. 99 in this case, and which are the data upon which the Defendant's Exhibit No. 295 are based. I have compared these data with the curves which Dr. Becker has given in Defendant's Exhibits Nos. 297 and 299, and I believe from these data that Dr. Becker has greatly exaggerated the change in current that would have resulted if the pressure had been lowered to a point where the further reduction of pressure would have had no appreciable effect.

This conclusion is based upon a re-examination of all the data, and I will try to give it as briefly as I can.

On a curve which I have here, which I have prepared, I have tabulated——

THE COURT: Can you all come up closer so that all of us can see it?

A. (Continuing.) I have repeated the table that Dr. Becker gave on the lower right-hand corner of Exhibit No. 295, using the same reference letters that he has, A, A-1, and so on, I have checked over the pressures that he has given, with two exceptions.

For the points C-1 and C-2, I have made a slight modification. For C-1, Dr. Becker gave the pressure 0.71 to 0.51. I think I can state very definitely that the pressure is .61, because I know the conditions under which the data were taken. I find by reference to this page of the notebook 1179——

MR. DAVIS: Just a minute, Doctor. I am afraid that won't be clear; that is Plaintiff's Exhibit No. 99.

THE WITNESS: No. 99.

THE CLERK: In this case No. 79.

A. That this current reading which is 3.9 milliamperes was taken at 2.20 o'clock, and with a gauge reading, was taken at 2.18, and one was taken at 2.21. These gauge readings were taken by Mr. Sweetser with watch in hand at exactly even minutes. The gauge was closed, or the mercury was raised exactly on the even minute, and it took about 35 seconds to take a gauge reading. The reading that was taken at the end of that time was, of course, entered up as the pressure at the beginning of that minute, so that they were taken with perfect regularity.

Now, I have simply taken the pressure two-thirds of the way between 2.18 and 2.21, because the pressure was decreasing at a steady rate, so that at 2.20, the pressure should have been two-thirds of the way between the pressures calculated preceding, and the subsequent reading, and that gives a pressure of 0.61 micron.

Now, in a similar way, I have gone back to the original data to get the values of the currents in milliamperes, because the original data are somewhat more accurate than the milliampere readings which were obtained from the original reading, by dividing by 16.5. The corrections are small, but I believe well worth making. So I have taken the original readings and have divided them by 16.5, instead of having taken the rougher calculations that Sweetser made, only using two figures, when he might have used three. The accuracy of the readings was in many cases to three significant figures. These are not very important changes.

Now, I have observed that in the two plots of the data with nitrogen, which Dr. Becker gave on Exhibits 297 and 299—and I can agree that are the data that are obtained from experiment 291, and which are plotted in his Exhibit No. 299—I find by examination of the lower ends of these curves, and for quite a distance along them, in fact, that they are quite well represented by parabolas. And if that is the case then in extrapolating to lower pressures—that is, in order to try to form an opinion as to what the current would have been if the pressure had been zero, (which is really what Dr. Becker attempts to do from these data), that the proper procedure is to extrapolate on a curve, obtained by plotting the current against the square of the pressure.

Now, I have produced two curves which are rather rough plots, but I think are substantially right. They are not as well drawn as they might be, but good enough, I think, to illustrate the point. I will mark the first curve sheet I referred to sheet A, and will mark the second one sheet B, and I will mark the third one, which I am going to refer to in a moment sheet C.

Now, the sheet B has been prepared from the data given from Dr. Becker in Exhibit No. 299.

On Sheet B, there were four curves marked A, B, C and D. Curve A is of the data that I have given for nitrogen on Exhibit No. 299, and D, is a parabola drawn to fit these points approximately. I think they fit them about as well as the experimental points do. At any rate sufficiently close for the purposes I have in mind.

If, on the other hand, instead of taking these two curves, I had plotted the squares on the pressures against the currents, then I would have obtained curves C and B, and for these curves the abscissa plotted at the top of the sheet should be used. Curve D then becomes a straight line, and curve B, which is obtained from experimental results, does not depart very greatly from the straight line.

I have done in Sheet C, the same thing, but the data are taken from Exhibit No. 297. I think these are self-explanatory, and there is a description on the sheet as to how the data were obtained. I think the fact that the experimental points fit as well as they do on a parabola mean that for the purpose of extrapolation, it is much better to use a plot against the square of the pressure, because it is much easier that way.

Now, the reason that I have done this, that I have gone back to analyze the data in this way, was that it was very apparent to me from even a preliminary examination of the data, that Dr. Becker produced, namely, of Exhibit No. 297, that the effect he obtained in his approximate duplicate tube of the variation of the current with pressure, was very much greater than that which I obtained in the experiments in August, and which were shown in this table, which is on the sheet A.

Now, for example, to make this clear: It should be noticed that in Exhibit No. 297, the highest pressure that was used and recorded was less than 0.3 micron, and the current was then about twice as great as it was with the best vacuum obtained.

Now, if we extrapolate on that curve in any reasonable way, for instance, if we use the parabolic extrapolation, we would find that the current would be close to three times as great at 0.5 micron, as it was at 0.3 micron. Well, now, referring to the data obtained in the experiment of August, 1912, it is very clear that the current, when the pressure fell from about 0.5 to 0.3 micron, that the changes were at the most, 20 per cent., instead of in the ratio of one to three; and for that reason, it seemed to me that we should use the data themselves in order to extrapolate back to the zero pressure rather than use data that were obtained in another experiment, especially when I would like to show later that conditions that would be hard to reproduce, may well affect the particular relationship, the quantitative relationship that exists between the current and the pressure in a tube of this character.

For this reason, therefore, I have plotted on sheet A all the currents corresponding to all the points on sheet A against the square of the pressure and

I have marked on the sheet the points and labeled each point.

Taking the point corresponding to B and C, there are four of these points altogether, plotted at the lower part of the curve, corresponding to the readings taken at 200 volts. It is seen that these four points, particularly the corresponding ones taken under similar conditions, give a very flat curve.

Whether we take B-1 and B-2, or whether we take C-1 and C-3, it does not make a great deal of difference in the result, and particularly taking the lower values under corresponding conditions such as C-1 and C-3, extrapolating back we find a current of 2.8 milliamperes as the current that you would have in high vacuum, which is only about five per cent lower than the observed readings C-3.

In other words, I believe from these data that if the pressure observed at point C-3 where the pressure was 0.43 micron had been lowered down to 0.1 micron or a few hundredths of a micron, the current would have gone down about five per cent. And I think that that change would been due almost entirely to the changes in the potential of the bulb and not to the effect of ~~ions~~ on the electron space charge.

Taking the data obtained at 250 volts we must consider first of all that these data are much less accurate because they were taken with a milliammeter and the readings were very small and they were only recorded apparently to the nearest half a milliampere so that the points do not lie as definitely on a regular curve as the upper ones.

Since several points were obtained at the highest pressure, that is, two points at A_0 and A_1 at a pressure of about a little over 0.5 micron, and taking the lowest pressure recorded where the current is four milliamperes and drawing a line between those two on the straight line plot, the current for zero pressure should be about 3.5 milliamperes.

However, if we take about the highest line which seems reasonable it might be about 4.6. So that we have an uncertainty somewhere between 3.5 to 4.6 as the probable range of current where the data should have come if the vacuum had been very much higher than it was.

This range of 3.5 to 4.6 extends beyond the range taken by the lowest points observed so that it is unlikely that the higher value (4.6) is to be considered as reliable.

On this Exhibit 295 the range that I have just spoken of would come at 250 volts from 3.5 milliamperes up to 4.6. That is the range which you calculate here which is far above the range given by Dr. Becker as the range that he estimated would have obtained if the vacuum had been higher.

If we take the lower point as the one that is best established, that is, at the lower voltage around 200 volts, that point comes at about 205 volts and 2.8 milliamperes, and if you take that point and assume that the current is according to the 3/2 power law, we find the point at 200 volts should be at 3.8 milliamperes and that comes within the limitation of uncertainty.

Q. 9. Referring now to Defendant's Exhibit 298 which was also one of Dr. Becker's curve sheets, do you find the alleged variation with pressure variation of current limited by space charge a normal characteristic of the tube in question and will you please discuss that?

A. Dr. Becker has quite correctly taken the data that was recorded in Experiment 317, Plaintiff's Exhibit 100, and has shown that as the filament temperature was raised the currents became constant above a certain temperature and he has concluded that these currents are limited by space charge.

He pointed out that in one case, curve 6, the current was over five times as great as it would have been at the same voltage with a high vacuum, with the same voltage on the electrodes.

I believe that this high value of five for this ratio was only possible in these runs because of the high series resistance of 16,500 ohms; in fact, I know that that must have been a very important factor and it is the reason that the values were as high as this. I have analyzed through the experimental data and find I think conclusive evidence that this factor was very important in these runs.

Mr. Davis: Dr. Langmuir, permit me to interrupt you. I would like to offer in evidence, if I may, the three plots referred to by the witness in his last answer which he lettered respectively A, B and C.

(Received in evidence and marked respectively "Plaintiff's Exhibits 219-A, 219-B and 219-C." *See Volume IV, Plaintiff's Exhibits, pages 358-360.*)

A. (Continued): I believe that the series resistance in this case functioned in accordance with the principle that was utilized by Dr. Arnold in the patent that has been referred to in this case where the presence of the series resistance stabilized the discharge so that the blue glow did not occur.

Now, I would like to explain how in this case the resistance was effective and just what effect it did have.

I have taken from the data of experiment 317 the runs that were made with nitrogen at various pressures and that are recorded at 1399 to 1403 of the record sheets.

There are not a great many points but the points enable us to conclude that the observed currents which were limited by space charge, that is, space charge in this case modified or influenced by charges on the wall which I believe is the main factor, that these currents varied with the voltage in the way that I have shown in the curve that I now call sheet D.

D

Mr. Davis: Which sheet I now offer in evidence.

(Received in evidence and marked "Plaintiff's Exhibit No. 220." *See Volume IV, Plaintiff's Exhibits, page 361.*)

A. (Continued): There are several points that are not recorded here that were obtained with very good vacuum, that is, with pressures in some cases, of considerably less than 0.1 micron and in some cases a little over 0.1 micron which were not recorded but which were used to draw the 3/2 power line which I have marked by the curve C on this plot. There were points around 100 volts and points up around 190 volts or 180 volts and they agreed excellently with the 3/2 power law.

It is very evident that if we go down to voltages close to ionizing voltages there will be very little ionization no matter what the gas pressure would be. That small amount of ionization, whether it led to a change in the wall potential or led to a modification of the space charge, in either case would not have any material effect so that the current voltage curves that are obtained for any given pressure, should all join the high vacuum curve at voltages in the neighborhood of the ionization voltage.

Take for instance when the pressure of nitrogen was from 1.0 to 1.1 micron. There are three points, one at about 100 volts, one at about a little over 120 and one at about 136 volts. Those three points show a rise above the 3/2 power law so that the current is going up considerably steeper than the 3/2 power law.

With six-tenths of a micron there are two points again which enable us to draw a curve the dotted portions of which I have drawn by extrapolation; more or less guessed at them, but I believe in a reasonable way and in a way that is in accord with other experiments I made at different times.

The curve that I have marked at about 0.3 micron has no observed points and I have simply interpolated between the curves at 0.6 micron, and the highest vacuum curves, and I meant to do it according to the parabolic law. Thus the pressure being about half-way between those two and I took the current increments about one-quarter as great. It is only a rough estimate anyway.

The observed points were of two kinds, some were taken at 250 volts and some were taken with 125 volts as line voltage, but there was a resistance of 16,500 ohms in the series so that the actual voltage on the anode fell off according to the dotted line which I have marked E in one case on the 250-volt potentials and F when 125 volts was used.

At the pressure of 1.8 microns, I only have one point and that point was not on a flat top curve so that I am not very sure of its exact position, but I believe it is substantially right.

I believe from various things that I have observed in more recent experiments that at higher pressures the curve should not rise the way I had originally drawn curve A, passing through the point of 1.8 microns but should bend back, that is, should go as I have drawn curve B, should bend backwards at a certain point.

Actually such a curve as that can never be observed experimentally except by putting in series resistance and I have made many such measurements of "negative resistance characteristics" of gassy tubes and have even used such tube as a method of producing oscillations and have studied them in great detail.

Although I have no proof in this regard, it is my opinion that several of these curves should bend back at the upper ends and I believe further that they bend back at a value of current which is about twice the value that you would get in high vacuum, I believe that without resistance you can only get about twice as high a current as you would get in a perfect vacuum.

By the introduction of gas in a tube such as that which was used in August, you can only go to about twice that value of current unless you put in a high series resistance in order to stabilize that discharge and thus enable you to balance out the negative resistance of the voltampere characteristic.

I do not know that I can make this any clearer and perhaps it is not worth while, but the point I wish to make is that from these considerations and from experience I have had with the negative characteristics I know the importance of a series resistance and I know that from this tube, the curves for which were shown by Dr. Becker (where in Exhibit 298 such large ratios as five to one were obtained), it would not have been possible to obtain such large increases in current if a definite voltage had been applied to the anode. They have only been possible by the use of a large series resistance.

Q. 10. Have you completed your discussion of the effect of gas in limiting space charge as affected by voltage, is that fully completed?

A. There is just one further point and that is there is a relation between what I have just said and what I have said in the preceding answer. From these data, the curve which I have drawn at 0.3 micron, which I believe to be reasonable, would indicate that at 250 volts, the current I believe would have gone up about 30 per cent., this is not the device of August, it is the device of experiment 317 which was very much like it, except it had a smaller bulb. At 200 volts the current would have gone up only a little over 10 per cent. as the result of 0.3 micron as compared to what it would have been in high vacuum.

Those increments are of the same order of magnitude as the values that I have discussed in the preceding answer where I found that values of 5 or 10 per cent. or so below the lowest points recorded would have been the values corresponding to the highest vacuum.

I believe in that connection that this way of getting at the data is much better than following the suggestion made by Dr. Becker when he tried to compare the two curves of Exhibits 297 and 299. He said that the distance between the electrodes in Experiment 317 was 3 millimeters and in 291 it was about 12 millimeters. He is right when he suggested that that three millimeters was at the tip of the filament. The effective distance between the filaments would be very much more than that because at the upper end the filaments were probably half an inch apart or 12 millimeters.

Dr. Becker, I think, overemphasized the cooling effect of the leads which would extend not over 10 per cent. of the way along the filament, not very far down from the leads, so that the electrons were emitted in large numbers nearly all along the length of the filament.

Dr. Becker suggested that by having the filament further—he took the illustration of its being four times as far in one case as in the other, that therefore you would get something like four times as much ionization in one case as in the other. That does not apply at all to a device of this character.

If you had a filament between two parallel plates as you have more or less in the radio tubes, the electrons that come out of the filament go to the anode and terminate on the anode surface after having travelled about the distance between the anode and the cathode. But in this case they formed orbits around it and I have no way of telling how the lengths of the orbits varied as the distance between the filaments increased or how much greater the chances of ionization became when the distance between the two electrodes is increased from 3 millimeters or 10 or 12 millimeters. In any case the electrons travel many times the distance between the electrodes and I believe that the amount of ionization would be relatively uninfluenced by the distance between the electrodes. I see no reason why the data of experiment 317 for the effect of gas should not be comparable with that of 291.

I do not know just what effect the bulb size would have. The data as far as I can examine them seem to indicate that the effect of gas pressure in the August experiment, 291, was a little less than it was in the experiment of November and December, 317.

Q. 11. Were you present this afternoon when Dr. Arnold demonstrated the tube in blue glow?

A. Yes.

Q. 12. Do you consider that the blue glow which was present when the tungsten filament was lighted or was functioning was the same as that which was present when the Wehnelt filament was functioning?

A. No, I do not think it was.

Q. 13. Please state your reasons.

A. In the first place I was not able to see any blue glow at all, and I believe I would have been able to see blue glow if there were as much as there was in the other case. In looking at the construction of the tube, and besides the effect that was spoken of, that the current was only about three-quarters as great with the tungsten filament as with the Wehnelt oxide——

Q. 14. And by current you mean space current?

A. Yes, it seems to me that it is one factor that I would expect at least to be of vital importance in determining a difference between the discharge in these two cases.

The tungsten filament is a three mil. wire in the form of a V, very small wire in the form of a V. The Wehnelt cathode is in the form of a ribbon which is over one-sixteenth of an inch wide, about that, maybe a little more, flat as a ribbon, which is also bent in the form of a V, parallel to the V of the tungsten filament, but the plane of the ribbon is perpendicular to the plates.

As I have said, I think several times already, at these high gas pressures where space charge is eliminated (and it certainly would be in the neighborhood of the electrodes in a device like this with eight microns of argon) there would be a very thin layer over the surface of the cathode in which the cathode drop occurs. In the case of the small tungsten wire that will be a little cylinder surrounding the filament in which there is a large positive ion space charge, and in the case of the ribbon it would take the form of a little thin, flat layer over each of the two faces of the ribbon. The electrons acquire their velocity, practically corresponding to the anode potential, in traveling this minute distance close to the cathode.

In the case of the tungsten filament the electrons are thrown radially out from the filament in all directions, so that a very large fraction of those—the filaments are more or less vertical and from each leg of that filament the electrons are thrown out in all directions and about three-quarters of those electrons will strike the anode traveling a distance not much more than half the distance between the plates. In other words, they will travel six or seven millimeters on the average before they strike one of the plates. A few of those electrons will escape out between the plates and they will go out into the gas and travel along straight lines until they either collide with gas molecules or become acted upon by the field which is close to the glass and thus return back into the discharge, so that ultimately they either reach the anode, or other electrons which are produced by ionization take their place and reach the anode.

In the case of the Wehnelt cathode the sheath will be a little thin, flat layer over each leg of the ribbon filament. The electrons will be projected in a direction parallel to the plate. Practically none of the electrons that get out of that filament will go straight to the plate, they will all move at first at right angles to it, projected out in a perfectly definite path and they will have to go back across the tube a good many times before they can possibly strike the anode.

Therefore the average distance that the electrons will travel coming from the Wehnelt cathode will probably be many times greater than the distance that the electrons travel that originate with the tungsten filament.

There is one other point that seemed to me rather peculiar in connection with the experiment and that is the use of argon. Blue glow or glow of any kind in a gas is very different for different gases. If you take for example an electric discharge in neon or in argon at the same current you get more light from neon than you do from argon. The reason for that is that although argon produces probably just as much light as neon does in a given electric discharge, it so happens that nearly all the energy lies in the ultra-violet part of the spectrum which is invisible to the eye.

Neon produces; nearly all the light that it produces is in the visible spectrum. Different gases are entirely different with regard to the effect that they have in producing visible light, and argon is one of the gases that produces relatively less light than any of the others. It produces very little light.

You cannot build an argon lamp but a neon lamp is an efficient source of light. Argon probably would not give one one-hundredth as much light as neon under similar conditions.

Q. 15. Can you have blue glow without ionization?

A. Ionization is not the cause of the blue glow. It is perfectly possible to have a discharge in which there is a great deal of light produced, a glow throughout the whole bulb without any appreciable ionization of the gas as such. Glow in the gas is due not to ionization but to excitations of the atoms. It is due to the impact of electrons against atoms and molecules by which the electrons in the atoms are not knocked out of the atom but are displaced to other possible positions in the atom, and when they return they emit light.

Blue glow does not necessarily run parallel with ionization. Certainly the intensity of light due to it does not run parallel with ionization or other characteristics of the discharge except in so far as the given gas and given conditions with a given voltage and vary the current.

In general the more current you get the more light, but I have seen cases where just the reverse is true. I have seen a discharge in nitrogen where by increasing the current you absolutely stop the luminosity. I have seen currents of amperes in a mercury arc where I have not been able to see light at all as compared with a gas where there was less ionization and many times more light. In different parts of the same discharge tube you may have very great ionization in one place and very little light, and very much smaller ionization in another place with a great deal of light.

Q. 16. I want to be sure about the identification. This is the tube which you have in your hand and of which you were speaking in your answer with reference to the blue glow test this morning.

A. Yes.

Q. 17. And that is Defendant's Exhibit No. 329?

A. Yes.

MR. DAVIS: Direct examination closed.

(After a short recess.)

MR. DARBY: We have no cross-examination, your Honor.

THE COURT: What further evidence have you, Mr. Davis?

MR. DAVIS: I have merely, if your Honor please, to express the thanks of myself and my associates, and counsel on the other side, for the very great patience and kindness you have shown during this trial.

THE COURT: I appreciate very much the expression of those sentiments, but I want also to express to counsel in this case particularly, probably more so than any other, my realization of the great patience that they have had with me, layman, entirely unfamiliar with the art, and if you will be good enough, both of you, when you prepare your briefs, to forget that I sat in this case, and that I am taking it up afresh, as if I had not had the benefit of this trial, I think I will be able to make greater progress than if you presume possibly that I had learned something during the trial. I shall then be that much ahead, if I have done so.

MR. HAIGHT: When does your Honor wish to fix a time for argument?

THE COURT: I assume probably two days is what you want. March 9th and 10th. We will adjourn court until tomorrow at nine o'clock.

(Whereupon at 5.30 P. M., on November 11, 1926, the taking of testimony was closed.)

APPENDIX TO PLAINTIFF'S RECORD.

[Note: Taken under Rule 46. *See Volume II, page 1227.*]

A. I think that the long question had a "whether" in it, so that it cannot be answered as a yes or no question. I will have to ask to have it read. I thought you asked whether one thing happened or another?

Mr. Davis: Please read the question, Mr. Stenographer.

(Question repeated as follows: "Is it or is it not true that Professor Wien is a very distinguished physicist who has won the Nobel Prize and who has done a great deal of work and published a great deal on electrons and their properties——")

The Witness: May I answer that?

Mr. Davis: If you will, Doctor.

The Witness: It is true.

(The stenographer repeated the further part of the question as follows: "That you met Dr. Wien at dinner in the spring of 1913, and that you then and there discussed with him that you and your associates at Schenectady had tubes which operated by pure electron discharge, substantially independent of positive ionization?")

Mr. Davis: Will you please answer that, Doctor, under the rule?

The Witness: That is true also.

(The stenographer then repeated the further part of the question as follows: "And if your answer to that question is 'yes,' then I will ask you whether or not Professor Wien on hearing that statement expressed astonishment or incredulity?")

THE COURT: That asks for a witness's conclusion, and the only question that I could conceive would be on the border line of admissibility would be the one which asks what he did when that disclosure was made.

By MR. DAVIS:

Q. 179. Will you please answer that question, Dr. Langmuir, and state what Dr. Wien did when that was explained to him?

A. He expressed the utmost incredulity.

MR. HAIGHT: I ask that be stricken out.

THE COURT: I am not going to do that, because it is under Rule 46, and it is out any way, but it seems to me, Mr. Davis, if you want anything to be stated at all under Rule 46, to stay in, and be of any value, I may be wrong on the main proposition, but the answer of the witness would have to embody facts and not a conclusion of the witness.

Q. 180. Please state facts, Dr. Langmuir, as to what he did, whether he sat quiet, or whether he did not sit quiet, and what he said, if he said anything?

A. In referring to my statements that we had obtained pure electron discharges in the very highest vacuum, he said: "Dass kann nicht sein"—"That can't be so," and then told me of the work that had been done in Germany by various physicists, which he believed, or he stated he believed, proved to him that in a perfect vacuum, or a nearly perfect vacuum, electron currents could not be obtained from hot cathodes.

MR. DAVIS: Now, that is all subject to the rule, as I understand it, absolutely.

MR. HAIGHT: I am not entirely sure how that should be handled. Does that actually appear in the record at that point under the rule?

THE COURT: It will not appear in the record.

Mr. Haight: It should not be separated and put out?

The Court: No, that should be separated. I thought you meant whether it should be spread at large somewhere in that form.

Mr. Haight: I have no objection to that. I do not want it to appear in the body of this testimony.

The Court: That should appear in an appendix to the record.

Mr. Haight: Yes, sir.

OPINION OF COURT
(Filed January 3, 1928)

IN THE DISTRICT COURT OF THE UNITED STATES,
FOR THE DISTRICT OF DELAWARE.

General Electric Company,
Plaintiff,
v.
The De Forest Radio Company
Defendant.

IN EQUITY.
Nos. 589 and 598.

These two suits of General Electric Company against De Forest Radio Company were tried together. In the first suit all the claims of patent No. 1,558,436, granted to Irving Langmuir, assignor to the plaintiff, October 20, 1925, for "electrical discharge apparatus and process of preparing and using the same" upon an application filed October 16, 1913, and renewed March 14, 1916, are in issue. It is known as the high vacuum tube patent. Infringement is conceded if the claims are valid. Validity is denied for want of invention and novelty and because of prior knowledge and use, for double patenting and upon the ground that Harold D. Arnold, not Langmuir, was the first inventor.

The specification, claims and testimony are so interwoven with scientific theories, more or less abstruse, that it is somewhat difficult to isolate and keep separate from the principles of physics involved Langmuir's conception and idea of means. Yet an analysis of the Langmuir device and its elements discloses that, apart from its functioning and results, it is nothing more nor less than a Fleming valve or De Forest audion, for example, in which a higher vacuum, maintainable during operation, exists. How much higher the vacuum must be to bring the tube within the patent is not definitely fixed in terms of pressure. The specification states merely that "the evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned". A micron is a pressure equal to a millionth of a meter or a thousandth of a millimeter of mercury. It corresponds to a barometer reading of that value. The normal barometer reading in the open air is about 760 millimeters. The justification for the failure to assign definite pressure limits is that the invention "comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization"—a device in which the residual gases play no part in the operation. The results desired to be obtained are stability and reproducibility of operation and increase of power. The production of these results by the specified manner of functioning is dependent not on the degree of vacuum alone but upon four co-ordinating variables—geometry or relation of parts of the tube, temperature of cathode, voltage of anode and degree of vacuum. This fact makes it apparently unavoidable that the claims be functional in form. But they must, of course, be construed to cover the thing. Walker on Patents, § 183. Claim 26 is comparatively simple. It is:

> "A discharge device comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes, the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge, so that the device is capable of passing a sustained discharge

of one-tenth of a milliampere at forty volts, without developing any substantial positive ionization effects."

The Fleming and De Forest tubes are "discharge devices comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes". The next clause of the claim—"the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge"—has to do with the manner and degree of evacuation. Underlying this clause are these facts: The glass wall and the electrodes harbor large volumes of occluded gases. Heat is necessary to expel these gases so they may be removed by the pump. If not removed before the tube is sealed off the heat occurring during the operation of the tube expels them, destroying in large degree the vacuum. "The spacing of the electrodes"—one illustration of the geometry of the tube—is a factor because the permissible gas pressure in the tube increases with the proximity of the electrodes to each other. This varying relation is due to the fact that the opportunity for the electrons to collide with gas molecules varies with the length of the path the electrons have to travel. "The energy of the discharge" may be interpreted in terms of power which is the product of the current values and the voltage. The unit of current flow is the ampere or the current which flows at a pressure of one volt through a closed circuit having a resistance of one ohm. The power of a circuit having a pressure of one volt and a current of one ampere is one watt. The power output of the device of claim 26 is .004 of a watt or 4 milliwatts. An increase of energy means an increase in the number and velocity of the electrons passing from cathode to anode and consequently an increase in the number and effect of collisions of electrons with gas molecules. It follows, of course, that if the maximum voltage at which a given tube will function without ionization is increased ionization will occur and the tube fail to function in the manner specified in the patent. "Ionization", by which is meant the conversion of atoms or molecules into ions, is explained by the "Electron Theory". By this all atoms known to chemistry are deemed to be made up of a nucleus endowed with a permanent positive electrical charge around which one or more electrons, each of which has mass or weight and carries, or is, a natural unit of electricity, revolve at inconceivably great speeds in regular orbits in somewhat the same manner as that in which the planets of our solar system revolve about the sun. According to this hypothesis the chief difference between the chemical atoms lies in the number and arrangement of their electrons. Under normal conditions the electrons are maintained within their atoms and in their orbits by the attractive force of the positive nucleus which, electrically, exactly balances and neutralizes the negative charge of the electrons of the atom. Consequently every atom having its normal complement of electrons exhibits no electrical effects. If, however, by impact, or otherwise, an atom loses an electron and becomes an ion it is thrown out of electrical balance. The positively charged nucleus predominates and exhibits a unit positive charge. In thermionic tubes ions are created by the impact upon the gas atoms or molecules of some of the myriads of electrons constituting the current flowing from the hot cathode to the cold anode—the Edison Effect. See *Westinghouse Elec. & Mfg. Co. v. De Forest Radio Tel. & Tel. Co.*, 21 Fed. (2d) 918. To dislodge an electron from its atom the colliding electron must have sufficient momentum. The velocity required for this momentum is given to the electrons mainly by the pull or attractive force of the positively charged anode. The strength of the pull increases, other conditions being stable, with the anode voltage. For the gases with which we are here concerned 15 to 25 or 30 volts constitute the ionizing voltages.

When substantial numbers of atoms or molecules are being converted into positive ions by the electron stream the "ionization effects" forbidden by claim 26 occur. One effect of ionization is an increase in the current across the tube over the value it would have at the same voltage in the particular tube were the vacuum sufficiently high to prevent ionization. Such increase is due to two facts. First, the electrons, being negative charges of electricity, tend in the absence of a countervailing force, violently to repel one another and thus to diminish the number, and, so, the value of the current, passing to the anode. Positive ions in the field constitute a countervailing force and consequently expedite the flow of the electrons to the anode. Second, the positively charged ions are drawn with great force to the cathode, the negative electrode, bombard it and thus increase its temperature. As the electron emissivity of the cathode increases with its temperature the ion bombardment of the cathode serves to increase the supply of electrons and consequently the current passing to the anode. This bombardment is so severe that, if continued, it destroys the filamentary cathode. Another effect to which substantial ionization usually gives rise is a blue glow in the tube. This, as I understand it, is accounted for upon the hypothesis that as the electrons are shifted in the atom, by impact of the electrons, from one orbit to another at prodigious speeds they produce waves or vibrations in the ether which constitute light. The ultimate effect or result of ionization is an unstable, non-reproducible and, in a measure, non-controllable current. As it is necessary, in order to prevent the destruction of the cathode and obtain a stable current, to operate gassy tubes below ionization, their power output—the product of current and voltage—was limited. These constitute obvious defects.

These defects are not present in the tube of the patent. It operates without substantial ionization. When there is no substantial ionization the current increases and decreases in a fixed relation to the voltage of the anode unless and until the anode voltage is made sufficiently high to draw to the anode all the electrons emitted at the cathode. The electronic emissivity of a given cathode increases with its temperature. This fact is known as "Richardson's Law". When a voltage high enough to carry across the tube all the electrons emitted is reached a further increase of voltage, which has no power to increase the supply of electrons of which the current consists beyond the limit of emissivity imposed by the temperature of the cathode, produces, of course, substantially no change in current. The current that is thus substantially independent of the voltage is known as the saturation current. Operation of the tube above and below this critical voltage is spoken of as in the saturation region and below saturation respectively. If a tube is operating below saturation an increase of the electron supply by an increase of cathode temperature, but with no increase in voltage, produces no marked change in the current. Decreasing the electrons emitted by the cathode by decreasing the cathode temperature is likewise without effect upon the current, provided, of course, that the decrease in the supply of electrons is limited to the electrons emitted in excess of those pulled across the tube by the given voltage. The fact that if the anode voltage remains stable the current can not be increased by an increase of the cathode temperature, beyond that required to supply the electrons capable of being pulled across the tube at the given voltage is illustrated by the "flat top temperature curve" on the following graph:

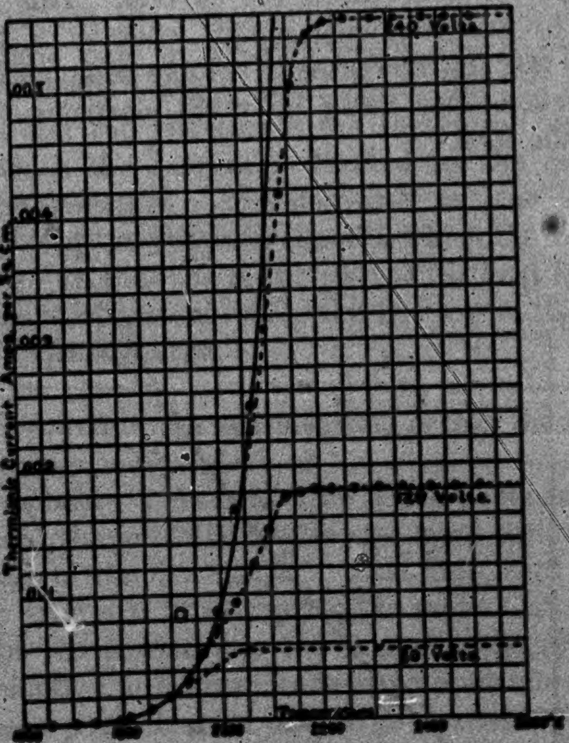
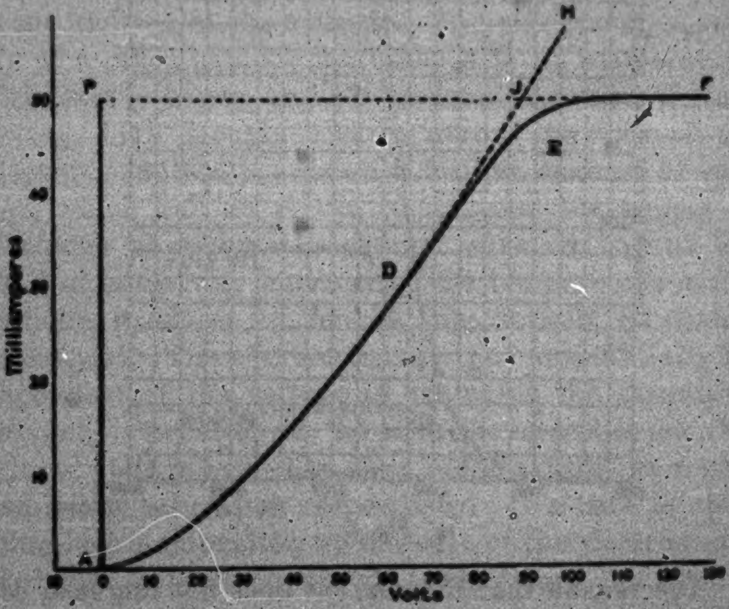


Fig. 1.

The reason that the current does not increase beyond a certain point dependent upon anode voltage with the increase of the temperature of the cathode is that the electrons, all being negatively charged, exert powerful repelling forces on one another. When this force of repulsion equalizes the pull or effect of the voltage on the anode, the anode is without power to draw to itself a greater number of electrons. The current-limiting effect of the electric field of the electrons on one another is known as the "space charge effect".

It is space charge which produces the flat top of the temperature emission curve in the foregoing graph.

When the temperature of a cathode is fixed and constant and the voltage is increased the limitation upon the electrons limits the current. This is illustrated by the following graph whereby it appears that the last few increases in voltage make no increase in current—there being no more electrons to draw across the tube.



The curve of this graph which when plotted on logarithmic paper appears, up to the point approaching saturation, as a straight line, discloses a relation existing between current and voltage. That relation is expressed in the specification thus:

> "In most devices of simple construction which embody my invention, the discharge current passing through a given space with the cathode at a sufficiently high temperature with respect to the

> voltages employed, varies directly with the 3/2 power [square root of the cube] of the impressed voltages."

"A" to "D" of the curve on the current-voltage chart, in which the temperature is constant, is the space charge part or that in which the current is limited by anode voltage and follows the 3/2 power law. The flat top represents the saturation part or that in which the current is limited by the cathode and its temperature. The converse is true in the first or current-temperature chart in which the voltage is constant. In that the rising part is the part limited by cathode temperature while the flat top is the part limited by space charge.

Another characteristic peculiar to the tube of the patent, as stated in the specification, is that the device is "practically independent of the pressure when the pressure is below a certain value which depends upon the size and shape of the device and upon the current and voltage of the discharge". That statement is undoubtedly true if it be interpreted to mean that if in a given tube the pressure is low enough to enable the tube to function at a given voltage without ionization, that is, as a pure electron discharge device, a further decrease in the pressure will not affect the discharge. It is likewise true that if the pressure is less than that required for a given voltage in a given tube it may be increased up to the pressure immediately below that at which substantial ionization would occur at the given voltage, without affecting the discharge. The discharge, however, is in no sense independent of the pressure if the maximum voltage at which a given tube will function without ionization is increased, for ionization would instantly occur and the tube fail to function in the manner specified in the patent. In such instance a decrease in pressure simultaneously with the increase in voltage would be necessary to avoid ionization. In its simplest aspect this is due, of course, to the fact that if ionization is to be avoided above ionization voltages collisions must be avoided between electrons and gas molecules and that the number of collisions in a given tube, dependent upon the relative density of the two, is increased, the pressure being stable, by an increase in the number of electrons pulled to the anode by the increased voltage.

These scientific explanations, arising mainly out of the electron theory, of the functioning of the high vacuum tube change not at all the fact that it differs structurally from the Fleming valve and De Forest audion only in the degree of vacuum maintainable during operation. This was expressly conceded during the pendency of the application in the Patent Office. The fundamental questions here in issue are not changed and their solutions are, I think, but little affected by the theories by which the functioning of the high vacuum tube is accounted for. If it was not known to those skilled in the art how to produce, in a Fleming or De Forest structure, for example, a vacuum sufficiently high to enable the tube to function above ionization voltages without substantial ionization and Langmuir solved the problem and made the necessary disclosure of its solution in his patent, manifestly he would be entitled to a patent for his disclosed method and device as a reward quite apart from his knowledge or lack of it with respect to scientific principles or laws of physics explaining the functioning brought about by the high vacuum. Moreover, independently of whether or not invention was necessary to create a vacuum of the required degree, Langmuir would be entitled, I take it, to a patent for his device regardless of his ability or inability to explain its functioning in principles of physics, if he was the first to appreciate that a high vacuum maintainable during operation in a Fleming or De Forest structure, for example, would constitute means whereby the results produced by the high vacuum tube could be accomplished, provided, of course, he reduced to practice with reasonable diligence the device of his mind.

Upon the question whether the claims for the process of making the high vacuum tube or those for the tube itself, which because of its stability, reproducibility and power has made possible radio broadcasting, modern radio reception and long distance telephony, involve novelty and invention the parties differ widely. The plaintiff asserts, with apparent confidence, that the patent is for invention of a high order —equal to or greater than that of De Forest for the three electrode tube. The defendant, with equal confidence, finds not only all that Langmuir did but all that he discloses with respect to the principles in accordance with which the device functions spread upon the records of the prior art. Since the Fleming valve and the De Forest audion were old and the structure of the tube of the patent differs from these only in the degree of vacuum maintainable during operation the first crucial question is whether claims 30, 31 and 32, directed to the process of making tubes having a vacuum of the required degree are valid. Claim 31 is:

> "In the process of producing a hot cathode discharge device, treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein, continuing these operations until the occluded and original free gas is so thoroughly removed as to enable the finished sealed-off device to operate below saturation in a stable and reproducible manner at a voltage above fifty volts and with a current greater than one milliampere and with the energy of the discharge delivered mainly at one or more anodes."

To find wherein, if at all, this and the other process claims go beyond the discoveries and ideas of others, beyond the use of wise judgment in selecting and combining those discoveries and ideas, or beyond mechanical skill in applying them to practical results, the specification and the prior art must be examined. The specification states:

> "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. The heating, especially of solid anodes such as shown in Figure 2, may take place in a suitable vacuum furnace, the temperature preferably being raised to 2,500° C. or even higher. Bombardment is a very effective means of removing occluded gas from anodes."

The steps and precautions requisite to successfully evacuate by bombardment are then described after which the specification adds:

> "After the metal has been freed from occluded gas reabsorption of gas will not readily take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated with less electron bombardment of the anode or

> anodes. . . . It is also true that when the anode has been carefully freed from gas, residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated."

The prior art, however, as I understand it, discloses that long before the earliest date claimed for Langmuir it was known not only that large quantities of gas are occluded in the glass walls and electrodes of an electrical discharge device and that unless removed before or during evacuation the gas will be driven out by the heat of operation and thus detrimentally increase the pressure of the vacuum, but also that the occluded gases could be removed and the vacuum created and maintained by the very steps prescribed by Langmuir for removing the occluded and free gases of his device. In May, 1896, the "American Electrician" published an article by Thomas Duncan in which he said:

> "If an incandescent lamp be exhausted until no air can be seen escaping through the valves of the pump, and the filament then incandesced, considerable quantities of air will be expelled at each operation of the pump, thereby showing that this air has been occluded in the pores of the carbon filament, and could not have been gotten rid of without heating the filament and driving the air out into the vacuous space surrounding it.
>
> "This heating also assists in drawing off the air which clings or adheres against the glass upon the inside of the bulb. . . . If the electrodes are made from aluminum or other porous metal, the secondary terminals from a spark coil can be applied to them, and set in operation in a similar manner to that in which the tube is to be used afterwards. This cannot help but be a ready and satisfactory means of eliminating the air occluded within the electrodes."

A résumé of Incandescent Electric Lamp Exhausting by S. E. Doane, published in the "Electrical World and Engineer" of May 21, 1904, says:

> "The exhausting of incandescent electric lamps has developed into a highly specialized branch of the lamp manufacture. . . . The completed lamp must not only be free from gases and vapors, but must also have had those parts capable of giving off gases and vapors, thoroughly freed from them. The only way we knew to accomplish this was to highly heat everything we wished to free from gas. We had three things to heat: the glass, the filaments and the joints between filaments and leading-in wires.
>
> "The glass was heated by an asbestos cone-shaped hood painted black on the inside. The heat from the lighted lamp furnished all the heat necessary. The lamps could be heated hot enough to cause the bulb to collapse if the hoods were made too thick. The filaments were also heated sufficiently by the current, . . ."

Dwyer, in his Patent No. 596,694, granted January 4, 1898, for a process of producing high vacuums in incandescent electric lamps or similar receptacles during their manufacture recites that in the past such lamps have been exhausted by mechanical pumps, "by chemical processes involving the displacement or absorption of the gases contained in the lamp, or by combinations of these processes". He says that a partial vacuum is readily obtained by a good mechanical or mercurial pump but that complete exhaustion by this means alone is not possible. He then adds:

> "To carry the vacuum still higher, it has been a common practice to heat the lamp-bulb by either an external source of heat, such as a gas-flame, or by an electric current passed through the lamp-filament, or by both of these means combined, so as to expand the gases in the lamp, and also to

> drive off from the lamp-filament itself and its supports, more particularly the joint between the leading-in wires and the filament, which joint is usually made of some form of hydrocarbon paste, gases occluded therein, while continuing the pumping operation."

Soddy, in his Patent No. 859,021 of July 2, 1907, for the employment of certain reagents in the process of producing high vacuum, declares:

> "In the production of high vacua not only has the air to be removed but also the gases occluded or condensed on the walls of the vessel being exhausted and on the contained electrodes or filaments or other contents of the said vessel, which condensed gases are given up slowly after exhaustion and if not removed during the exhaustion cause the vacuum to deteriorate. . . .
>
> "The heating and expelling of the condensed and occluded gases may be effected in any usual, or suitable, manner of expelling condensed or occluded gases from the walls and contents of vessels being exhausted. The usual manner of effecting such an operation is to heat the vessel while it and its contents are subjected to the same treatment as they are subjected to in after use. In incandescent electric lamps for example an electric current is passed through the filament, and in X-ray bulbs an electric discharge is passed between the electrodes during the continuation of the exhaustion."

Many other references disclose the baking of the walls of the envelope of a discharge device, the heating of the electrodes, incandescing the filament and electron bombardment of metallic electrodes to expel occluded gases. The gas clean-up effect was likewise old at the time Langmuir began his operations. One instance of its disclosure is in patent to Thatcher No. 1,028,636, granted June 4, 1912, application for which was filed March 30, 1910, for method of exhausting vessels, in which it is said in part:

> "I institute the intensive incandescence of the filament proper, that is I bring the current voltage up to a sufficient intensity to produce the blue haze phenomenon, and maintain the same until the blue haze disappears and the desired almost perfect vacuum is attained, . . . "

Dr. E. Leon Chaffee testified (R., Vol. 1, p. 159):

> "It has long been known that the existence of this blue glow improves the vacuum, probably by bombarding the walls with gas ions and consequently causing them to stick to the glass walls. . . . "

These steps of the prior art are the identical steps disclosed by Langmuir. Nor are his disclosures with respect to how these steps are to be employed any more ample or complete with the possible exception of heating by bombardment. But bombardment has no saving power for the claims are not restricted to heating by bombardment. They are broad enough to include any method of "treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein". The plaintiff, however, places some reliance upon the clause in the claims directing continuance of the steps until the desired vacuum is attained and cites *Badische v. Kalle*, 104 Fed. 802. But in that case those skilled in the art were of the opinion that a more prolonged or intense application of the old steps would not accomplish the desired result. Such is not the evidence here as I understand it. Moreover, the tools of the evacuating art were constantly improving. In the early days of the incandescent lamp art manufacturers used the Sprengle pump to obtain their vacua. It gave way to the Geissler pump which, in its turn was superseded or supplemented by chemical evacuating processes. It is, I think, not denied that these old pumps and at least some of the chemical processes left in the tube mercury or other vapors having a pressure too high for the tube of the patent. But if Langmuir makes in his specification any disclosure of steps or means to avoid that result it is by the use of the new, improved Gaede molecular pump. That pump is highly efficient and, when properly used, leaves no free gas or vapor that will prevent the functioning of a thermionic tube above ionization voltages without substantial ionization. But Langmuir is entitled to no credit for that. I think the process claims are invalid.

This conclusion carries with it as a necessary corollary that the device itself, apart from its functioning and use, is lacking in patentable novelty. The inventive quality of the device claims, if any they have, must consequently reside in the discovery of a new principle that thermionic discharges above ionization voltages can be produced without substantial ionization if the vacuum be sufficiently high and the disclosure that the device of the claims constitutes suitable means for putting the principle into practice to obtain useful results, or, in the application of that principle, if known, to a useful purpose—in the realization that the instability, non-reproductibility and lower power output of the gassy tube was due to inadequate vacuum and the conception of a tube with a higher vacuum as a means whereby stability, reproductibility and high power output in thermionic devices might be had. That Langmuir was not the first to discover that a pure electron discharge, a discharge without substantial ionization, can be produced in a thermionic device if the vacuum is sufficiently high was indicated by Richardson's Law, evolved and formulated about 1903. If, perchance, that law was not universally accepted by physicists as being operative in high vacua, as was suggested by Soddy, Pring, Parker and some others, the publications of

Lilienfeld in 1910 were clear, complete and specific upon this point. In fact, Langmuir admits (I. R., p. 1378) that Lilienfeld had thermionic discharges above ionization voltages "substantially free from the effects of positive ionization". Moreover, if a thermionic discharge is unaccompanied by substantial ionization all the asserted "earmarks" or characteristics of plaintiff's device are present for they are but incidents flowing from a sufficiently high vacuum for the voltages employed, or, otherwise expressed, from an absence of ionization. These characteristics are, or include, (1) regularity and reproductibility of operation, (2) 3/2 power relation of current to voltage, (3) no blue glow or other visible evidence of discharge, (4) cathode not heated by the discharge, (5) current limited by space-charge effect, and (6) discharge independent of pressure in vacuum below certain pressure in the sense hereinbefore stated. As I understand the evidence these "earmarks" are likewise characteristics of the Fleming valve and original De Forest audion when operated at non-ionizing voltages. It thus seems obvious that the merit of the invention, if any, must lie in the realization that the known pure electron discharge to be had in a high vacuum would overcome the special difficulties and limitations of thermionic discharge devices. Whether this realization and the increase of vacuum in structures of the Fleming and De Forest type was a probable natural development of the art or one requiring inventive skill is, like the question of the presence or absence of invention in other cases, not without some difficulty.

One class of evidence which often carries much weight is the necessity for a series of experiments before the result can be arrived at. Such evidence raises a strong inference that the result was not obvious and constitutes a real addition to public knowledge. But for such experiments to be of much value the patentee must have started his experiments with knowledge of the state of the art or his experiments may have succeeded in enabling him to redisclose only what was already known. Langmuir made many experiments over a long period of time. Those that were first made were, however, for the purpose of discovering abstract principles and not for the purpose of arriving at practical results. He made discoveries but he did not immediately, or for some time, perceive that they had any practical use. Moreover, the discoveries to which his experiments led him, so far as we are here concerned, were those already made by Lilienfeld and others. Great credit, bearing upon the issue of invention, is claimed by the plaintiff for Langmuir for discovering from his experiments that electrons will boil out of a hot cathode in a high vacuum, that in a high vacuum the current varies with the 3/2 power of the voltage and other characteristics or incidents of a discharge in a high vacuum without substantial ionization. But disclosures of the prior art reveal that Langmuir, great and renowned physicist that he is justly conceded to be, was, in this instance, traveling all unknown to him, over a field already well explored. Fleming, the inventor of the Fleming valve, published in the "Scientific American Supplement" for January 20, 1906, an article on the electric conductivity of a vacuum, disclosing not only that electrons are emitted by a hot cathode in a high vacuum but also "that a high vacuum may be a very good conductor, provided that the negative electrode is rendered incandescent. This shows that the obstruction which a high vacuum offers to the passage of electricity is not due to the mere reduction of the matter in the space (that is, to the rarefaction of the gas), but is, in some way or other, largely dependent upon the temperature of the electrodes; the resistance to the passage of electricity through a vacuum can be rendered very small by intensely heating the negative electrode", thus revealing that a current could be had passing from cathode to anode. In addition, Fleming stated: "If we take measurements of the current passing through the vacuum when the negative electrode is an incandescent carbon filament and the other a cold metal plate, and, at the same time, measure the difference of potential between the electrodes, we find that the conductivity, as measured by the ratio of current to voltage, is not constant, but varies with the electromotive force." Furthermore, that Fleming knew the difference between a high and low vacuum is made manifest by his statement: "The vacuum is said to be low when the original normal air pressure in it is reduced to one-thousandth atmosphere, or it may be only to one three-hundreth. It is said to be high when it is reduced to one hundred-millionth of an atmosphere." It is true, as shown by the Fleming curve sheet, that Fleming did not employ in his valve a high vacuum but it is also true that Langmuir, Q. 212, conceded "There is no advantage in the device of the character of the Fleming valve to go to pressures of less than 50 microns". Both C. D. Child, in an article in the "Physical Review", Vol. 32 (1911), and Lilienfeld, in an article entitled "Conduction of Electricity in Extreme Vacuum", published in "Annalen der Physik", Vol. 32, (1910), disclosed that with the aid of certain simplifying assumptions, such as the ignoring of the initial velocity with which the electrons are boiled out of the cathode, the discharge current varies in accordance with the three-half power of the voltage. This is conclusive evidence, as I understand it, that in a high vacuum the current is under control, stable and reproducible and, since high voltages were employed, that high power levels may be attained by the employment of a high vacuum. "Space charge effect" was, likewise, but a rediscovery. This is made certain by an article by Lilienfeld in "Physikalische

Zeitschrift", 1908, in reply to an article by Soddy dealing with the Wehnelt cathode in high vacuum in which Lilienfeld said:

> ". . . it is not exclusively the electrons emitted from the oxide cathode which, as was often assumed, determined the discharge in high vacua, but that the discharge depends essentially on a second factor. I pointed out more specifically in my second paper this view, that in consequence of the absence of the last traces of gas the number (volume density) of the negative electrons supplying the current becomes great in comparison with the number of gas molecules per unit volume, so that therefore the tendency exists for the formation of the greatest possible negative space charge—which opposes the current transport by the negative electrons.
>
> "The higher the vacuum, the greater the current density, the more prominent this new kind of discharge becomes . . ."

That the discharge in high vacuum devices is practically independent of the pressure when the pressure is below a certain value was discovered by Langmuir after Lilienfeld had made the disclosure in his article of 1910, where he said:

> ". . . from a certain maximum value of the gas density downwards the number of positive charges formed per negative charge, *i. e.*, per negative electron is independent of the gas density.
>
> "Since we usually regard positive charges as originating from molecules (or atoms) we can put this result in the following form: the number of positive charges per molecule increases continually with diminishing gas density in the region of validity of the function K which is independent of the gas density provided other conditions (the potential gradient) are kept constant."

In view of these publications it seems to me that the only permissible inference to be drawn from Langmuir's experiments is not that they constitute evidence of invention but is rather that Langmuir was not abreast of the developments in this particular art when he made his experiments.

Other evidence bearing upon the issue of invention is the great utility of the high vacuum tube. But in 1912 the radio art was young. Fleming did not need for his purposes, as Langmuir testified, a higher vacuum than that employed by him. The De Forest audion was not in wide use. Langmuir did not see one until 1913. Under such circumstances it would be difficult to say that the high vacuum tube satisfied a long felt want or produced results long sought or that the evidence of utility is here indicative of anything more than a proper natural development of the art. Moreover, the fact that falls but little short of a demonstration that the employment of the known pure electron discharge above ionization voltages in tubes of the De Forest type was but the availment of those skilled in the art of the store of knowledge that had been accumulated and lay ready at hand is that when Arnold, who had had long experience with electrical discharges in high vacuum, was shown a De Forest audion for the first time on November 1, 1912, and saw it in operation he immediately realized and said, in effect, that by increasing the vacuum the discharge would be sufficiently stable and at adequate power levels to enable the tube to be employed as a relay device in trans-continental telephony. While not unmindful that invention may sometimes be the result of an instantaneous happy thought, yet the state of the art is strongly confirmative of Arnold's own view at the time that the improvement suggested by him was obvious to one skilled in the art. The act of Arnold turns the scale so overwhelmingly that it lies athwart a finding of invention.

The patent is likewise invalid, in my opinion, because of prior knowledge and use by De Forest. The specification states: "Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts." That, as I understand it, means that at this voltage the current becomes affected by positive ionization and the tube ceases to function as a pure electron discharge device. Yet, prior to August, 1912, the Federal Telegraph Company of California, by which De Forest was then employed, used a B battery of 36 cells, another of 45 cells, or 54 and 67½ volts respectively, with the audion. When used as an amplifier the amplification increases with the voltage. The testimony of Langmuir, x-Qs. 761-767, as I understand it, makes it clear that this voltage was employed for amplifying purposes and so with a discharge current substantially unaffected by ionization. That De Forest though not skilled in the art of evacuating his device, knew the effect thereon of an increased vacuum, though he was very probably unaware of the extent to which it could be carried, is disclosed by his letters of July 26, 1912, and August 14, 1912, to the McCandless Company, the manufacturer of audions for the Federal Telegraph Company. The first letter is:

> "Out of the last lot of 24 audion bulbs which you manufactured for us there are only 4 that came up to proper sensitiveness test. Apparently the vacuum in the other bulbs is too low, because in these latter bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive."

The other letter reads:

> "We took two of the poorest of the discarded 20 to a San Francisco glass-blower, unknown to fame, and had him exhaust same to as high a vacuum as his pumps would take. These re-exhausted bulbs now show a sensitiveness equal to those of the first four which proves exclusively

> that our contention is correct. For the work which we demand from these bulbs they are not sufficiently sensitive and we would be glad therefore if you will re-exhaust them. You certainly should be able to put them in as good condition as the aforesaid San Francisco glass-blower."

The testimony discloses that the glass-blower referred to heated the tubes under an asbestos hood almost to the collapsing point of the tube while they were being exhausted. The references of the prior art which reveal that a lamp may be made to collapse by heating under an asbestos hood leave no room to doubt this testimony. Such heat was sufficient to heat to a certain degree the metal electrodes as well as the walls of the tube, thereby driving off from the electrodes as well as the walls some of the gasses occluded therein. The energy of the discharge of the De Forest tube was low. The bombardment was probably not adequate to heat the anode to a temperature even approximating that to which it was raised by the Bunsen burner under the asbestos hood. Consequently, little, if any, occluded gas would escape from the anode and the gas clean-up effect probably tended to improve the vacuum more that it was caused to deteriorate by the molecules of gas that escaped from the anode. The tubes were thus enabled to function substantially above ionization voltages without substantial ionization.

Upon the issue of priority, too, I think the plaintiff must fail. In the contest in the Patent Office between Arnold and Langmuir upon this issue the Examiner of Interferences awarded priority to Langmuir. The Examiners-in-Chief arrived at the same conclusion but for reasons conflicting with those of the Examiner of Interferences. The Commissioner of Patents awarded priority to Arnold. The Court of Appeals of the District of Columbia decided in favor of Langmuir for the reasons stated by the Examiner of Interferences and the Board of Examiners-in-Chief. I am in accord with neither of the divergent views expressed by the Examiner of Interferences and the Board of Examiners-in-Chief but, generally, with the reasoning and conclusion of the Commissioner of Patents. The defendant asserts that Arnold is entitled to the date of November 1, 1912. Upon that date Arnold, who because of his training and experience in the matter of electrical discharges in vacuum and upon recommendation of Dr. Robert A. Millikan, had been theretofore employed by Western Electric Company to aid in making possible trans-continental telephone service at the opening of the San Francisco Exposition, was shown by Doctors Jewett and Colpitts a De Forest tube that had been brought by De Forest to the Western Electric Company a day or so before. Arnold examined the audion and tested its performance as a repeater of speech currents. It functioned well with weak currents but choked, distorted the speech and blue hazed when increased plate voltage or loud speech currents were applied. Though Arnold had been engaged in perfecting a different device of his own to be employed for telephone relay purposes, he instantly saw that the performance of the tube which made it too unstable in its existing state for a telephone repeater was due to ionization and that this could be removed by increasing the vacuum. This he then disclosed to Colpitts and Jewett. He also understood and then explained to Colpitts that the hot cathode would emit electrons in the high vacuum, that they would be subject to the space charge effect and that it would require high plate potentials to obtain the desired electron flow from cathode to anode. Corroboration of the oral testimony of Arnold, Colpitts and Jewett, if needed, is to be found in the fact that every act of the Telephone Company from that time on is consistent only with the intended use of the audion made more rugged and with a higher vacuum in its trans-continental service. Arnold's conception of the invention, consisting in the full performance of the mental part of the inventive act, was complete. Nothing remained to be done but to give the device practical embodiment with reasonable diligence. If, in view of the fact that those skilled in the evacuating art knew how to reduce to physical form Arnold's mental conception, a physical reduction of his conception to practice was necessary, and I think it was not, *McCormick Harvester Mach. Co. v. Minneapolis Harvester Works*, 42 Fed. 152, 155; *Otto v. Linford*, 46 L. T. (N. S.) 35, this requirement was performed by Arnold with reasonable diligence, thus giving to him an effective date of November 1, 1912. He obtained, knowingly, in that month with audion 7-A a current of 3 milliamperes at 80 volts without substantial ionization. Again, Arnold met the requirements of reduction to practice in April and May of 1913. In the tubes of these experiments 250 volts were impressed upon the plate without ionization effect. The tubes used in Philadelphia in the fall of 1913 functioned well for many hours, one as long as 267 hours as commercial repeaters. The fact that the output energy of one of these tubes was less than that of the usual, original De Forest tube does not negative its being a tube of the patent, for the output energy of claim 26 is likewise less than the output energy of the usual, old De Forest tube. Moreover, it seems to me that other claims of the patent, for example 11, which was an original claim, differs from 26 in the same way and only in the same way that claim 26 differs from the original De Forest device.

Langmuir began his experiments in August of 1912. He now asserts and the defendant denies that he then obtained a pure electron discharge substantially unaffected by positive ionization but concedes, XQ. 380, that though he now knows that he did then obtain such a discharge he did not know it then. This lack of contemporaneous knowledge denies to his August work any effective value upon the issue of priority. Robinson on Patents, sec. 79, p. 121. In November Langmuir made other experiments but these he concedes were for the purpose of ascertaining the accuracy and existence of certain laws of physics. I find no evidence that he then thought of applying the scientific principles in which he was interested to any practical result in the useful arts. Consequently, there is no satisfactory evidence that Langmuir had a conception of the device of the patent before the end of November. "It is not while the creative energies are at work shaping and sharpening the idea of means that the conception of the invention becomes perfect. It is when these energies have ceased to act, when the idea stands before the mental vision of the inventor as clearly as a concrete invention before the eyes of an observer, that the conception is complete and the work of reduction is ready to begin." Robinson on Patents, sec. 379. Tested by this rule even the statements of Langmuir to Coolidge in December, 1912, did not reveal a complete idea of means and, consequently, did not disclose a complete conception within the meaning of the patent law. It was not until March 21, 1913, as I read the record, that Langmuir's conception or idea of means to a useful end began to take shape. He then made a record of it in these words: "Now, what I intend to do is to construct an audion which will operate entirely and exclusively on the electron discharge. I shall attempt to get the vacuum so good that positive ions are present in negligible amounts." It is not necessary to inquire when the conception became complete and his idea reduced to practice for Arnold had had the conception long before and had proceeded diligently to reduce it to practice.

The bill of complaint in this case must be dismissed.

In the second of the two suits between the same parties, tried together, three patents are involved. The first is No. 1,244,216 granted to Irving Langmuir, assignor to the plaintiff, October 23, 1917, upon an application filed July 15, 1914. In the record this is called the second patent, that for the high vacuum tube being referred to as the first. It is likewise known as the thoriated tungsten cathode patent. The specification states:

> "The present invention relates to electrical devices operating with a pure electron discharge and comprises a novel cathode material and the method of its preparation."

It recites that various refractory metals—platinum, carbon, tungsten, molybdenum—have been used as cathode materials and then announces:

> "I have discovered that the electron emissivity of pure thorium is of an entirely different order of magnitude than the emissivity of refractory materials heretofore used in electron discharge devices. It is not necessary that the electrode should consist entirely of thorium. When, for example, a thorium compound, such as the oxid, has been added during the process of production to one of the highly refractory metals, for example tungsten, and the metal subjected to a preliminary heat treatment in a high vacuum, the electron emission in a high vacuum is enormously increased."

The method of obtaining the high vacuum enabling the device to operate with a pure electron discharge is stated thus:

> "The preliminary evacuation of the envelope is carried out by the usual methods of producing high vacuum, which includes baking out the envelope to remove water vapor. The final state of

the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means, —that is, to about .001 micron. While the apparatus is still on the pump the filaments 2, 3 are heated to a temperature of about 2900° K. (absolute) for a short time and the envelope 1 is baked out in an oven at a temperature of about 360 to 450° K. [C.]. The apparatus may then be sealed from the vacuum system at the contraction 10." (Incidentally this statement is strongly confirmative, it seems to me, of the conclusion arrived at with respect to the process claims of the first patent.)

Directions for aging follow. The disclosure that the vacuum may be increased by vaporizing one of the filaments is added. The economic and practical advantage arising from increased electron emissivity at the same temperature or an equal emissivity at a lower temperature is the lessened expense incident to the lessened energy required to heat the cathode. The claims in issue are 1 to 7 inclusive, 10 and 11. Claim 3 is:

> "A cathode for electron-discharge apparatus consisting largely of a highly refractory metal and a surface layer of material having an electron emissivity at a given temperature materially greater per unit surface than said refractory metal independently of and in the absence of positive ionization."

The "surface layer" element of the claim is based upon the fact or theory that by incandescing the filament some of the thoria therein is converted into metallic thorium which forms into a film or skin one atom thick on the surface of the cathod.

The pith of invention, if it exists, lies in the employment of a thoriated tungsten filament for the cathode in a high vacuum tube. That invention is to be found in any claim the defendant denies. This denial it rests primarily upon the ground that thoriated tungsten filaments were in general use in incandescent lamps for some time before the date of Langmuir's application and were gradually supplanting all other filaments. It asserts that, by reason of the analogy existing between the incandescent lamp and the radio tube it was both natural and obvious to use in the tube a filament the same as that employed in the lamp. It shows by evidence that since the origin of radio tubes filaments the same as those used in incandescent lamps had been employed in the tube—in fact, that it was not unusual actually to take filaments from lamps and put them in tubes. It points out that the preparation of filaments is the same for tube and lamp. It contends that it being natural and obvious to use in tubes filaments identical with those employed in lamps and it appearing that it was not unusual actually to transfer filaments from lamp to tube, the analogous user is not converted into a non-analogous use and invention by the discovery that a thoriated tungsten filament possesses greater electronic emissivity than the earlier filaments. It urges that the public should not be barred from reaping all the advantages and benefits incident to doing that which was the natural and obvious thing to do.

It is conceded that lamps with thoriated tungsten filaments were on the market as early as the fall of 1912 and that they gradually superseded lamps with other filaments. It is not denied that filaments identical with those employed in incandescent lamps were used in radio tubes. In fact the specification of the patent in suit states that platinum, tungsten and molybdenum, as well as carbon—lamp filament materials—had been used as cathode materials. The evidence is clear that it was not unusual in the manufacture and repair of De Forest audions to obtain cathode filaments directly from incandescent lamps. Indeed, the evidence indicates a strong probability that thoriated tungsten filaments were used in radio tubes before Langmuir's effective date although it lacks, I think, the degree of certainty required to sustain a finding of prior knowledge and use. Nor is the parallelism or identity of filament in lamp and tube surprising. Fleming, in patent No. 803,684 issued in 1905, employed for the original radio tube "a carbon filament like the carbon filament of an incandescent lamp." Each carries current, is heated in operation to a high temperature and so must not be readily fusible. It is true that the ultimate purpose of the current in the lamp filament is light and in the filament of the tube is electronic emission, yet these are not independent of each other as witness the Edison effect discovered in the lamp and the light visible in the radio tube. To be sure the different materials differ in their electronic emissivity. But this was pointed out at least as early as 1910, by Fleming in his patent No. 954,619. When the thoriated tungsten filament went into general use in the lamp art those skilled in the radio art knew with certainty that it had all the requirements for that art if it possessed the property of electronic emissivity to a satisfactory degree. The ascertainment of that fact called, I think, only for the routine work of those skilled in the art in the selection of the best among the materials known to be available. At most it required only the judgment and skill of the engineer and not the acumen and genius of the inventor. The question pertinent in all cases of this character—whether the new use lies so far out of the track of the former use as not naturally to suggest itself to a person skilled in the art turning his mind to the subject—must, consequently, I think, be answered in the negative.

The third patent of this record, No. 1,244,217, granted to Irving Langmuir, assignor to the plaintiff, October 23, 1917, upon an application filed October 28, 1915, relates to electrical devices having a thoriated cathode. The specification sets out that in the preparation of these devices "great care must be exercised to remove the last traces of oxygenous gases, particularly water vapor, and precautions must be observed not to evolve water vapor from the bulb walls during the operation of the device." The object or purpose of the invention is to improve the device and render its preparation easier "by providing in the envelop a quantity of a vaporizable reagent of low vapor pressure capable of preventing the oxidation of thorium." An alkali metal, for example, potassium, is preferred for this purpose but it is stated other reducing materials may be used. It is asserted in the specification that "The presence of the reducing agent in the main receptacle maintains the thorium reduced in spite of traces of water vapor which may be liberated from the glass. In an event the high electron emissivity of the thoriated cathode is more easily secured and maintained in the presence of the reducing agent than without it." The claims in issue are:

> "1. An electrical discharge device comprising electrodes, one of which contains thorium, an inclosing envelop the space within which is evacuated to a pressure so low that positive ionization is substantially absent, and a quantity of vaporizable reagent capable of preventing the oxidation of thorium in communication with the space within said envelop."
>
> "4. An electrical discharge device comprising electrodes, one of which consists of metallic tungsten and a thorium material in an oxidizable state, an inclosing envelop, and a quantity of a vaporizable reagent within said envelop capable of preventing the oxidation of thorium at an elevated temperature."

Conceding infringement if the claims are valid, the defendant denies validity upon the grounds of anticipation, non-invention, aggregation and double patenting.

Many exhibits evince the earlier knowledge that certain vaporizable reagents constitute means of obtaining—"getting" a vacuum of a high degree. As early as 1894 Malignani discovered, and disclosed in his patent No. 537,693, granted in 1895, this process for evacuating incandescent lamps. The reagent was put in a tubular elongation of the bulb and the bulb exhausted by pumping. The vacuum having been obtained, the lower end of the tube was soldered up and the carbon filament brought to intensive incandescence, to expel the gases contained therein. Simultaneously the part containing the vaporizable substance was heated by suitable means such as a spirit lamp to vaporize the chemical reagent. The vapors so generated combine with the free gas and vapors of the tube and those expelled from the filament and form a solid or liquid precipitation, "so that an almost perfect vacuum is obtained." Arsenic and iodine were the reagents employed by Malignani. Dwyer also in patent No. 595,695, granted in 1898, made use of a chemical "having the property of evolving a condensable gas or vapor which, when the heating is discontinued, goes down as a solid upon the cooler portions of the receptacle and requiring quite a high temperature to be afterward again vaporized." Dwyer limited the amount of the chemical so as to have the least possible amount of foreign substance deposited as a film upon the inner surface of the lamp bulb. Doane, R., Vol. V, p. 138, describes the employment of phosphorus as a chemical exhausting means or aid. Merritt, patent No. 909,811, granted in 1909, after reciting the earlier use of suitable substance to act upon the deleterious gases, particularly oxygen, remaining in the bulb after pumping, and to convert them into harmless compounds shows the advantages to be had from putting the chemical in the bulb instead of in the tubulature. He restricted, however, the amount so there would be no excess to discolor the bulb. Soddy, patent No. 859,021, issued in 1907, described the process of bringing a heated alkaline earth metal—particularly calcium—capable of absorbing gas into the presence of the rarefied atmosphere whereby the remaining gases were absorbed. His article in "Nature" of November 21, 1907, showed that by means of calcium a copious mirror deposit on the inner walls of the tube might be had. But he does not indicate that such a deposit is useful or desirable. Clark, in patent No. 1,121,802, issued in 1914, made use of vaporized sodium/or potassium to coat the inner wall of projector lamps with reflecting surfaces. He explained that since sodium and potassium oxidize very readily when in the presence of oxygen it is necessary to apply the coating with no trace of oxygen. Von Recklinghausen, in patent No. 946,068, applied for in 1904 and granted in 1910, made use of magnesium, in mercury vapor apparatus, for absorbing some of the gases which remain after a certain degree of exhaustion by pumping has been attained. He claimed "The combination with a closed container, of a holder within the container, magnesium within the holder, and a source of electric current connected with the opposite ends of the magnesium whereby the same may be rendered active for absorbing injurious gases in the container."

An analysis of these and other disclosures of the prior art shows, however, that they all fall short of the underlying idea of the third patent. They reveal that chemical agents had become a most potent aid to the pump in creating—"getting"—vacua of the required degree. But nowhere is it indicated that the reagent has any practical value after the moment of volatilization—after it becomes cold—and nowhere is there a suggestion that by retaining the volatilized reagent within the sealed off bulb the vacuum obtained may be maintained. In short, the prior art discloses the use of chemicals as "getters." It does not disclose their use as "keepers." Langmuir made a step forward. He grasped the fact that by retaining the reagent within the tube it would continue to function after the moment of volatilization even though cold and so combine with and form into a harmless solid compound any molecules of free gas, particularly oxygen, that might evade the evacuation process and any molecules of occluded gas that might escape from walls or electrodes during operation of the tube. By this means the efficiency of the readily oxidizable thoriated cathode is preserved and its life prolonged. It is a true combination—not an aggregation.

Patent No. 1,159,307, applied for March 20, 1914, and granted November 2, 1915, to William C. White, assignor to the plaintiff herein, upon which defendant herein relies to show invalidity of the claims of the third Langmuir patent here in issue on the ground of double patenting is for a different purpose. The vaporizable substance retained in the tube by White is of a character to maintain the gas in the tube at the definite pressure at which the device possesses a critical region of sensitiveness. That retained by Langmuir, within the meaning of the claims, is of a character to capture and combine with the molecules of gas and maintain the vacuum. I think the claims in issue of the third patent are valid and infringed.

The fourth and last patent in suit is No. 1,529,597, applied for August 11, 1921, and granted March 10, 1925, to Irving Langmuir, assignor to the plaintiff herein. Like the third patent it has to do with "keepers." The advance marked by it is in the employment for that purpose of an alkaline earth metal, preferably magnesium, instead of potassium or other alkaline metals suggested in the third patent. The claims in issue are 12, 13, 18, 19, 21, and 22. Claim 13 is:

> "An electrical discharge device comprising a sealed envelope, electrodes therein one of which is of the thoriated type and a film of magnesium deposited on the inner surface of said envelope."

The claim to invention rests upon the discovery of special advantages incident to the use of magnesium. One advantage is set out in the specification thus:

> "A thoriated cathode may be deleteriously affected by positive ion bombardment, that is, when voltages materially higher than the ionization voltages are impressed between a thoriated cathode and a positive electrode in the presence of ionizable gas, then the beneficial effect of the thorium may be largely or entirely destroyed by positive ion bombardment. Although the alkali metals are entirely satisfactory as agents to remove deleterious gases when the operating temperature of the bulb is only moderately above room temperature, as in the case of radio receiving tubes, these alkali metals have a sufficiently high vapor pressure at the operating temperature of power devices in which cathodes of the thoriated type are used to become ionized at higher voltages and to cause removal of the active film of thorium from the cathode by bombardment. I have found that it is advantageous in many cases to provide a device containing a cathode of the thoriated type, with a material having an affinity for gases, such as magnesium, for example, which at the operating temperature of the device, has substantially no vapor pressure. . . . "

Another advantage lies in the avoidance of the danger incident to the use of potassium which is so oxidizable that it must be kept under oil for it breaks into flame when exposed to the air. Magnesium is handled without difficulty. Obtained in the form of wire or foil it can be cut up in the open air and fed to the machines without danger.

The broad question here presented is, of course, whether making the keeper element, of the old device, of magnesium instead of some other material, particularly an alkali metal, involved invention. As I understand the law there may be invention in selecting a particular material for a particular purpose although other materials of the same class have been used before for the same purpose and even though a patent has been previously granted for the use of the whole class. *Potts v. Creager*, 155 U. S. 609; *Andrew's Patent*, 25 R. P. C. 477. But courts which scrutinize such patents somewhat narrowly require, before invention may be found, that it must at least appear not only that there is a special advantage attached to the use of the particular substance claimed but also that its use is not the mere substitution of a superior material for an inferior, is not the result of judgment and skill in the selection of materials, nor a probable consequence of the natural development of the art. That magnesium has an affinity for gases, particularly oxygen, has long been well known. The availability of magnesium as a "getter" because of that property, was disclosed by Von Recklinghausen in patent No. 946,068, by British patent No. 15,788 of 1914 granted to the British Thomson-Houston Company, Limited, as a result of a communication from the plaintiff herein, and by Mackey in patent No. 1,208,597. Soddy, in patent No. 859,021, made use of alkaline earth metals, preferably calcium, which is suggested by the patent in suit as an equivalent for magnesium, to absorb the residual gases of a vacuum not sufficiently high.

It is of course true that magnesium, though highly oxidizable, does not oxidize so readily as potassium, yet in view of its known efficiency as a "getter" I find nothing in the record to indicate that its use as a "keeper" involved more than judgment and skill in the selection of materials by those conversant with the art.

The language of claims 1 and 4 of the broad "keeper" patent and the known properties of the alkaline earth metals make it certain, I think, that those metals lie within the scope of those claims. Langmuir could not have been restricted in the exercise of the invention of those claims by a subsequent patent to another for the employment of the alkaline earth metals as keepers. Conversely, Langmuir can make no valid claim whose effect would be to extend the term of the monopoly that he obtained by the grant of the third patent. This makes inevitable a conclusion that the claims here in issue of the fourth patent are invalid.

Decrees in conformity herewith may be presented.

(Sgd.) HUGH M. MORRIS, *J.*

January 3, 1928.

DECREE

(Filed January 16, 1928)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *De Forest Radio Company.*	No. 589. IN EQUITY.

And now, to wit, this sixteenth day of January, 1928, this cause having come on to be tried and heard at this term and having been argued by counsel, and thereupon, upon consideration thereof, it is

ORDERED, ADJUDGED and DECREED by the Court, that the bill of complaint herein be and it hereby is dismissed for want of equity with costs to be taxed by the clerk in favor of defendant and against plaintiff.

(Sgd.) HUGH M. MORRIS,
U. S. Judge.

Form assented to.

(Sgd.) WM. G. MAHAFFY,
Solicitor for Plaintiff.

(Sgd.) HOWSON & HOWSON,
Counsel for Plaintiff.

PETITION FOR APPEAL

(Filed January 23, 1928)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *De Forest Radio Company.*	No. 589. IN EQUITY.

The plaintiff, General Electric Company, conceiving itself aggrieved by the decree made and entered herein as of the sixteenth day of January, 1928, does hereby appeal from said decree to the United States Circuit Court of Appeals for the Third Circuit, for the reasons specified in the assignment of errors which is filed herewith, and it prays that this appeal may be allowed and a citation granted directed to the above-named defendant, De Forest Radio Company, commanding it to appear before the United States Circuit Court of Appeals for the Third Circuit, to do and receive what may appertain to justice to be done in the premises and that a transcript of record, proceedings and papers upon which said decree was made be duly authenticated and sent to the said United States Circuit Court of Appeals for the Third Circuit.

GENERAL ELECTRIC COMPANY,
By (Sgd.) WM. G. MAHAFFY,
(Sgd.) HOWSON AND HOWSON,
Solicitors for Plaintiff.

Dated January 23, 1928.

ORDER ALLOWING APPEAL

(Filed January 23, 1928)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company
v.
De Forest Radio Company.

No. 589.
IN EQUITY.

AND NOW, to wit, this twenty-third day of January, A. D. 1928 upon consideration of the annexed petition for appeal in the above cause, it is, upon motion of William G. Mahaffy, solicitor for the petitioner,

ORDERED BY THE COURT that the appeal of the said plaintiff prayed for therein be and is hereby allowed, and the amount of the appeal bond to be entered by appellant is hereby fixed at the sum of five hundred dollars ($500).

(Sgd.) HUGH M. MORRIS,
J.

ASSIGNMENT OF ERRORS

(Filed January 23, 1928)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company
v.
De Forest Radio Company.

No. 589.
IN EQUITY.

The plaintiff, General Electric Company, in the above-entitled suit, conceiving itself aggrieved by the decree entered in this suit on the sixteenth day of January, 1928, now appears by its counsel and presents with the accompanying petition for appeal from said decree the following assignment of errors:

First.—The trial Court erred in entering a decree dismissing the bill for want of equity.

Second.—The trial Court erred in not entering a decree for the plaintiff for injunction against, and for an accounting by, defendant, by reason of infringement of the Langmuir Patent No. 1,558,436.

Third.—The trial Court erred in holding said patent invalid.

Fourth.—The trial Court erred in holding the subject matter of said patent lacking in invention.

Fifth.—The trial Court erred in holding the subject matter of said patent to be lacking in patentable novelty.

Sixth.—The trial Court erred in holding the patent invalid because of prior knowledge and use by Lee De Forest.

Seventh.—The trial Court erred in holding that the subject matter of said patent was previously invented by Harold D. Arnold.

Eighth.—The trial Court erred in not holding said Langmuir Patent No. 1,558,436 valid and infringed by defendant as to all the claims thereof.

GENERAL ELECTRIC COMPANY,
By (Sgd.) WM. G. MAHAFFY,
(Sgd.) HOWSON AND HOWSON,
Its Solicitors.

January 23, 1928.

CITATION
(Filed January 30, 1928)

IN THE UNITED STATES DISTRICT COURT,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *De Forest Radio Company.*	No. 589. IN EQUITY.

THE PRESIDENT OF THE UNITED STATES,

To the De Forest Radio Company,

GREETING:

You are hereby cited and admonished to be and appear in the United States Circuit Court of Appeals for the Third Circuit to be held in the City of Philadelphia, in the State of Pennsylvania, on the twenty-sixth day of February, 1928, pursuant to an appeal duly allowed and filed in the office of the clerk of the District Court of the United States for the District of Delaware, wherein General Electric Company is plaintiff-appellant, and you are defendant-appellee, to show cause, if any there be, why the decree in such appeal mentioned should not be corrected and speedy justice should not be done to the parties in that behalf.

Given under my hand in the City of Wilmington, in the District of Delaware, this 27th day of January, A. D. 1928, and of the independence of the United States the one hundred and fifty-second.

(Seal)

(Sgd.) HUGH M. MORRIS,
United States Judge.

Service of the within citation with copy accepted this 30th day of January, 1928.

(Sgd.) E. E. Berl,
Solicitor for Defendant.

STIPULATION AS TO TRANSCRIPT

(Filed March 8, 1928)

In the District Court of the United States,
For the District of Delaware.

General Electric Company v. *The De Forest Radio Company.*	No. 589. In Equity.

It is hereby stipulated and agreed by and between counsel for the respective parties, with respect to the transcript of record on the appeal taken by the plaintiff from the decree entered in the above-entitled cause and also the cross appeals in the cause between the same parties No. 598 in equity in this court, as follows:

1. That the two causes having been tried together in 1926, a single consolidated transcript of record for the appeals may be used in the United States Circuit Court of Appeals for the Third Circuit for the two causes, and such consolidated transcript of record having been printed early in 1927 in six volumes for the use and convenience of the District Court, without reduction of the testimony to narrative form, in the belief that such printed record could and would be available for use also in the United States Circuit Court of Appeals, it is stipulated that said six printed volumes shall constitute the transcript of record on said appeals when there shall have been added thereto the following

(a) Additional docket entries and new index,
(b) The opinion of the District Court,
(c) Decree,
(d) Plaintiff's petition for appeal, allowance of appeal, assignment of errors,

(e) This stipulation and order thereon, and
(f) Clerk's certificate.

2. That the three-volume record in the Interference Arnold v. Langmuir need not be reprinted, but may go up as a physical exhibit, in three copies.

3. That all exhibits not printed in the six volumes referred to in clause 1 hereof but listed therein, shall also go up as physical exhibits.

(Sgd.) WM. G. MAHAFFY,
Solicitor for Plaintiff.

(Sgd.) HOWSON AND HOWSON,
Counsel for the Plaintiff.

(Sgd.) E. E. BERL,
Solicitor for Defendant.

(Sgd.) SAMUEL E. DARBY, Jr.,
Counsel for the Defendant.

February 23, 1928.

ORDER APPROVING STIPULATION

(Filed March 8, 1928)

And Now, to wit, this eighth day of March, A. D. 1928, on motion of William G. Mahaffy, Esq., solicitor for plaintiff-appellant,

It Is Ordered by the Court that the foregoing stipulation be and hereby is approved and the clerk is hereby authorized to certify the transcript of record prepared in accordance therewith, and to transmit the same together with the physical exhibits referred to therein, to the United States Circuit Court of Appeals for the Third Circuit, at Philadelphia, Pennsylvania.

(Sgd.) HUGH M. MORRIS,
J.

DECREE.

(Filed January 16, 1928)

IN THE DISTRICT COURT OF THE UNITED STATES,
FOR THE DISTRICT OF DELAWARE.

General Electric Company
v.
The De Forest Radio Company.

No. 598.
IN EQUITY.

And now, to wit, this sixteenth day of January, 1928, this cause having come on to be tried and heard at this term, and having been argued by counsel, and thereupon, upon consideration thereof, it is

ORDERED, ADJUDGED AND DECREED by the Court that the bill of complaint herein be and it hereby is dismissed for want of equity as to the two Langmuir patents numbered 1,244,216 and 1,529,597, but as to those patents only;

That as to the Langmuir Patent No. 1,244,217 it is ORDERED, ADJUDGED and DECREED as follows:

1. That Letters Patent of the United States here in suit No. 1,244,217, dated October 23, 1917, to the plaintiff General Electric Company as assignee of Irving Langmuir, for electron discharge apparatus and method of operating the same, are good and valid in law as to claims 1 and 4 thereof;

2. That the plaintiff, General Electric Company, is the owner of said Letters Patent 1,244,217 and of all

rights therein and thereunder and has been such ever since the grant thereof;

3. That the defendant, The De Forest Radio Company, has infringed upon said claims 1 and 4 of said Patent 1,244,217 and the rights of the plaintiff therein and thereunder;

4. That a permanent injunction issue out of and under the seal of this Court directed to said defendant, its officers, employees, servants, attorneys, agents and privies, and each of them enjoining and restraining them and each of them from directly or indirectly infringing upon said claims 1 and 4 of said letters patent or either of them or contributing to the infringement of the same;

5. That the plaintiff do recover of the defendant all of the profits, gains and advantages which the defendant has derived, received or earned or made by reason of said infringement and the damages which the plaintiff has sustained by reason of said infringement, the account to be taken and stated and the damages to be assessed by proceedings appropriate for such purpose;

6. That the question of costs in this suit be reserved for the entry of final decree.

(Sgd.) HUGH M. MORRIS,
J.

PLAINTIFF'S PETITION FOR APPEAL

(Filed January 23, 1928)

IN THE DISTRICT COURT OF THE UNITED STATES,
FOR THE DISTRICT OF DELAWARE.

General Electric Company
v.
De Forest Radio Company.

No. 598.
IN EQUITY.

The plaintiff General Electric Company conceiving itself aggrieved by the decree made and entered into herein as of the sixteenth day of January, 1928, in so far and only in so far, as said decree relates to Patents No. 1,244,416 and No. 1,529,597, does hereby appeal from said decree so far as it relates to said two patents to the United States Circuit Court of Appeals for the Third Circuit for the reasons specified in the assignment of errors which is filed herewith, and it prays that this appeal may be allowed and a citation granted directed to the above-named defendant De Forest Radio Company, commanding it to appear before the United States Circuit Court of Appeals for the Third Circuit to do and receive what may appertain to justice to be done in the premises and that a transcript of record, proceedings and papers upon which said decree was made be duly authenticated and sent to the said United States Circuit Court of Appeals for the Third Circuit.

GENERAL ELECTRIC COMPANY,
By (Sgd.) WM. G. MAHAFFY,
(Sgd.) HOWSON AND HOWSON,
Solicitors for Plaintiff.

January 23, 1928.

ORDER ALLOWING PLAINTIFF'S APPEAL

(Filed January 23, 1928)

In the District Court of the United States,
For the District of Delaware.

General Electric Company v. *De Forest Radio Company.*	No. 598. In Equity.

And Now, to wit, this twenty-third day of January, A. D. 1928, upon consideration of the annexed petition for appeal in the above cause, it is, upon motion of William G. Mahaffy, solicitor for the petitioner,

Ordered by The Court that the appeal of the said plaintiff prayed for therein be and is hereby allowed, and the amount of the appeal bond to be entered by appellant is hereby fixed in the sum of five hundred dollars ($500).

(Sgd.) HUGH M. MORRIS,
J.

PLAINTIFF'S ASSIGNMENT OF ERRORS

(Filed January 23, 1928)

IN THE DISTRICT COURT OF THE UNITED STATES,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *De Forest Radio Company.*	No. 598. IN EQUITY.

The plaintiff General Electric Company in the above-entitled suit conceiving itself aggrieved by the decree entered in this suit on the sixteenth day of January, 1928, with respect to the Langmuir Patents No. 1,244,416 and No. 1,529,597, now appears by its counsel and presents with the accompanying petition for appeal from said decree, the following assignment of errors:

First—The trial Court erred in entering a decree dismissing the bill as to said Patents No. 1,244,416 and No. 1,529,597, for want of equity.

Second—The trial Court erred in not entering a decree for the plaintiff for injunction against, and for an accounting by, defendant, by reason of infringement of the said Patents 1,244,416 and 1,529,597.

Third—The trial Court erred in holding said Patent 1,244,416 invalid as to claims 8 and 9 thereof.

Fourth—The trial Court erred in holding the subject matter of claims 8 and 9 of Patent 1,244,416, lacking in invention.

Fifth—The trial Court erred in holding Patent 1,529,597 invalid as to claims 12, 13, 18, 19 and 21 thereof.

Sixth—The trial Court erred in holding the subject matter of claims 12, 13, 18, 19 and 21 of Patent 1,529,597 lacking in invention.

Seventh—The trial Court erred in not holding the Langmuir Patent 1,244,416 valid and infringed by defendant as to claims 8 and 9 thereof.

Eighth—The trial Court erred in not holding the Langmuir Patent 1,529,597 valid and infringed by defendant as to claims 12, 13, 18, 19, 21 and 22 thereof.

GENERAL ELECTRIC COMPANY,
By (Sgd.) Wm. G. Mahaffy,
(Sgd.) Howson and Howson,
Its Solicitors.

January 23, 1928.

CITATION ON PLAINTIFF'S APPEAL

(Filed January 30, 1928)

In the District Court of the United States,
For the District of Delaware.

General Electric Company v. *De Forest Radio Company.*	In Equity. No. 598.

The President of the United States,

To the De Forest Radio Company,

Greeting:

You are hereby cited and admonished to be and appear in the United States Circuit Court of Appeals for the Third Circuit, to be held in the City of Philadelphia, in the State of Pennsylvania, on the twenty-sixth day of February, A. D. 1928, pursuant to an appeal duly allowed and filed in the office of the Clerk of the District Court of the United States for the District of Delaware, wherein General Electric Company is plaintiff-appellant, and you are defendant-appellee, to show cause, if any there be, why the decree in such appeal mentioned should not be corrected and speedy justice should not be done to the parties in that behalf.

Given under my hand in the City of Wilmington, in the District of Delaware, this twenty-seventh day of January, A. D. 1928, and of the Independence of the United States the one hundred and fifty-second.

(Sgd.) HUGH M. MORRIS,
United States Judge.

Service of the within citation with copy accepted this thirtieth day of January, 1928.

(Sgd.) E. E. BERL,
Solicitor for Defendant.

DEFENDANT'S PETITION FOR APPEAL.

(Filed February 17, 1928)

IN THE DISTRICT COURT OF THE UNITED STATES,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *De Forest Radio Company.*	IN EQUITY. No. 598.

The defendant, De Forest Radio Company, conceiving itself aggrieved by the decree made and entered into herein, as of the sixteenth day of January, 1928, in so far and only in so far as the decree relates to Patent No. 1,244,217 does hereby appeal from said decree in so far as it relates to the said patent to the United States Circuit Court of Appeals for the Third Circuit for the reasons specified in the assignment of errors, which is filed herewith, and it prays that this appeal may be allowed and citation granted directed to the above-named plaintiff, General Electric Company, commanding it to appear before the United States Circuit Court of Appeals for the Third Circuit to do and receive what may appertain to justice to be done in the premises and that a transcript of record, proceedings and papers upon which said decree was made be duly authenticated and sent to the United States Circuit Court of Appeals for the Third Circuit.

DE FOREST RADIO COMPANY,
By (Sgd.) E. E. BEEL,
Solicitor for Defendant.

Dated February 17, 1928.

ORDER ALLOWING DEFENDANT'S APPEAL

(Filed February 17, 1928)

IN THE DISTRICT COURT OF THE UNITED STATES,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *De Forest Radio Company.*	IN EQUITY. No. 598.

AND NOW, to wit, this seventeenth day of February, 1928, upon consideration of the annexed petition for appeal in the above case, it is upon motion by E. E. Berl, solicitor for the petitioner.

ORDERED by the Court that the appeal of the said defendant prayed for therein be and is hereby allowed and the amount of the appeal bond to be entered by appellant is hereby fixed in the sum of five hundred dollars ($500).

(Sgd.) HUGH M. MORRIS,
U. S. D. J.

DEFENDANT'S ASSIGNMENT OF ERRORS
(Filed February 17, 1928)

IN THE DISTRICT COURT OF THE UNITED STATES,
FOR THE DISTRICT OF DELAWARE.

General Electric Company v. *De Forest Radio Company.*	IN EQUITY. No. 598.

The defendant, De Forest Radio Company, in the above-entitled suit conceiving itself aggrieved by the decree entered in this suit on the sixteenth day of January, 1928, with respect to Langmuir Patent No. 1,244,217, now appears by its counsel, and presents with the accompanying petition for appeal, from said decree, the following assignment of errors:

First.—The trial Court erred in entering a decree adjudging claims 1 and 4 of said patent to be valid.

Second.—The trial Court erred in not entering a decree adjudging claims 1 and 4 of the said patent to be invalid because of anticipation.

Third.—The trial Court erred in not entering a decree adjudging the said claims of the said patent to be invalid for want of patentable novelty.

Fourth.—The trial Court erred in not holding that such claims of the said patent are invalid because of double patenting by plaintiff.

Fifth.—The trial Court erred in not entering a decree dismissing the bill of complaint with respect to the said patent.

DE FOREST RADIO COMPANY,
By (Sgd.) E. E. BEBL,
Its Solicitor.

February 17, 1928.

CITATION ON DEFENDANT'S APPEAL

(Filed March 8, 1928)

In the District Court of the United States,
For the District of Delaware.

General Electric Company
v.
De Forest Radio Company.
} In Equity.
No. 598.

The President of the United States of America,

To the General Electric Company,

Greeting:

You are hereby cited and admonished to be and appear in the United States Circuit Court of Appeals for the Third Circuit to be held in the City of Philadelphia, in the State of Pennsylvania, on the sixth day of April, A. D. 1928, pursuant to an appeal duly allowed and filed in the office of the Clerk of the District Court of the United States for the District of Delaware, wherein De Forest Radio Company is defendant-appellant, and you are plaintiff-appellee, to show cause, if any there be, why the decree in such appeal mentioned should not be corrected and speedy justice should not be done to the parties in that behalf.

Given under my hand in the city of Wilmington, in the District of Delaware, this seventh day of March, A. D. 1928 and of the Independence of the United States, the one hundred and fifty-second.

(Sgd.) HUGH M. MORRIS,
U. S. D. J.

Service of the within citation with copy, accepted, this eighth day of March, 1928.

(Sgd.) Wm. G. Mahaffy,
Solicitor for Plaintiff.

STIPULATION AS TO TRANSCRIPT OF RECORD

(Filed March 8, 1928)

In the District Court of the United States,
For the District of Delaware.

General Electric Company
v.
The De Forest Radio Company.

In Equity.
No. 598.

It is hereby stipulated and agreed by and between counsel for the respective parties, with respect to the transcript of record on the appeals taken by the plaintiff and defendant from the decree entered in the above-entitled cause and also on the appeal taken by plaintiff in the cause between the same parties No. 589 in Equity in this court, as follows:

1. That the two causes having been tried together in 1926, a single consolidated transcript of record for the appeals may be used in the United States Circuit Court of Appeals for the Third Circuit for the two causes, and such consolidated transcript of record having been printed early in 1927 in six volumes for the use and convenience of the District Court, without reduction of the testimony to narrative form, in the belief that such printed record could and would be available for use also in the United States Circuit Court of Appeals, it is stipulated that said six printed volumes shall constitute the transcript of record on appeal when there shall have been added thereto the following:

(a) Additional docket entries and new index,
(b) The opinion of the District Court,
(c) Decree,
(d) Plaintiff's and defendant's petitions for appeals, allowance of appeals, assignments of errors,

(e) This stipulation and order thereon, and
(f) Clerk's certificate.

2. That the three-volume record in the Interference Arnold v. Langmuir need not be reprinted but may go up as a physical exhibit, in three copies.

3. That all exhibits not printed in the six volumes referred to in clause 1 hereof but listed therein, shall also go up as physical exhibits.

(Sgd.) WM. G. MAHAFFY,
Solicitor for Plaintiff.

(Sgd.) HOWSON AND HOWSON,
Counsel for the Plaintiff.

(Sgd.) E. E. BERL,
Solicitor for Defendant.

(Sgd.) SAMUEL E. DARBY, JR.,
Counsel for the Defendant.

February 23, 1928.

ORDER APPROVING STIPULATION

(Filed March 8, 1928)

AND NOW, to wit, this eighth day of March, A. D. 1928, on motion of William G. Mahaffy, Esq., solicitor for plaintiff-appellant,

IT IS ORDERED BY THE COURT that the foregoing stipulation be and hereby is approved and the clerk is hereby authorized to certify the transcript of record prepared in accordance therewith, and to transmit the same together with the physical exhibits referred to therein, to the United States Circuit Court of Appeals for the Third Circuit, at Philadelphia, Pennsylvania.

(Sgd.) HUGH M. MORRIS,
J.

CLERK'S CERTIFICATE

United States of America, }
District of Delaware, } *ss.:*

I, Henry C. Mahaffy, Jr., clerk of the District Court of the United States for the District of Delaware, do hereby certify that I have carefully compared the writings annexed to and accompanying this certificate, in six volumes, *viz.:*

Vol. I, Pleadings and Testimony, pages 1 to 648, inclusive,
Vol. II, Pleadings and Testimony, pages 649 to 1382, inclusive,
Vol. III, Pleadings and Testimony, Opinion of Court, Decrees and Appeal Papers, pages 1383 to 2003, inclusive,
Vol. IV, Plaintiff's Exhibits, pages 1 to 361, inclusive,
Vol. V, Defendant's Exhibits, pages 1 to 634, inclusive,
Vol. VI, Defendant's Exhibits, Pages 635 to 1375, inclusive;

and find the same to be true and correct copies of their respective originals so full and complete as the same now remain on file and of record in my office, being a complete exemplification of the record and proceedings in the cases of General Electric Company v. The De Forest Radio Company, No. 589 in Equity, and General Electric Company v. De Forest Radio Company, No. 598 in Equity, pending in said court, made up in accordance with the stipulations of counsel for the respective parties and order of Court approving same filed in said causes.

In Witness Whereof, I have hereunto set my hand and affixed the seal of said court, at Wilmington, in said district, this twenty-eighth day of March, A. D. 1928, and the Independence of the United States of America the one hundred and fifty-second.

(Seal)

(Sgd.) H. C. MAHAFFY, Jr.,
Clerk, U. S. District Court,
District of Delaware.

UNITED STATES CIRCUIT COURT OF APPEALS,
FOR THE THIRD CIRCUIT.

No. 3799. March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

No. 3800. March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

No. 3801. March Term, 1929.

DeForest Radio Co.,
Appellant,
v.
General Electric Co.,
Appellee.

And afterwards, to wit, on the third day of April, 1929, come the parties aforesaid by their counsel aforesaid, and this case being called for argument sur pleadings and briefs, before the Honorable Joseph Buffington, Honorable Victor B. Woolley and Honorable J. Warren Davis, Circuit Judges, and the Court not being fully advised in the premises, takes further time for the consideration thereof, And afterwards, to wit, on the third day of October, 1929, come the parties aforesaid by their counsel aforesaid, and the Court, now being fully advised in the premises, renders the following decision:

UNITED STATES CIRCUIT COURT OF APPEALS,
FOR THE THIRD CIRCUIT.

No. 3799. March Term, 1928.

General Electric Company,
Appellant,
v.
The DeForest Radio Company,
Appellee.

No. 3800. March Term, 1928.

General Electric Company,
Appellant,
v.
The DeForest Radio Company,
Appellee.

No. 3801. March Term, 1928.

The DeForest Radio Company,
Appellant,
v.
General Electric Company,
Appellee.

APPEALS FROM THE DISTRICT COURT OF THE UNITED STATES FOR THE DISTRICT OF DELAWARE.

(Filed October 3, 1929.)

Before **Buffington**, **Woolley** and **Davis**, *Circuit Judges.*

Per Curiam.

The issues raised on these appeals were fully discussed in the opinion of the learned district judge and we agree with his conclusions. The decrees are, accordingly, affirmed on his opinion.

Buffington, *Circuit Judge*, dissents.

A true Copy:
Teste:

Clerk of the United States Circuit Court of Appeals for the third Circuit.

ORDER AFFIRMING DECREE.

(Filed October 3, 1929.)

UNITED STATES CIRCUIT COURT OF APPEALS,
FOR THE THIRD CIRCUIT.

No. 3799 (List No. 26). March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES, FOR THE DISTRICT OF DELAWARE.

This cause on to be heard on the transcript of record from the District Court of the United States, for the District of Delaware, and was argued by counsel.

On consideration whereof, it is now here ordered, adjudged, and decreed by this Court that the decree of the said District Court in this cause be, and the same is hereby affirmed, with costs.

Philadelphia, October 3, 1929.

(Sgd.) J. WARREN DAVIS,
Circuit Judge.

ORDER AFFIRMING DECREE.

(Filed October 3, 1929.)

UNITED STATES CIRCUIT COURT OF APPEALS,
FOR THE THIRD CIRCUIT.

No. 3800 (List No. 27). March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES, FOR THE DISTRICT OF DELAWARE.

This cause came on to be heard on the transcript of record from the District Court of the United States, for the District of Delaware, and was argued by counsel.

On consideration whereof, it is now here ordered, adjudged, and decreed by this Court that the decree of the said District Court in this cause be, and the same is hereby affirmed, with costs.

Philadelphia, October 3, 1929.

(Sgd.) J. WARREN DAVIS,
Circuit Judge.

ORDER AFFIRMING DECREE.

(Filed October 3, 1929.)

UNITED STATES CIRCUIT COURT OF APPEALS,
FOR THE THIRD CIRCUIT.

No. 3801 (List No. 28). March Term, 1929.

DeForest Radio Co.,
Appellant,

v.

General Electric Co.,
Appellee.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES, FOR THE DISTRICT OF DELAWARE.

This cause came on to be heard on the transcript of record from the District Court of the United States, for the District of Delaware, and was argued by counsel.

On consideration whereof, it is now here ordered, adjudged, and decreed by this Court that the decree of the said District Court in this cause be, and the same is hereby affirmed, with costs.

Philadelphia, October 3, 1929.

(Sgd.) J. WARREN DAVIS,
Circuit Judge.

PETITION FOR REHEARING.

UNITED STATES CIRCUIT COURT OF APPEALS, FOR THE THIRD CIRCUIT.

March Term, 1928. Nos. 3799 and 3800.

General Electric Company
v.
DeForest Radio Company.

In asking the Court to reconsider this case we do so with full appreciation of the careful and patient attention accorded to counsel at the argument, and with sympathetic understanding of the Court's reluctance to grant a rehearing except upon a showing of material and palpable error. We are convinced that such an error has been made, and we conscientiously feel that unless opportunity is given to correct it, grave injustice will result, and a meritorious and highly useful invention denied the protection which the Constitution intended to afford.

1. THE INVENTION IN RELATION TO THE PRIOR ART.

What the invention is.

The invention is an improvement in radio tubes, specifically the Fleming valve and DeForest audion.

In a radio tube electric current flows through a metal conductor, such as copper wire, from the battery to the filament, then somehow flows across the gap between the filament and the plate and then flows through a metal conductor from the plate back to the battery, forming a complete electrical circuit. The particular thing with which we are concerned in this case is how the current flows across the gap between the filament and plate and what causes it to flow.

For many years the art believed that electric current at any reasonable voltage would flow only through a metallic or liquid conductor. Then came EDISON in 1884 with his great discovery of the "Edison effect," which was, that somehow electric current would flow in a vacuum tube across a gap from a heated filament to a cold plate or anode. This was a startling discovery because at first thought it appeared to be utterly inconsistent with the accepted belief that current would flow only through a conductor. But like all great discoveries it appeared simple enough when it was explained. The explanation was that there was enough gas in the tube to form a conductor, or as it was sometimes described, that there was a "column of conducting gas" which served as a conductor to carry the current across the gap from the filament to the plate.

FLEMING merely utilized the Edison effect in a vacuum tube with its column of conducting gas for the production of radio signals. This was his contribution to the art.

DEFOREST simply improved the Fleming valve by adding the grid. This was DeForest's contribution.

Both Fleming and DeForest depended on the conductivity of gas as the fundamental basis of the operation of their tubes. They and the art believed, and repeatedly stated, that this physical conductor, this column of conducting gas, was necessary if any current was to flow across the tube. The Edison effect still depended on gas.

Then came LANGMUIR with a discovery quite as startling as the Edison effect. He got rid of all the gas so that there was no longer any gas to serve as a conductor, and he discovered that by a proper arrangement of the electrodes the current could be made to flow from the filament to the plate *without a con-*

ductor of any kind, and moreover that this current would follow a fixed law with relation to the voltage as contrasted with the current in a gas tube which followed no fixed law but varied with the conductivity of the gas.

IN SIMPLE LANGUAGE, LANGMUIR'S INVENTION CONSISTED IN TAKING OUT THE CONDUCTOR WHICH WAS IN THE FLEMING VALVE AND THE DEFOREST AUDION AND PUTTING NOTHING IN ITS PLACE; HE DISPENSED WITH WHAT WAS REGARDED AS AN ESSENTIAL ELEMENT IN THE OPERATION OF THE TUBE AND BY DOING SO MADE A TUBE WHICH WORKED INFINITELY BETTER.

This idea that current could be made to flow through sheer space without any conductor was just as startling, we submit, and quite as novel, as Marconi's original conception that telegraph signals could be transmitted without wires.

It has been suggested that the difference between Langmuir and DeForest is a mere matter of the degree of vacuum in the tube. This statement, however, overlooks the essence of the invention. If all Langmuir did was to make a tube work with less gas, still depending upon the gas for a conductor, this would be a mere matter of degree, just as for example the substitution of a larger copper wire conductor for a smaller wire would be a mere change of degree lacking in patentability, even though better results were accomplished; but to substitute for a wire conductor sheer space would not be a matter of degree, and to substitute for a gas conductor sheer space is likewise not a matter of degree.

Recognition of Utility.

The remarkable utility of Langmuir's invention is sufficiently attested by the Court's statement that the thing which he invented *"because of its stability, reproducibility and power, has made possible radio broadcasting, modern radio reception and long distance telephony."*

We conceive it to be an axiom of patent law that a thing which revolutionizes an art, which makes possible that which before was impossible, is invention. Yet notwithstanding this demonstration of novelty and utility, the majority of the Court, adopting the opinion of the lower Court, has said it is not entitled to patent protection because it represents nothing more than an obvious and natural development of the art.

Not an obvious development of the Art.

There is nothing in the record to support this astounding conclusion. **THE IDEA THAT A FLEMING VALVE OR DEFOREST AUDION COULD BE IMPROVED BY INCREASING THE VACUUM TO THE POINT WHERE THERE WAS NO GAS TO ACT AS A CONDUCTOR, WAS OPPOSED TO ALL THE EXPERIENCE AND TEACHING OF THE ART.**

What the art knew or thought is abundantly evidenced by the contemporaneous statements of those most conversant with it. It knew, through experience, that a good audion should be neither too soft nor too hard; that the tube must be exhausted *but not too well exhausted,* otherwise it would not function. DeForest said that "if the exhausting process is carried too far, the audion loses its sensitiveness" (Reply brief, p. 9), and this was supposed to be, and was, due to the fact, as explained by him, that the conductivity of the audion was "due to the ionization of the residual gases" (Main brief, p. 13). As he put it *"The gas particles, rather than the particles of metal dust are the carriers"* (I. R. 1496). Even after Langmuir had made his disclosure in a paper read before the Radio Institute, DeForest still insisted that he was working on the wrong track (Main brief, p. 39).

Fleming said the same thing, over and over again, with respect to his "valve"; for example in the year 1908 he stated that his valve depended "on the unilateral conductivity of a mass of rarefied gas" (I. R., p. 1337). In 1910 he spoke of this gas as being ionized (I. R., p. 1343). In 1916, long after Langmuir's invention was known to the world and to Fleming, he spoke of the "ionized gas" in his valve as a "conductor" (Main brief, p. 77).

It is easy enough to argue now that if the trickiness and unreliability of the audion were due to gas, the obvious way to get rid of those undesirable qualities was to get rid of the gas. But in the view of the art the gas was the thing that made the tube work; if you got rid of the gas you destroyed the tube. It might be an obvious way to get rid of the trickiness, but in the view of the art it would have been very much like cutting out a man's tongue to cure him from stuttering.

Certainly it is not an obvious and natural development of an art to improve an existing device by eliminating the very thing which is supposed to be essential to its operation.

The District Court apparently labored under the mistaken idea that an audion improved as the vacuum improved, and from this false premise concluded that the obvious way to improve the audion was to improve the vacuum. But the audion did *not* improve as the vacuum improved; it functioned at a certain vacuum which had to be neither too low nor too high. *When the vacuum improved, the tube did not improve; it became useless.* The transition from an audion to a high vacuum tube is not a gradual evolution; it is the creation of an entirely new and different thing.

Prior Art References.

We cannot but feel that the Court has unconsciously appraised the knowledge of the prior art in the light of Langmuir's work, and doing so has assumed that what now appears perfectly obvious, must have been so at the time. But as the Supreme Court has said:

> "Knowledge after the event is always easy, and problems once solved present no difficulties, indeed may be represented as never having had any, and expert witnesses may be brought forward to show that the new thing which seemed to have eluded the search of the world was always ready at hand and easy to be seen by a merely skillful attention. But the law has other tests of the invention than subtle conjectures of what might have been seen and yet was not. *It regards a change as evidence of novelty, the acceptance and utility of change as a further evidence, even as demonstration.*" (*Diamond Rubber Co.* v. *Consolidated Rubber Tire Co.*, 220 U. S. 428.)

The opinion gives RICHARDSON credit for discovering the phenomenon of pure electron discharge; yet Richardson himself makes no such claim; on the contrary in his book he speaks of the essential characteristic of pure electron discharge, the limitation of current by space charge, as "*an interesting effect which was discovered and explained by Langmuir,*" (Vol. IV, p. 339), citing Langmuir's *Physical Review* paper. *Richardson's law was not a law of the passage of current through a tube;* it was simply an expression of how electrons are boiled out of a heated filament.

The Court referred also to Child's 3/2 power law; this was a mathematical theory as to how currents might flow through ionized gas. But that had no bearing on Langmuir's invention; *the essence of Langmuir's invention is that there should be no gas to ionize.*

Fleming in his popular article casually speaks of a "high vacuum," by which he clearly means, as we have shown on pages 71 to 77 of our main brief, the vacuum of an incandescent lamp or of an X-ray tube, which is a matter of several microns. His own publication shows that when he said "high vacuum" he meant a vacuum in which the electrons *"ionize the residual gas"* (I. R., p. 1337). Fleming never suggested that a tube could be built in which current would flow from filament to plate without a gas conductor; on the contrary his *1916 book not only gives Langmuir credit for being the first to produce such* a tube, but shows that even at that date Fleming did not understand the characteristic difference between the old tubes and the Langmuir tubes.

Lilienfeld taught the world nothing so far as the production of a useful tube was concerned. Richardson in his 1921 book dismisses Lilienfeld's work as inconclusive (Main brief, p. 88).

All these references and many others were considered by the Law Examiner on the motion to dissolve the interference. We quote his conclusion (I. R., p. 2468):

> "It is not seen that any of the remaining references made fully available to the public by proper disclosure the device now claimed in the issue as reformed, or that the proposed combinations of references, *with results not suggested by any one of them,* were obvious. The fact seems incontrovertible that a substantial and valuable contribution to the art has been made and that, within the limits explicitly stated or necessarily implied in the claims retained, it is entitled to patent protection."

From 1904, when Fleming invented his valve, to 1912, when Langmuir entered the field, the only improvement was the DeForest audion of 1906; an improvement only in that it utilized a third electrode or grid. The art waited for Langmuir to invent the thing which superseded these devices, the thing which made modern radio possible.

Why if this thing was so obvious, was it left for Langmuir, the scientist? Why did it never occur to Fleming or DeForest, or some of the other practical men who were familiar with the needs of the Art? The lower Court says because the radio art was young, and there was no pressing need for such an improvement. But the art was not so young. Wireless telegraphy had been in practical use since 1898 (138 Fed., p. 671). If the art was in its infancy, it was because it was held back by the lack of proper appliances. *It would be in its infancy today if it still depended on the Fleming valve and the DeForest audion.*

But DeForest had in mind another use for his audion; as a telephone repeater. Here was a real need for a high vacuum tube; the thing which has made long distance telephony possible. He must have realized, as the Telephone Company engineers did, that the energy limit of the audion made it unsuitable for telephone use. A high vacuum was just what he needed. Why, if it was such an obvious thing to do, did not DeForest give the Telephone Company a tube which would answer the purpose? The only answer, of course, is that it was not obvious, and that DeForest had no conception of a tube which would function without gas, or of any way of avoiding the serious difficulties and limitations which were inherent in the audion.

2. THE DeFOREST PRIOR USE.

Yet in spite of this conclusive demonstration to the contrary, the Court holds the patent invalid because of prior knowledge and use by DeForest. This holding is based in part upon the supposed use by the witness Hewlett (not DeForest) of an audion with a B-battery of 67½ volts.

We have pointed out in our main brief, page 51, that on the very page of the record where Hewlett says that he had a B-battery of 45 cells, which the Court assumes to mean 67½ volts, he testifies that *he never used the whole of the voltage at once.* We have also demonstrated that even if 67½ volts were used, that would be no proof that the tube was a high vacuum tube. Hewlett's testimony that by heating the tube he was able to control the amount of B-battery used, shows conclusively that it was not (Reply brief, p. 23).

The lower Court also found, by a curious process of reasoning, that the Lamont tubes must have been high vacuum tubes, because Lamont heated the bulbs during the exhaustion, and this in the face of the *uncontradicted testimony* that the process which Lamont used was a prior-art process, incapable of producing a high vacuum tube. *Defendant had a tube exhausted by Lamont by what was said to be the same process—but never put it in evidence* (Rec., Vol. II, pp. 1060 to top 1063; see also p. 1042).

The error in the decision below on this DeForest defense is so clear and so serious, and so easily demonstrated and understood, that we are sure that this Court will wish to correct it.

3. THE ARNOLD DEFENSE.

Arnold's claims are refuted by his own statements and conduct (Reply brief, pp. 60-70). The fact that he used old DeForest audions in connection with his important demonstration in February, 1913, is of itself sufficient answer to his claim that he had conceived the invention and reduced it to practice in November, 1912.

Here was a demonstration staged for the benefit of the President and other high officials of the Telephone Company to determine the practicability of the transcontinental telephone to which the Telephone Company had practically committed itself in time for the opening of the San Francisco Exhibition. Because of the limitations of the DeForest audions the energy in the circuits had to be kept very low. For a laboratory demonstration, such as this was, where all outside interference could be eliminated, the energy was sufficient, but Arnold himself admitted that it was insufficient for an ordinary commercial line (Vol. II, p. 742). The demonstration, therefore, left much to be desired; the Telephone Company still faced the problem of improving the audion so that it would be capable of handling the energy required in an ordinary commercial line. If Arnold had conceived the invention and reduced it to practice in November, 1912, as he alleges, common sense tells us that he would have used it and made his demonstration a real demonstration of the commercial practicability of long distance telephony without any ifs or buts. This of itself is enough to dispose of Arnold.

THE SECOND AND FOURTH PATENTS.

The decision on the second patent is based on the assumption that when the thoriated tungsten filament was put in a tube it would produce the emission of the second patent. No witness testifies that it would. We have demonstrated in our little brief in Nos. 3800 and 3801 that it would not; we have shown that, without special treatment of the filament *combined with radical modification of the tube itself*, such a filament would function exactly as the old tungsten filaments function; that the second patent covers a new combination, leading to a new and remarkable result.

The fourth patent is held invalid on the very references which are disregarded in the consideration of the third patent. We are unable to understand why, not being effective against the third patent, they are effective against the fourth patent (brief in 3800 and 3801, p. 28). The real question of law involved in the issue on the fourth patent is not discussed in the opinion.

CONCLUSION.

In his recent speech in Dearborn, on the occasion of the Edison celebration, the President of the United States, himself an engineer of no mean attainments, spoke of Mr. Edison's invention of the incandescent lamp as "an outstanding illustration of the value of the modern method and system of invention, by which highly equipped, definitely organized laboratory research transforms the raw material of scientific knowledge into new tools for the hand of man."

We submit that Langmuir's invention is another such "outstanding illustration," and that Langmuir is, still in the language of the President's speech, another of the "great leaders who have converted the pure physics of electricity into a taxable product"; one of those "men who have that originality of mind, that devotion and industry to carry scientific thought forward in steps and strides until it spreads to the comfort of every home."

We realize that the record is heavy and that some of the matters discussed therein are complex. We believe that on a rehearing we can show the Court that the real issues are actually very simple, and that we can demonstrate that Langmuir has made a great invention and that the patent on that invention should be sustained.

In view of the importance of this case to the public, to Langmuir's assignee and to the assignee's many licensees, we respectfully ask the Court to grant a rehearing, and to stay the mandate pending the disposition of this petition.

Respectfully submitted,

Hubert Howson,
Albert G. Davis,
Ralph B. Evans,
Counsel for General Electric Company, Petitioner.

CERTIFICATE.

I certify that this petition for rehearing, in my opinion, is well founded in law and in fact, and that it is not filed for the purposes of delay.

Ralph B. Evans.

November 1, 1929.

ORDER ALLOWING PETITION FOR REHEARING.

(Filed December 2, 1929.)

UNITED STATES CIRCUIT COURT OF APPEALS,
FOR THE THIRD CIRCUIT.

No. 3799 (List No. 26). March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

SUR PETITION FOR REHEARING.

AND NOW, to wit: December 2, 1929, after due consideration, the petition for rehearing in the above-entitled case is hereby granted.

Philadelphia.

(Sgd.) J. WARREN DAVIS,
Circuit Judge.

ORDER ALLOWING PETITION FOR REHEARING.

(Filed December 2, 1929.)

UNITED STATES CIRCUIT COURT OF APPEALS,

FOR THE THIRD CIRCUIT.

No. 3800 (List No. 27). March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

SUR PETITION FOR REHEARING.

AND NOW, to wit: December 2, 1929, after due consideration, the petition for rehearing in the above-entitled case is hereby granted.

Philadelphia.

(Sgd.) J. WARREN DAVIS,
Circuit Judge.

UNITED STATES CIRCUIT COURT OF APPEALS,
For the Third Circuit.

No. 3799. March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

No. 3800. March Term, 1929.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

No. 3801. March Term, 1929.

DeForest Radio Co.,
Appellant,
v.
General Electric Co.,
Appellee.

And afterwards, to wit, on the second day of April, 1930, come the parties aforesaid by their counsel aforesaid, and this case being called for reargument sur pleadings and briefs, before the Honorable Joseph Buffington, Honorable Victor B. Woolley and Honorable J. Warren Davis, Circuit Judges, and the Court not being fully advised in the premises, takes further time for the consideration thereof,

And afterwards, to wit, on the eleventh day of November, 1930, come the parties aforesaid by their counsel aforesaid, and the Court, now being fully advised in the premises, renders the following decision:

IN THE

UNITED STATES CIRCUIT COURT OF APPEALS,

FOR THE THIRD CIRCUIT.

No. 3799. March Term, 1928.

GENERAL ELECTRIC COMPANY,
Appellant,
v.
THE DEFOREST RADIO COMPANY,
Appellee.

No. 3800. March Term, 1928.

GENERAL ELECTRIC COMPANY,
Appellant,
v.
DEFOREST RADIO COMPANY,
Appellee.

No. 3801. March Term, 1928.

DEFOREST RADIO COMPANY,
Appellant,
v.
GENERAL ELECTRIC COMPANY,
Appellee.

APPEALS FROM THE DISTRICT COURT OF THE UNITED STATES FOR THE DISTRICT OF DELAWARE.

(Filed November 11, 1930.)

Before BUFFINGTON, WOOLLEY and DAVIS, *Circuit Judges.*

Buffington, J.

In the Court below the General Electric Company charged the DeForest Radio Company with the infringement of four patents. On final hearing that Court held one of the patents valid and infringed and the other three invalid. By appropriate steps its so holding was brought before this Court for review. Without entering into detail, we may say that, save as to patent No. 1,558,436, the reasoning, conclusion and decree of the Court below commend themselves to us and we affirm the same. In the case of patent No. 1,558,436, we feel the Court below committed error in holding the patent invalid and dismissing the bill.

As usual in litigation over a patent of great commercial value, the vast mass of expert speculation, the protracted argument covering days and with briefs that in the aggregate covered several hundred pages, the case, on re-argument, narrowed to the simple question of the patent paternity of what is known commercially as the Langmuir tube. The Court below held the tube had no patent paternity and to that question we now address ourselves. The subject matter of the patent and the general features of the pertinent art are set forth at length in the comprehensive opinion of the Judge below and by reference thereto we avoid the necessity of present restatement.

Laying aside for the present technical language and scientific discussion and confining ourselves to simple statement, the Langmuir tube is a tube in which for example the gaseous conductor incident to a Fleming valve and a DeForest audion is dispensed with and a vacuum substituted therefor.

In the patent sued on, No. 1,558,436, granted October 20, 1925, to Irving Langmuir, assignor to the General Electric Company for "electrical discharge apparatus and process of preparing and using the same," the specification states:

"The present invention relates to electrical *vacuum* discharge devices, and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of *gaseous ionization* such as occurring, for example, in the ordinary Roentgen tube.

"My present invention comprises improvements in electron-discharge apparatus which make possible a *high load capacity* and operation with the *highest voltages,* but the invention is also applicable and useful for moderate loads and moderate voltages."

Existing objectionable incidents to the use of gassy tubes and the erratic, non-determinable action of gas are pointed out as follows:

"In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a *pure electron* discharge as distinguished from a discharge through *ionized gas.* In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon *gas ionization.* Without a certain *minimum amount of gas* a Roentgen X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

"The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the *vacuous space.* If these electrons when moving above a certain velocity collide with *gas molecules* they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of the electrons and the ions; these phenomena are in general *erratic and non-reproducible.* The cathode under these conditions is disintegrated, technically it is 'sputtered', which causes its rapid destruction. As *gas ionization* continues at higher voltages a *blue glow* may appear. The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. *These voltages are different for different gases.* In the case of gases such as nitrogen, hydrogen, oxygen, argon, helium and neon, they are of the order of magnitude of fifteen to twenty-five volts."

Describing the DeForest audion and differentiating it from the alleged invention of the patent, the specification says:

> "The phenomena above described as being characteristic of devices involving *gas ionization* are taken advantage of in an incandescent cathode device with three electrodes known as the 'Audion.' This device has been used as a receiver for radio-telegraphy and depends in its operation upon the rapid change of the discharge current when *gas ionization begins*. This point depends upon various *accidental* conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts."

Describing the Fleming valve and its limitations, the specification states:

> "Another discharge device previously used to some extent was the *Fleming valve*. This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the voltages at which positive ionization by collision occurs. It was not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects."

Referring to high voltage, the specification makes this statement:

> "No prior hot cathode devices are known to me operating with currents as great as above 5 milliamperes with voltages as high as about 200 volts; indeed no prior discharge devices are known to me operating in a practically usable manner and without substantial positive ionization effects with currents as great as about one-tenth of a milliampere with voltages as high as about forty volts."

Specifying some of the differences and advantages of the alleged invention, the specification states:

> "In devices made in accordance with my invention *gas ionization* is either entirely *absent* or is negligible and a discharge takes place which is *distinct* in its characteristics from the described discharge taking place in an *ionized gas.* The cathode is not heated by the discharge itself. Blue glow, glass fluorescence and in fact all readily visible indications of a discharge are ordinarily absent."

Referring to the evacuation of the tube, the specification sets forth:

> "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes *vapors as well as gases* . . .
>
> "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. . . .
>
> "It is also true that when the anode has been carefully freed from gas, residual free gas, even if

present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated."

Claim 12, which is,

> "An electrical discharge device, comprising a gas-tight-envelope, an electronemitting cathode, an anode *deprived of ionizable gas* and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that when operated below saturation and materially above the ionization voltages, the current is controlled by *space charge* substantially unaffected by positive ionization."

is typical in character of the alleged invention.

Does the defendant use a tube answering this general description? We think it does and that in giving up the old gaseous tube and using one of the "very high vacuum", a change which it announced in its statements to the public, we have a virtual admission of the essential difference between the two tubes. The tube of this disclosure is aptly described as "non gaseous" and "of a very high vacuum" by the defendant when putting it on the market, as follows:

> "The tube consists of a highly evacuated vessel, cylindrical, rather than bulbular, in shape enclosing the three elements, grid, plate and filament in the form of the old type T tubular DeForest tube with which amateurs are familiar. The plate is of nickel, cylindrical in shape and surrounds a helical grid also of nickel. The filament is a crimped tungsten wire passing through the center of the grid exactly as it did in the old style type DeForest tube. The chief difference between this tube and the type T tube of similar mechanical construction is in its evacuation. The old style type T was an *ionic or gaseous tube* very unstable in operation and requiring a variable 'B' battery.

It had the decided disadvantage that after continued use the tube would get 'hard' and require more 'B' battery until it reached such a state as to be inoperative. The new 'VT' tube, like the DeForest standard tubes to-day, is purely an electronic tube exhausted to a *very high vacuum,* so that it is non-gaseous and will stand very high plate potentials. When used as a detector, however, a battery of 20 to 40 volts is sufficient to give the proper plate current although voltages of 80 to 100 may be used without detrimental effect upon the tube. The 'B' battery moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work. . . . The gaseous type tubes are, however, no longer being manufactured."

Turning next to the question on which the validity of the patent depends, we inquire first as to its usefulness, for the constitutional power to create the monopoly of a patent in that regard conditioned "to promote the progress of . . . useful arts" and the Congressional enactment in pursuance of the Constitution is that "any person who has . . . discovered any new and useful" etc. For in the final analysis, use, usefulness, is the acid test, the SINE QUA NON of patent grant.

The unusual degree of usefulness of the tube may be assumed. The defendant by its use evidences its usefulness and has, we have seen, adopted it and ceased making "gaseous type tubes," and the Court below, after its exhaustive study of the art, aptly described the tube, and we agree with its estimate, as an agency which "because of its stability, reproducibility and power has made possible radio broadcasting, modern radio reception and long distance telephony."

Seeing then we are here dealing with a progressive step which next to the telegraph, the telephone and the wireless, is probably one of the most far reaching and beneficent in human progress, there can be no question of a non-gaseous, vacuum tube's usefulness. Such being the case, is it novel? The simple fact is that we see such a tube in universal use to-day; we know in the quoted language of the Court below of its "stability"; of its "reproducibility"; of its "power." We know that these elements have, as stated by the Court below, made "possible radio broadcasting, modern radio reception and long distance telephony." Indeed the fact that a non-gaseous vacuum tube makes possible the present improved practice shows that such practice did not exist before the Langmuir tube and that no other device or devices, all important as they may have been in their spheres, did either singly or collectively produce the present practice. The patent office recognized that. In the opinion of The Board of Examiners they found, in affirming the decision of the Examiner of Interferences, that "Langmuir was the first to conceive and the first to reduce."

While all the vast mass of knowledge testified to in these records was open to everyone to use, the simple fact remains that the non-gaseous tube of modern use did not occur to scientists. Every one of the two hundred and sixty-six words in Lincoln's Gettysburg Speech is found in the dictionary; most of them in the Bible. But it remained—not for Noah Webster or even the Prophets of old—but for Abraham Lincoln to take these isolated words and so use them conjointly as to produce the most remarkable combination in literature.

We do not disregard or minimize the all important part of DeForest's audion and Fleming's valve play in the utilization of them in the Langmuir tube, but in spite of such high value, neither of them, in isolation or conjoint use, gave the world the tube here in question and it remained for Langmuir to so couple and coordinate the two by means of eliminating gas and using vacuum as to produce the tube here involved. What scientific credit is due to DeForest or Langmuir or to what patent tribute Langmuir subjected himself in thus using their devices are questions not before us.

Moreover the statement in the Commercial Circular of the DeForest Company that gas was an element of operation, was in accord with the then scientific belief. In 1911 Gernsback, an experienced savant, wrote that in the audion "the operating principle is the shattering of a column of conducting gas by a received electrical impulse."

The function of a gaseous tube as a conductor was stated by the Circuit Court of Appeals of the Second Circuit in 243 Fed. Rep. 565, where Fleming's valve and DeForest's audion were considered, in these words: "The 'gaseous medium' of the audion is nothing but the commercial vacuum of the ordinary electric light bulb—air being a gas, and the bulb containing some residual air. In other words, defendant uses the same 'vacuous vessel' that Fleming does." And in its opinion it stated that it was asserted in that case that the audion was "an apparatus in which the bulb contains a substantial amount of gaseous medium essential to the operation of the device." To the same effect is the testimony of Langmuir, of which we find no contradiction, that

> "In the devices of the old art, in the DeForest audion, the pressure was continually changing. It sometimes increased and it sometimes decreased. Both things went on and there was an evolution of gas, water vapor would come off the bulb and be decomposed by the filament and it would generate gas. Gases would come out of the electrodes. Positive ions would bombard the walls and the electrodes and would drive gas off."

It will also be noted this Court in its able and exhaustive statement of the art in 21 Fed. (2) 918, said: "We observe that at the time of both the DeForest and the Armstrong inventions the only audion tubes in use were 'gassy' or 'soft':"

That its action was eccentric, is shown by DeForest's statement:

> "In the first place, anyone who has had considerable experience with numerous audion bulbs must admit that the behavior of different bulbs varies in many particulars, and to an astonishing degree. The wing potential wing current curves for different bulbs, or even for the same bulb at different times, under different conditions (filament temperature, etc.) vary widely.
>
> "What may appear to be a fixed law for one bulb may not hold for another."

On the other hand, the current in Langmuir is practicable, steady, reproducible at any particular voltage.

It further appears that the Langmuir tube has a great advantage when it comes to replacement. When a tube is defective, another of the same type can be bought and placed in the same socket. Not so with the audion. It required frequent replacement and where replacements were made it was necessary to readjust throughout the circuit. In that respect the proof is:

> "XQ. 35. What practical effect would harmful ionization have upon an audion amplifier such as, for example, as is used in the telephone line?
>
> "A. The worst immediate effect would be as to uniformity of operation, which would make continued adjustments necessary and would interfere with the replacement of one device by another, that is to say, when one tube burned out and another were put in an amount of ionization that would interfere with uniformity of operation would make it necessary to readjust throughout the circuit to take care of the substitute tube."

As to the replacement, the proof is that

> "Another consequence of this uniformity is that replacement of the tubes without changing the apparatus becomes possible. That is particularly important in telephone repeaters and in radio devices both of the receiving and transmitting type. One wants to know that he can replace a burned-out tube with a new tube without having to make substantial changes in the apparatus."

It will also be noted that the whole trend of the art was against the use of a vacuum, and even after Langmuir had shown its use, it was deemed impractical. Thus in a paper of 1914 Wehnelt and Leibreich said that ionization persisted in the best vacuum they could get.

Moreover, it is of great present significance that the then view of DeForest himself was against Langmuir's use of the vacuum, he then stating in a paper read by him before a scientific body: "I believe, however, Dr. Langmuir has, by working into these high vacua and the high potentials necessitated thereby, pursued the less promising of the two paths of research." The record shows no explanation, comment or retraction by him of this statement.

Such being the general state of the case, has the defendant by evidence overcome the prima facies of the patent? We think not. As said by this Court in 159 Fed. Rep. 948, citing the Barbed Wire Case, "the burden of proof upon this part of the case rests upon the defendant, and every reasonable doubt should be resolved against it." And in our view the crux of the case is one of fact, namely, whether the use of a vacuum in the combination of the claim was Langmuir's novel disclosure. We are not concerned with scientific theories and speculations as to what might have been done or what could possibly have been done for, as well said by the Circuit Court of Appeals of

the Second Circuit in 298 Fed. Rep. 582, we sit "not as scientists, but as weighers of evidence." But we are concerned with the fact whether the combination of the claim which Langmuir disclosed was new. That some had bombarded anodes of X-ray tubes to get some of the gas out of them; that others had heated bulbs or used pumps to lessen the gas, may all be true, but none of them had produced the commercial tube which Langmuir gave to the public. And such actual contribution in use and not theory and possibility of speculation is, and of right should be, the decisive factor in patent reward. As was said by the Circuit Court of Appeals of the Second Circuit: in O Rourke vs Mc Mull
Fed. 933;

> "The keynote of all the decisions is the extent of the benefit conferred upon mankind. Where the court has determined that this benefit is valuable and extensive it will, we think, be difficult to find a well considered case where the patent has been overthrown on the ground of non-patentability."

We regard as of high evidential significance the statements made by the defendant in its circular to the public, already quoted. It will not do to brush aside and ignore it on the suggestion it was the work of some enthusiastic subordinate or sales agent. It was a deliberate statement of a great mechanical company of its ceasing to make and market a superseded article and to thereafter make and market a new and different one. No such change would in business practice be made by subordinates, but was, in the nature of things, the mechanical, scientific and commercial determination of a great business organization. In this statement the defendant recognized a "gaseous," non highly vacuum tube as new. As we have seen, it differentiated it from its "gaseous" tubes up to then made and publicly announced that such gaseous type tubes would no longer be manufactured. And indeed, that no such non-gaseous, highly vacuum tube existed is shown by the fact that the testimony of experts and the laborious research by the Judge below, whose industry is proverbial, did not disclose any such tube as both parties to this litigation now make and contend for the right to make, existed or had advanced the arts in question to this new standard of theretofore non-attained efficiency.

Such being the case, the defendant is driven to take the position—which found favor with the Court below—that in view of what existed in the prior art, that it required no invention to so utilize these things in the prior art to produce a non-gaseous, highly vacuum tube, and that this great progressive step was due simply to the art's natural advance and improvement.

But in point of fact no such advance toward a non-gaseous tube, as we are now told was to be looked for in the art, was actually made by the art. We would not be misunderstood. Advance, inventive and non-inventive, was being made in the art, but their efforts were in other directions. We would not detract from the great advance made by DeForest and exemplified by his audion and by Fleming with his valve, but great as these steps were—both separately and collectively—and we regard them as the foremost in the advance of the art in the sphere here involved—the gaseous tubes still continued to be used and the art generally regarded gas as incident, if not, indeed, indispensable to their use.

Indeed, had the art followed the caution of DeForest heretofore quoted, we would have no vacuum tube, a situation akin to that referred to by this Court in the Turbine case, 202 Fed. Rep. 932, where we said:

> "Finding, then, as we do, that the disclosures of the Moorehouse patent had no helpful bearing or practical effect on the impulse turbine art, and supported in that conclusion by the fact that its

vagueness is such that fair-minded witnesses in this record greatly differ as to what its disclosures really are, we are not warranted in attributing to it any effect in the way of vitiating, or even minimizing, the work of Curtis."

Now as it seems to us, the art, although it did not exactly know how the gas in gaseous tubes acted and just why it was able to so conduct, nevertheless continued to use it and regarded it as the indispensable means of conducting. As against this firmly entrenched teaching and practice of the art, Langmuir's suggestion of eliminating gas as a conductor was a radical change and even more so was not the substitution of some other tangible conductor, but the disclosure of supplanting the tangible gaseous conductor by the intangible conductor of a vacuum. Vacuums, per se, were of course known. DeForest's audion and Fleming's valve were equally known, but the suggestion of dispensing with gas and utilizing a vacuum between the two was as novel in practice as it was unlooked for in result. Indeed, shortly before the patent in suit was applied for and even though the use of a vacuum may possibly have been suggested, the director of the Research Laboratory stated in a paper read before the American Institute of Engineers: "In connection with this work of Fleming's, we have studied the effect of vacuum on the current, and also found that the presence of gas is necessary for this negative discharge." And that Langmuir's use of high vacua did not appeal to so practical and eminent a scientist as DeForest was evidenced by his statement, heretofore quoted, made even after Langmuir had made known his process publicly,—"I believe, however, that Dr. Langmuir has, by working into these extremely high vacua and the high potentials necessitated thereby, pursued the less promising of two paths of research." For the defendant to now contend that the use of these extremely high vacua by Langmuir was simply the natural and to be expected growth of the art is to credit the ordinary art with a scientific capacity which a master of the art like DeForest did not himself possess. If it was an obvious thing, as the Court below believed and decided, for the ordinary art to do away with gas and gaseous tubes and substitute high vacua therefor, surely such an extraordinary mind in that art as DeForest, when confronted with the substitution, would not have pronounced high vacua a mistaken path. Had the ordinary art followed the advice of this super ordinary adviser and leader and discarded the suggestion of high vacua, it would seem so far as the universally used non-gaseous tube is concerned, it would not be in use to-day.

But it is contended by the defendant and the Court below so held, that all that Langmuir did was simply to vary in degree the prior use of the vacuum and that a mere difference in degree does not constitute invention or to use the defendant's contention, the Langmuir tube is "nothing more or less than the identical thing of the prior art with possibly a little higher vacuum, depending on the specific use to which the device is to be put." Assuming the correctness of this general proposition, we think it is not applicable to the present case. In considering change in degree, the test is not the quantum or minimum of change made but the quantum of change in function and result which such change, great or small, effects. A great change may effect but a slight change in function and result, while a slight change may effect a radical difference in function and effect. The effect, the practical progress and use in the arts, are the aim and end of patent grants and where great results follow a change, the slightness of the change tends to emphasize and make all the more remarkable, unexpected and inventive the disproportionate result the slight change effects. It was the slight turn of a screw and the closer proximity of the diaphram that made the telephone diaphram the carrier of speech and gave Bell the due reward—not for the slight turn of the screw but for the great effect it wrought. But a vacuum, or indeed change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so co-ordinate and interwork that current flow is not affected by gas. We say not affected by gas because of necessity an absolute vacuum is an impossibility, but the degree of vacuum is such the current flow is no longer objectionably affected [illegible] gas. Just what the degree of vacuum shall be is dependent on several elements and, as stated in the patent, cannot be exactly stated. In that regard the specification says: "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned."

So regarding what we believe to be the basic question in the case, we limit ourselves to the foregoing statement of our reasons for our conclusion. But in thus limiting our discussion, we deem it proper to say that the numerous questions and considerations advanced in the case in other particulars, have been duly considered.

The decree of the Court below holding this patent invalid is reversed and the record remitted with instructions to enter a decree that the patent is valid and infringed.

(GENERAL ELECTRIC COMPANY v. DE-FOREST RADIO COMPANY)

WOOLLEY, *Circuit Judge,* dissenting:

I am constrained to dissent from the judgment of the court holding the Langmuir patent No. 1,558,436 valid. I have the same trouble that other tribunals have had throughout the twelve years of the patent prosecution and five years of the patent's life in finding precisely what Langmuir invented. My trouble, like that of others, has been increased by the difficulty which attorneys for the patent have had in defining the invention and by the difference between their definitions and the claims of the patent.

This is more than a mental disturbance, for manifestly a patent to be valid must relate to some invention, something patentably new and useful, and must disclose the invention so that a court, looking through the eyes of those skilled in the art, can see what it is.

The art—really two related arts—is that of wire and wireless telephony, the latter commonly called radio. The invention relates generally to an electron discharge device comprising the familiar vacuum tube in which the customary electric current is carried by negative charges called electrons from the cathode to the anode, sometimes associated with a grid, and relates particularly to a vacuum space so free from gases as to avoid ionization. If the parts and principles of the mechanical construction were new and the gas evacuation old, there might be invention; and also if the structure and its principles were old and the gas evacuation—high vacuum—were new, still there might be invention. But the essential parts and principles of the mechanism, comprising a tube, cathode, anode and grid, were old, and high vacuum in the tube also was old. So the inventor was forced to admit the presence of these old elements, yet, still insisting he had created something new, he was compelled to avoid the common art terms applicable to these elements and particularly that of "high vacuum" in disclosing his invention and use technical terms which, as I understand them, mean the same old things. With this necessarily general preface to a highly complicated situation arising out of a difficult art, I come to the matters in hand.

In an effort to find what Langmuir invented, it is well to begin at the beginning. I shall therefore turn to his application for a patent, for in that instrument must appear the substance of the invention as the basis for subsequent amendments and for the patent as it eventually matured.

A recital of the prosecution of a patent application through the Patent Office is dreary reading yet, in this instance, it shows quite clearly that even the applicant was far from certain what he had invented. Naturally I hesitate to say this about Irving Langmuir, a great physicist, yet, saying it with entire respect, I am convinced that the history of the application establishes that fact and therefore is pertinent to the ever present inquiry: What did Langmuir invent?

The patent issued on October 20, 1925. The application was filed on October 16, 1913; renewed March 14, 1916. These are critical dates. The original application contained five claims; two for process of removing ionizable gas from vacuum electron discharge devices, that is, in plain words, for obtaining a high vacuum, and three for methods of preparing such devices, and no claims for discharge devices themselves. The specification conformed to these claims, referred to the art, stated the problem, disclosed construction adapted to the operative principle of such tubes and showed how they can be "evacuated" of gases by heating the glass walls, heating and bombarding the metal parts thereby expelling occluded gases, and drawing off both free gases and expelled gases "by a suitable evacuating means, for example, a Gaede molecular pump".

It should be noted that when the application was filed in 1913 the radio art was in its infancy but that, in 1925, when the patent issued, the art had attained an amazing growth. It is pertinent to inquire what happened to the application during this span of twelve years during which the mysteries that had enveloped the early art were largely dispelled and replaced by a broad knowledge of its principles.

After the application was filed in 1913 it lay practically dormant for several years, the applicant filing enough amendments by additions and cancellations to keep it alive. Amendments to the specification occurred as follows: two in 1913; eight in 1914; one in 1915; five in 1916; three in 1917; three in 1919 and forty-five in 1925, the year the patent issued.

Amended claims were filed and additions thereto and cancellations thereof made as follows: four in 1913; fifteen in 1914; twenty in 1916; five in 1917; nine in 1919; five in 1921 and forty-two in 1925, the year of the patent.

Analyzing these amendments, it appears that the five original claims (which were for process and method) were at different times wholly cancelled. Late in the year 1913 Langmuir first made claim to invention of a structure or device, that is, to invention of a tube. This he did by four claims. The first was amended four times and cancelled in 1925. The second also was amended four times and cancelled in 1925. The third was amended four times and was not cancelled. The fourth was amended once and cancelled in 1925. Of the thirty-two claims allowed in the issued patent, four are for method and process, being amplifications of the original method and process claims cancelled; twenty-eight are for a device. Of these device claims one was filed by amendment in 1913; one in 1917; nine in 1919; three in 1921 and fourteen in 1925, the year the patent issued. Bearing on the question whether Langmuir knew and disclosed in 1913, or indeed in succeeding years, what he had invented, it is significant to note that during twelve years, and mainly in the latter part of that period when the art had grown and reached a high stature, he rewrote, by sixty-seven amendments, the major part of his specification and cancelled all the original method and process claims and by one hundred amendments added, changed and cancelled claims until finally he was allowed the thirty-two claims of which twenty-eight, the claims for a device, are entirely new. It would be instructive, yet impossible within the permissible bounds of an opinion, to trace the progressive changes from the method and process claims of the original application to the device claims of the matured patent. But device claims having been allowed, they inevitably bring into the case certain devices of the prior art of which two are presently pertinent.

Long before Langmuir applied for a patent, Fleming, an English inventor, brought into a very feeble art a practical electron discharge device, comprising a cathode and anode in a vacuum tube. Also long before Langmuir's application, DeForest improved on Fleming by producing an electron discharge tube which he described as an oscillation detector and called an "audion". The improvement consisted in adding a grid to Fleming's elements. The construction and functions of both devices are given in an elementary way in the opinion in Westinghouse Electric & Mfg. Co. v. DeForest Radio T. & T. Co., 21 Fed. (2d) 918, 919. The audion as conceived by Fleming and improved by DeForest at once became and has ever since continued to be the basis of the modern art of transmitting sounds great distances both by wire and through the air. Just here dates are important. A patent for the audion (No. 879,932) issued to DeForest in 1908. The audion vacuum tube was therefore in existence and its principles of operation presumably known by Langmuir when in 1913 he filed his application for a method of evacuating such a tube, although he had not seen one until that year. In 1912 or 1913, the American Telephone & Telegraph Company, committed to the operation of transcontinental telephony by the opening of the San Francisco Fair, acquired rights under the DeForest patent and, first exhausting the gas and heightening its vacuum, used the DeForest audion as an amplifying telephone relay, thus making possible the first transmission of vocal words from coast to coast by wire. In 1917 the DeForest Radio Telephone Company, assignee of the DeForest patent, granted (with certain rights reserved) a license to the Western Electric Company to make, use and sell the invention for certain purposes with the right to grant sub-licenses. In 1920 the General Electric Company, the plaintiff in this suit and the assignee of the Langmuir patent in suit, acquired through mesne conveyances a sub-license to make, use and sell the DeForest audion, DeForest Radio T. & T. Co. v. Radio Corporation of America, 20 Fed. (2d) 598, 599, 600, which (probably with a heightened vacuum) it did on a vast scale until the DeForest patent expired in 1925, the year in which the patent in suit, after twelve years of travail in the Patent Office, issued to Langmuir, assignor to the General Electric Company, for an electron discharge tube including the essential parts and now universally accepted principles of the Fleming-DeForest tube. The Langmuir patent now completely covers the field previously occupied by the audion of the expired DeForest patent, and will, on the decree of this court, continue to cover it for twelve years more; hence the importance of this litigation.

Turning to the patent as it issued, the specification must first be looked at, for it contains some references to the behavior of electricity in a vacuum tube, old and well known, which are necessary to an understanding of the case. First there is a description by words and diagrams of mechanism for a vacuum tube. If new, this, it would seem, is unimportant as the specific mechanism is not claimed. Its importance resides in the fact that the patented device comprises the three elements of the general mechanism found in the art—the cathode, anode and grid, variously positioned in a vacuum tube to get the best electrical result—and in the fact that, as I read the record, these three elements, separately and in combination, operate on the same principle in which they operated in the art. Describing their operation, as the art then knew it, Langmuir said:

"The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the vacuous space. If these electrons when moving above a certain velocity collide with gas molecules they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of electrons and the ions; . . . . The cathode under these conditions is disintegrated, . . . , which causes its rapid destruction . . . . The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages . . . . (It should, for later use, be noted here that Langmuir said nothing about gas being a supposed medium for conducting electrons from one electrode to the other.)

"If for a given cathode temperature the voltage is sufficiently high to cause all the electrons emitted or liberated at the cathode to be drawn away, then a further increase in voltage produces substantially no change in the current. The current thus determined is called the saturation current, and the range of operation in which the current is substantially independent of the voltage or approaches this condition may be called the saturation range or more briefly designated merely as saturation. If for a given cathode temperature the voltage is not high enough to cause all of the electrons which are emitted or liberated at the cathode to be drawn away, the operation occurs in a range below the saturation range. Operation in this range may be spoken of as operation below saturation."

Predicated on these two definitions of ionization and saturation Langmuir by claim 2, which has been treated in this litigation as a typical claim, said that his invention is:

"A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization."

That, as I read it, simply means "high vacuum," for a tube properly fashioned and shaped by skilled workers and highly (thoroughly) evacuated of gases—

free and occluded—will in conjunction with a two electron group or with a group of two electrons and a grid produce these results; both groups, then and now, being in common use for different purposes by the ar and by the plaintiff itself.

For the purposes of this case, vacuum means gas evacuation, high vacuum means vacuum above the ionization point, and, by the same token, a high vacuum tube means a non-gaseous tube. If the language of the claims means high vacuum, it is prior art, for the art was entirely familiar with the fact and effect of such a vacuum; and if prior art, Langmuir invented nothing.

When the patent came into litigation in this case in the District Court of the United States for the District of Delaware the learned trial judge, having trouble with the claims, endeavored to get from the plaintiff a definition of the invention, asking time and again, as did this court on appeal: If not high vacuum, what is the invention? An answer to this question seemingly had its difficulties. The plaintiff, of course, could not say that the invention was high vacuum alone, or high vacuum in combination with Fleming and DeForest parts alone, for that would be an admission of old art and would instantly avoid the patent. It was forced to admit that the Langmuir device included all these old elements but claimed it included "something else." So, eventually, in order to show this something else—something new—it produced, under the insistence of the trial court, this carefully constructed definition of Langmuir's invention, on which the case was tried below and on which it was first argued and decided in this court on appeal:

"The Langmuir invention is a coordination of elements having a new functional relation between various factors, producing a new result. It is not a matter merely of maintaining a certain vacuum, far less of *producing* a certain vacuum which will be destroyed the moment the tube begins to operate. It involves primarily a relation between the shape, size and space relation or "geometry" of the parts of the tube and the nature and pressure of the gas therein contained, coordinated and adjusted with respect to the conditions of the electric circuit."

That, I surmise, would be a bad patent claim. However, as it was intended to describe the invention more clearly and more definitely than Langmuir had disclosed it in the patent claims I shall take it as it is written and try to find what it means. I discern in its generalization three factors: (1) gas pressure in the tube; (2) "shape, size and space relation or geometry of the parts of the tube"; and (3) the relation of one to the other.

The first factor of gas pressure, or, more properly, the lack of it, if it means anything, must mean a minimum of gas. This in turn means high vacuum. If it does not mean high vacuum there is no new vacuum factor of invention in the device, for low vacuum was old and that is an end to the case. If it does mean high vacuum then again it is not new, for high vacua, their uses and effect and how to produce them, were long known and practiced in the art.

The second factor, or "geometry," of the physical tube elements is not, so far as the claims reveal, involved in the invention. The physical elements themselves were old. This the plaintiff admits. Though differing in shape from some others, they are not claimed to be inventively novel in themselves. Indeed, each claim describes the invention not so much by its parts as by its characteristics of operation and results—characteristics inherent in any electron discharge tube possessing a high vacuum. Nor was this an inadvertence for when the Examiner, on rejecting certain device claims on prior art references, said:

"If applicant's device is an improvement over the reference he should define the difference by structural limitations," the applicant (Langmuir) replied by saying:

"The 'structural limitations' in this case are to be found in the *difference of vacuum.*"

So, thus far, the invention, with old parts and a high vacuum, gets back to the question whether there was invention in the "difference" between low vacuum and high vacuum, a difference existing in and known to the art.

The third factor, the relation of the two factors of gas pressure and physical parts, appears nowhere in the claim unless it be implicit in the words "the gas content or residue of said tube and the relation of the *parts* of the tube being such" as to produce a certain result. (Gas pressure is scarcely a *part* of a tube.) If it is so implied, Langmuir can not claim invention by implication. The claim therefore is void for inadequate disclosure. If it is not so implied, there is no claim for the third factor.

Whether I am right or wrong in this analysis of the plaintiff's statement of Langmuir's invention or in my disposition of its elements is not important for the validity of the patent depends not on the plaintiff's conception and definition of the invention but on the claims of the patent.

So I come back to the claims of the Langmuir patent to find Langmuir's invention. But before doing that I am arrested by still another entirely new definition of Langmuir's invention, this time made by the court in its opinion. The court did not adopt the plaintiff's definition of coordinating elements with functional relations but, stating that a non-gaseous electron discharge device did not exist before Langmuir, found the invention to reside in his producing a non-gaseous tube in place of a gaseous tube of the prior art or, in other words, in substituting a high vacuum for a low vacuum, the very thing which all along the plaintiff was forced to avoid in its definition because it was old. Without conceding its predicate, I agree with the court's succinct definition of the invention; but as the invention so defined was old I cannot agree to hold a patent for it valid.

It now appears, and I say this with entire respect, that in interpreting and sustaining the patent broadly for a non-gaseous tube the court has given the plaintiff more than it ever dared to claim. A high vacuum or non-gaseous tube being old, the plaintiff knew that an admission that the invention was a non-gaseous tube and nothing else would defeat the patent. Langmuir also must have known that a non-gaseous tube was old for otherwise, if he had believed he was the first to conceive and make one, he could, and doubtless would, have claimed it in a half dozen words: "A non-gaseous discharge tube," or "an electrical discharge device with a high vacuum tube," whereas in his original application for a patent he made no claim for a tube of that kind or, indeed, for a tube of any kind, the inevitable inference being that at that time he thought all he had invented was a new method or process of gas evacuation, that is, a new way to produce an old thing. But that the plaintiff realized the necessity of claiming for the invention something more than a high vacuum tube or non-gaseous tube is evidenced by its earnest and repeated contentions that Langmuir's invention, while including a non-gaseous tube—high vacuum—admittedly old, included "something else," that something else being disclosed by the remainder of the long claims and interpreted in its quoted definition. The plaintiff nowhere and at no time has claimed that Langmuir invented a non-gaseous tube per se. And wisely so, for it well knew that, while not in universal use, non-gaseous tubes were in commercial use before Langmuir for some purposes and that gas evacuations were as thorough as the instrumentalities of the art in 1913 would effect, and that was substantially above the ionization point, which is the crux of this case.

Returning to the patent claims and using claim 2 for convenience, it appears that the invention is an electron discharge tube which is capable of being operated below saturation and above ionization voltages. Langmuir called this a "pure electron discharge device"—"pure" because unaffected by gas ionization which is either entirely absent or negligible.

Electricity is an elusive subject. Therefore I shall, for the immediate purpose, restate in plain words, if I can, the theory of ionization.

Ionization is an effect produced by passing an electric current through gas which remains in a vacuum tube when it has not been thoroughly evacuated. The myriads of electrons, when passing from cathode to anode above a certain velocity, collide with and break up the molecules of gas present and charge the resultant broken parts or ions with positive charges of electricity. Thus electric reaction is inevitable. The ions (with their positive charges of electricity) fight against the electrons (with their negative charges) in the normal flow of the latter from cathode to anode resulting, at high voltages, in a blue glow which is the indication of bad action, a thing to be avoided. The central point of this statement is that ionization occurs at certain voltages in an electron discharge tube when, not being thoroughly evacuated, it contains air or gas, whether gas free in the tube or gas occluded in its parts and liberated by heat during operation. The amount of ionization depends upon the amount of gas present. Langmuir prescribed in his specification that occluded gas should be expelled from the tube parts; from the tube by heating its glass walls; from the cold electrodes by electron bombardment—the liberation of gas by the electric discharge itself; and from the incandescent cathode by the heat of an electric current; all old; and after this, that both the expelled gas and free gas should be pumped out of the tube during the heating process (old) by "a suitable evacuating means (old) for example, a Gaede molecular pump," then a new German invention.

Thus the capital requirement, if not the sole requirement, of Langmuir's claimed invention, is as nearly as possible to withdraw from the tube all gas, free and occluded; in other words, to obtain as high a vacuum as possible. When that is done ionization is avoided and a pure electron discharge follows. Was this new with Langmuir?

Langmuir was met in the Patent Office with the Law Examiner's statement that:

"It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. *An evacuated tube having therein an incandescent electron emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube were also well known and available to persons skilled in the art.*"

Was that statement of the Law Examiner correct? I think it was. Just here occurs my sharpest departure from the opinion of the court which is based, as I have before stated, on what I am constrained to believe is an erroneous theory or finding that all discharge tubes before Langmuir were gaseous and that Langmuir's invention is a non-gaseous tube.

If that was his invention, clearly he must have been the first to conceive it and reduce it to practice.

That the Examiner was right in saying that high vacua in electron discharge tubes were old before Langmuir and that a pure electron discharge—the inevitable result in a high vacuum non-gaseous tube and an impossible result in a gaseous low vacuum tube—also was old is sustained by many prior publications and patents. The same prior publications and patents contradict, I think, the court's holding that Langmuir was first to make and invent a non-gaseous tube. They are so numerous that it would not be permissible to quote them in an opinion. I shall therefore do nothing more than cite a few of them, ranging from 1881 to 1912, found in the record and to be used by anyone who should desire to check up this statement or who may be charged with the duty of re-trying the issue. They are: Lilienfeld, Fleming, Doane, VonBaeyer, Bissel & Hagen, Malignani, Edison, Dwyer, Duncan, Leonard, Soddy, Thatcher, Child; illumined by the testimony of Waterman and Chaffee.

On these references I stand; and on them I would hold the patent invalid for want of invention.

Passing from the literature and patents of the prior art as affecting the validity of the patent for want of invention, I come to the question of prior use. The trial court found the patent also invalid because of prior use by DeForest on evidence as to which there is little dispute on the facts as distinguished from inferences. The test is the voltage at which ionization ordinarily occurs in a "gassy" tube. It is given at from 20 to 30 volts. That is not disputed; they are Langmuir's figures.

Prior to August 1912, DeForest was the electrical engineer of the Federal Telegraph Company of California and was engaged in developing the transmission and reception of messages by radio. In this work he used his oscillation detector or audion then normally having a gas content. It was a "gassy" tube. But desiring to use it not as a detector but as an amplifier, as later it was almost universally used and indeed as made for that use by the plaintiff itself under license and by the Westinghouse Electric & Manufacturing Company, its sub-licensee, he had the audion exhausted of gas as far as it was possible in that day. That is, he sought and obtained as high a vacuum in the tube as existing means would produce. When the vacua were too low and the amplications poor he complained to the manufacturer and had the tubes re-exhausted. During that period (1910, 1911 and 1912) the Federal Telegraph Company used DeForest's amplifying audion at 54 and 67½ volts. This was possible only because he had exhausted the tubes of gas, which otherwise would produce ionization at 20 to 30 volts, and thereby heightened the vacuum above that danger line. This was "high vacuum" within the definition of vacuum above the point of ionization and was therefore high vacuum within the sense of those words as used in this case. It was not so high as that later attained by more modern means, for instance the Gaede molecular pump, which had just come into the art at the time of the patent application, referred to by Langmuir in his application and invented not by him but by Gaede. I agree with the court that DeForest did not then understand the change in operative principle for in later years he expressed views contrary to those advanced both before and after that time. But DeForest did change the vacua of his tubes in changing their function from detectors to amplifiers. Whether he knew the principle of the change is of no consequence. The fact is he did it. And he did it before Langmuir. And by doing it he got rid of the ionization of low vacuum and obtained, and put into commercial practice for nearly three years before Langmuir, the very electron discharge of Langmuir's claimed invention.

What I have said about the device claims applies equally to the method and process claims.

On the subject of validity as involving invention I shall conclude this phase of the discussion by referring very briefly to the claimed advance made in the art by Langmuir's invention, matter with which the plaintiff very earnestly began and ended discussion in its brief and at the argument and matter by which the court was impressed. Admittedly, when invention is in doubt—yet *only* when it is in doubt—favorable reception by the art may be placed in the scale. As the four judges who heard this case have divided evenly on the question of invention, I shall, for that reason only, assume there is doubt as to invention. The plaintiff says that today everybody uses "the Langmuir tube", a name given it not by the art (as the plaintiff frankly admitted at the argument) but by the plaintiff itself; that Langmuir, seeing through the mysteries of the art, made an invention that revolutionized the industry and made possible the transmission of sounds through the air for great distances which without his invention would be impossible.

Much litigation in respect to the radio art has drifted to this circuit. Oddly enough, in every case the plaintiff has claimed for his invention the whole credit for its growth. I am satisfied from the number of cases we have heard that the whole credit for the amazing advance of the radio art cannot be given to any one invention or even to a few of them. In truth, the art is the product of innumerable impulses. The original impulse was, of course, the vacuum tube appearing years ago in the incandescent lamp art. Another impulse given in the incandescent lamp art and transferred to the radio art was that of the Just and Hanaman unstable squirted tungsten filament displacing Edison's bamboo filament; still another was Coolidge's method for obtaining a filament of pure tungsten, strong and stable. Impulses in the radio art itself came from many inventors. At one time there were seven thousand applications for patents pending in the radio section of the Patent Office. To mention only one or two inventions, they include discharge devices of the Fleming two electrode type and the DeForest type with a grid added to Fleming, the feedback circuit invented at different times by DeForest, Armstrong, Langmuir and Meissner. There are many more, without any one of which it has always been said by the particular inventor that the art would have gotten nowhere. And now the plaintiff here says the same of Langmuir. Important and indeed great as some of these inventions were, no one of them is entitled to all credit for what has been accomplished in this great art, for the art has been impelled forward by hundreds of inventors and thousands of skilled workers. What Langmuir claims to have done—procured pure electron discharge above ionization voltages in tubes of the DeForest type—appears to me to be the natural growth of the art, begun by others before Langmuir and by them reduced to practice with means then available, and developed to their later perfection during the twelve years of his patent prosecution through the Patent Office.

I thought after the argument, and still think, the Langmuir patent invalid because of lack of invention and prior use. If I am wrong and the patent really involves invention, then, again, I think it invalid for, as I read the evidence, Langmuir was not the first and original inventor. On this point, to avoid repetition, I refer and subscribe to the opinion of Judge Morris holding on evidence substantially greater than the evidence in the interference proceeding that, if invention, Arnold was the first and original inventor.

And so this court, one judge dissenting, affirmed the decree of the District Court, on its opinion, holding the Langmuir patent invalid.

In due course the plaintiff filed a petition for rehearing based on this proposition:

"In simple language, Langmuir's invention consisted in taking out the conductor (gas) which was in the Fleming valve and the DeForest audion and putting nothing in its place; he dispensed with what was regarded as an essential element in the operation of the tube (gas) and by doing so made a tube which worked infinitely better."

The petition was allowed and the reargument was based on this entirely new statement of Langmuir's invention made for the first time four years after suit was brought, five years after the patent was issued and seventeen years after the application was filed. Of course if the facts asserted were facts established by the evidence there would be no doubt about what Langmuir did and no doubt that it was invention and, if claimed, no doubt he was entitled to a patent.

The plaintiff rests its proposition upon its own statement that "Both Fleming and DeForest depended upon the conductivity of gas as the fundamental basis of the operation of their tubes". It makes this statement without distinguishing between detectors and amplifiers and supports it by carefully selected quotations from scientific publications in the early days of the art ranging from 1905 to 1912 (one in 1915) when scientists were feeling for the theory of electron movement in electron discharge tubes, some of whom based it on conduction by rarified gases or air, some on conduction by ionized gases, and some not on conduction at all but on free passage of electrons through space in a high vacuum, that is, in the absence of gas or air. And in addition the plaintiff to support its statement points to an adverse criticism by DeForest in 1915 of Langmuir's "extremely high vacuum" quoted in the court's opinion. The plaintiff ignored all the testimony on the subjects of prior art high vacua and pure electron discharge, which means absence of gas as a conductor, their advantages and uses, to which I have previously alluded with citations.

Of course, if the belief and practice of the art were that gas conducts the electrons, that gas therefore is necessary to conduction and Langmuir discovered it to be wrong, that in fact gas is an enemy to conduction, and omitted gas as an element in his tube yet obtained the same or a better result, clearly he made an invention. These are the things which now the plaintiff and also the court say he did. But Langmuir did not say so. If that was his invention he should have disclosed it in his claims for we are called upon to judge the patent on Langmuir's disclosures, not on the plaintiff's definitions of his invention. To be sure, he did refer in his specification to several tubes—the Geisler tube and the Roentgen X-Ray tube—"whose operation depends upon gas ionization". He might, more or less correctly, have added to the list detectors with gas content, then and now in common use for certain purposes, whose usefulness depends on their sensitiveness and their sensitiveness on gas content. But he nowhere said in his patent that before his invention electron discharge tubes used for amplifying purposes in order more faithfully to reproduce sounds (one of the purposes of the DeForest audion and the thing we are dealing with in this case) depended on low vacuum or that the art regarded, as an essential element of such a device, gas as a conductor, for he probably knew the contrary was true. To show that the plaintiff's last definition of Langmuir's invention is without foundation in the evidence I refer to, but shall not repeat, what I have said about prior knowledge and prior use of high vacuum tubes. I shall endeavor, very briefly, to show that Langmuir by his own words contradicts the plaintiff's last definition of his invention and refutes the theory on which the court has in part based its judgment.

In Langmuir's original specification he stated that when there was enough gas in the tube to become ionized by the discharge of electrons "The positive ions (gas molecules) *take part* in the *conduction* of current, giving at first erratic readings on measuring instruments connected in circuit," which is what the plaintiff now says. Continuing, he said, that the audion, the DeForest tube, was a device that took advantage of that phenomenon. *But he cancelled the quoted statement before the patent issued.* At the trial he was examined with respect to that statement in his patent application and was asked whether the sentence would be true if it read; "The positive ions take part in the conduction of current by acting as *conductors* or carriers of current". He answered: "In my opinion the sentence would have *no sensible meaning* if the word 'conductor' was left in for *it is inconceivable that ions could be conductors of current.* I will, therefore, confine myself to the case where the positive ions act as 'carriers'. With this correction I can say that the statement would not have been true."

With this cancellation and explanation Langmuir rested. Neither by amendment nor in his testimony did he again advert to a prior art theory of gas conduction which the plaintiff now says "was regarded (by the art) as an essential element of the operation".

In the interference proceeding Langmuir testified with respect to the early work of Lilienfeld, as follows:

"Lilienfeld proved beyond question, I think, that he obtained discharges, in some cases at least, in which the effects that he measured *were not dependent upon gas ionization.* . . .

"Lilienfeld probably succeeded in obtaining a discharge *high vacuum substantially free from effects of positive ionization* in the device he described in his 1910 paper. . . .

"Lilienfeld in his experiments of 1910 heated the walls of the vessel, *he reduces the gas pressure to a low value,* and in some of his experiments *he heated his electrodes* by *electronic bombardment.* . . .

"*Heating of glass and electrodes, and exhaustion to low pressure,* are elements which were used by Lilienfeld and were known *prior* to Lilienfeld's article. . . .

"Factor No. 1 which I gave in answer to XQ84, viz., that the bulb should be heated *during* exhaust to a temperature materially higher than the operating temperature, was used by Lilienfeld in much of his work. . . .

"Factor No. 4, which is that which I gave in the first part of my answer to XQ87, refers to the lowering of the pressure to such a point *that a further lowering brings about no further change.* In many of Lilienfeld's experiments, this condition *was realized.*"

VonBaeyer stated as early as 1909 that his "experiments were of course carried out in the highest possible vacuum to avoid the influence of ionization". Langmuir admitted that "Wehnelt claimed that . . . currents of the order of 10 milliamperes could be obtained even in the highest vacuum".

Referring to an interview with Richardson in 1912 Langmuir said:

"Richardson . . . expressed himself as confident that even in the highest vacuum thermionic currents could still be obtained."

Langmuir admitted in the interference proceeding that "prior to 1912 (the year before his application) there were some experimenters who took precautions to remove gases from the walls, from vessels and from electrodes''.

This, I think, shows that the reargument, based on an incorrect premise, should leave undisturbed the court's first finding that the patent is invalid.

The plaintiff, however, prevailed. The court reversed its previous decision and will now enter a decree holding the patent valid. From the opinion announcing its judgment, in so far as it will reverse the decree of the District Court on the first (Langmuir) patent in suit, I dissent.

This is a long dissenting opinion. In view of the gravity of the Court's decision and its effect upon the art I make no apology for its length. I frankly admit that it is written with the hope that it will arrest the attention of the reviewing court.

A true Copy:
Teste:

Clerk of the United States Circuit Court of Appeals
for the third Circuit.

ORDER REVERSING DECREE, ETC.

(Filed November 11, 1930.)

UNITED STATES CIRCUIT COURT OF APPEALS, FOR THE THIRD CIRCUIT.

No. 3799 (List No. 33). October Term, 1930.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

District Court No. 589.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES, FOR THE DISTRICT OF DELAWARE.

This cause came on to be heard on the transcript of record from the District Court of the United States, for the District of Delaware, and was argued by counsel.

On consideration whereof, it is now here ordered, adjudged, and decreed by this Court that the decree of the said District Court holding Letters Patent No. 1,558,436 invalid and dismissing the bill in this cause be, and the same is hereby reversed, with costs, with instructions to the said District Court to enter a new decree holding the said patent valid and infringed.

Philadelphia, November 11, 1930.

PER CURIAM,

(Sgd.) BUFFINGTON,
Circuit Judge.

ORDER AFFIRMING DECREE.

(Filed November 11, 1930.)

UNITED STATES CIRCUIT COURT OF APPEALS, FOR THE THIRD CIRCUIT.

No. 3800 (List No. 34). March Term, 1930.

General Electric Co.,
Appellant,
v.
DeForest Radio Co.,
Appellee.

District Court No. 598.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES, FOR THE DISTRICT OF DELAWARE.

This cause came on to be heard on the transcript of record from the District Court of the United States, for the District of Delaware, and was argued and reargued by counsel.

On consideration whereof, it is now here ordered, adjudged and decreed by this Court that the decree of the said District Court in this cause be, and the same is hereby affirmed, with costs.

Philadelphia, November 11, 1930.

PER CURIAM,
(Sgd.) JOSEPH BUFFINGTON,
Circuit Judge.

ORDER AFFIRMING DECREE.

(Filed November 11, 1930.)

UNITED STATES CIRCUIT COURT OF APPEALS, FOR THE THIRD CIRCUIT.

No. 3801 (List No. 35). October Term, 1930.

DeForest Radio Co.,
Appellant,
v.
General Electric Co.,
Appellee.

District Court No. 598.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES, FOR THE DISTRICT OF DELAWARE.

This cause came on to be heard on the transcript of record from the District Court of the United States, for the District of Delaware, and was argued by counsel.

On consideration whereof, it is now here ordered, adjudged, and decreed by this Court that the decree of the said District Court in this cause be, and the same is hereby affirmed, with costs.

Philadelphia, November 11, 1930.

PER CURIAM,
(Sgd.) BUFFINGTON,
Circuit Judge.

CLERK'S CERTIFICATE.

UNITED STATES OF AMERICA,
EASTERN DISTRICT OF PENNSYLVANIA, } *Sct.*
THIRD JUDICIAL CIRCUIT.

I, WILLIAM P. ROWLAND, Clerk of the United States Circuit Court of Appeals, for the Third Circuit, DO HEREBY CERTIFY the foregoing to be a true and faithful copy of the original transcript of record and proceedings in this court in the cases of:- No. 3799—General Electric Co. v. DeForest Radio Co., No. 3800—General Electric Co. v. DeForest Radio Co., No. 3801—DeForest Radio Co. v. General Electric Co., on file, and now remaining among the records of the said Court, in my office.

IN TESTIMONY WHEREOF, I have hereunto subscribed my name and affixed the seal of the said Court, at Philadelphia, this day of December, in the year of our Lord one thousand nine hundred and thirty and of the Independence of the United States the one hundred and fifty-fifth.

(Seal)

(Sgd.) WM. P. ROWLAND,
Clerk of the U. S. Circuit Court of Appeals, Third Circuit.

SUPREME COURT OF THE UNITED STATES

ORDER ALLOWING CERTIORARI—Filed February 25, 1931

The petition herein for a writ of certiorari to the United States Circuit Court of Appeals for the Third Circuit is granted. And it is further ordered that the duly certified copy of the transcript of the proceedings below which accompanied the petition shall be treated as though filed in response to such writ.

Vol. IV

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DEFOREST RADIO COMPANY, PETITIONER,

vs.

GENERAL ELECTRIC COMPANY

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT

PETITION FOR CERTIORARI FILED JANUARY 8, 1931

CERTIORARI GRANTED FEBRUARY 25, 1931

(35,552)

PLAINTIFF'S EXHIBITS.

GENERAL INDEX.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
1.	Langmuir U. S. Patent No. 1,558,436, Oct. 20, 1925	I	35	IV	1
2.	Langmuir U. S. Patent No. 1,244,216, Oct. 23, 1917	I	36	IV	11
3.	Langmuir U. S. Patent No. 1,244,217, Oct. 23, 1917	I	36	IV	16
4.	Langmuir U. S. Patent No. 1,529,597, Mar. 10, 1925	I	36	IV	20
5.	DeForest Type H Rectifier Tube	I	51	—	—
6.	DeForest Type H Audion Tube	I	51	—	—
7.	DeForest DV 5 Vacuum Tube	I	51	—	—
8.	DeForest DV5 Vacuum Tube	I	51	—	—
8-A.	Data sheet accompanying DeForest DV 5 Vacuum tube	I	93	IV	27
9.	Defendant's Circular	I	51	IV	28
10.	Defendant's Leaflet	I	51	IV	29
11.	Hogan Fig. 1, Diagram of Two Electrode Tube	I	52	IV	31
12.	Hogan Fig. 2, Diagram of Three electrode tube	I	52	IV	32
13.	Hogan Table I showing Power of Numbers	I	69	IV	33
14.	Hogan Chart A of Table I, Simple Powers of Numbers, Arithmetic Paper	I	69	IV	34
15.	Hogan Chart B of Table I, Simple Powers of Numbers, Logarithmic Paper	I	70	IV	35
16.	Plaintiff's UV 199 Tube	I	92	—	—
16-A.	Data sheet enclosed with UV 199 tube	I	92	IV	36
17.	Plaintiff's UX 201A Tube	I	93	—	—
17-A.	Data sheet enclosed with UX 201A Tube	I	93	IV	37
18.	Hogan Drawing illustrating Plff.'s UX 201A tube	I	94	IV	38
19.	Hogan Drawing illustrating Defendant's DV 5 tube	I	94	IV	39
	[Nos. 20 to 161, incl. Langmuir Exhibits in Interference Record and not reprinted. *See Separate Index.*]	II	927	—	—
162.	Opinion of Court of Appeals, District of Columbia, in Langmuir v. Arnold, dated June 1, 1925	II	935	IV	41
163.	Langmuir explanatory diagram	II	1126	IV	45
164.	Langmuir 2/3 power plot diagram	II	1195	IV	46
165.	Langmuir 3/2 power plot diagram	II	1195	IV	47

PLAINTIFF'S EXHIBITS—GENERAL INDEX—Continued

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
166.	Langmuir plot of volts on plate and grid against current audion No. 2	II	1198	IV	48
167.	Langmuir explanatory diagram	II	1260	IV	49
168.	Langmuir explanatory diagram A	II	1267	IV	50
168-A.	Langmuir explanatory diagram A¹	II	1267	IV	51
168-B.	Langmuir explanatory diagram B	II	1267	IV	52
168-C.	Langmuir explanatory diagram B¹	II	1267	IV	53
168-D.	Langmuir explanatory diagram D	II	1267	IV	54
168-E.	Langmuir explanatory diagram E	II	1267	IV	55
168-F.	Langmuir explanatory diagram F	II	1267	IV	56
169.	Letter from Alexanderson to Patent Department, General Electric Co., February 5, 1913	III	1452	IV	57
170.	File wrapper and contents Arnold U. S. patent No. 1,297,309, March 18, 1919	II	788	IV	59
171.	White notebook No. 462 (certain pages only)	III	1468	IV	91
172.	White test records (Card & 7 sheets)	III	1479	IV	108
173.	White report on relaying of high frequency currents by means of improved audions	III	1483	IV	115
174.	Coolidge notebook No. 327	III	1506	IV	121
175.	Coolidge notebook No. 446, extract from	III	1518	IV	128
176.	Hogan diagram of vapor pressures of sodium	III	1612	IV	129
177.	DeForest Bulletin B-14 of 1914	III	1632	IV	130
178.	DeForest Bulletin B-15 of 1915	III	1632	IV	134
179.	DeForest Bulletin C-16 of 1916	III	1633	IV	140
180.	DeForest Catalogue L	III	1633	IV	153
181.	DeForest Catalogue B of 1919	III	1633	IV	156
182.	DeForest type T audion Tube	III	1633	—	—
183.	Circular of Sterling Reactivator	III	1638	IV	161
184.	Hewlett sketch of circuit	III	1639	IV	165
185.	Letter and data sheets furnished by witness Kelly	III	1738	IV	167
186.	Hogan Logarithmic plot of Audion 64-91	III	1744	IV	175
187.	Hogan Logarithmic plot of Kelly data for tube 102-D	III	1745	IV	176
188.	Hogan Logarithmic plot of characteristics of small receiving tube corrected for contact differential	III	1748	IV	177
189.	Hogan plot (Anode Current) 2/3—Anode Voltage Characteristics of Type G Power Tube	III	1749	IV	178

PLAINTIFF'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
189-A.	Hogan plot of Anode current—anode voltage Characteristics of Type G Power Tube	III	1749	IV	179
190.	Hogan logarithmic plot of plate current-plate voltage of UX-201A Tube (H-20)	III	1750	IV	180
191.	Logarithmic plot of Kelly's data on Tube 105	III	1752	IV	181
192.	Hogan copy of Deft.'s Exhibit 54-A, with additional lines thereon	III	1755	IV	182
193.	Hogan Logarithmic plot of Type 7510 with nitrogen	III	1758	IV	183
194.	Physical Review, Vol. 26, No. 4, October, 1925, pp. 436-435, "Probability of Ionization of Gas Molecules by Electron Impacts," by Compton and Van Voorhis	III	1761	IV	185
195.	Paper No. 4, Arnold v. Langmuir Interference 40,380	III	1762	IV	203
196.	Paper No. 6, Arnold v. Langmuir Interference 40,380	III	1762	IV	204
197.	Paper No. 9, Arnold v. Langmuir Interference 40,380	III	1762	IV	205
198.	Paper No. 10, Arnold v. Langmuir Interference 40,380	III	1762	IV	206
199.	Paper No. 32, Arnold v. Langmuir Interference 40,380	III	1762	IV	207
200.	Paper No. 85, Arnold v. Langmuir Interference 40,380	III	1763	IV	208
201.	Option Agreement, Dec. 16, 1912, between Hewett and A. T. & T. Co.	III	1763	IV	210
201-A.	Agreement A, between Hewett and A. T. & T. Co.	III	1763	IV	214
202.	Hewett U. S. Patent No. 781,001, Jany. 31, 1905	III	1763	IV	235
203.	Hewett U. S. Patent No. 781,002, Jany. 31, 1905	III	1763	IV	238
204.	Hewett U. S. Patent No. 749,791, Jany. 19, 1904	III	1763	IV	241
205.	Hewett U. S. Patent No. 749,792, Jany. 19, 1904	III	1763	IV	244
206.	Hewett U. S. Patent No. 749,793, Jany. 19, 1904	III	1763	IV	247
207.	Hewett U. S. Patent No. 758,650, May 3, 1904	III	1763	IV	250
208.	Hewett U. S. Patent No. 954,434, Apr. 12, 1910	III	1763	IV	252
209.	Hewett U. S. Patent No. 991,304, May 2, 1911	III	1763	IV	255
210.	Table of Mechanical Repeater Installations, 1904-1918, in Gherardi deposition	III	1765	IV	261
210-A.	Table of Repeater Installations, 1904-1918, Gherardi deposition	III	1766	IV	262
211.	Philosophical Magazine (1912), Vol. 23, pp. 192-200, "Ionization Produced by Carbon at High Temperatures," by Pring & Parker	III	1766	IV	263
212.	Fleming U. S. Patent No. 954,619, April 12, 1910	III	1766	IV	269

PLAINTIFF'S EXHIBITS—GENERAL INDEX—Continued

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
213.	DeForest U. S. Patent No. 879,532, Feby. 18, 1908	III	1766	IV	273
214.	Modification of license agreement dated July 1, 1920 between General Electric Co. and A. T. & T. Co.	III	1786	IV	277
215.	Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1820	IV	313
216.	Nicolson notebook (Not printed in full)	II	801	—	—
216-A.	Certain pages of Nicolson notebook	II	801	IV	322
217.	DeForest U. S. Patent No. 1,201,273, Oct. 17, 1916	III	1887	IV	328
218.	Certain pages of book of O. W. Richardson entitled "The Emission of Electricity from Hot Bodies"	III	1891	IV	332
219-A.	Langmuir replot of data taken from Defendant's Exhibit No. 295	III	1930	IV	358
219-B.	Langmuir Parabolic Plots of currents taken from Defendant's Exhibit No. 299	III	1930	IV	359
219-C.	Langmuir Parabolic plot of currents taken from Defendant's Exhibit No. 297	III	1930	IV	360
220.	Langmuir Logarithmic current voltage curve for different pressures of nitrogen	III	1931	IV	361

PLAINTIFF'S EXHIBITS.

CLASSIFIED INDEX.

Diagrams and Drawings.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
184.	Hewlett sketch of circuit	III	1639	IV	165
11.	Hogan Fig. 1, Diagram of Two electrode Tube	I	52	IV	31
12.	Hogan Fig. 2, Diagram of Three electrode Tube	I	52	IV	32
13.	Hogan Table I showing Power of Numbers	I	69	IV	33
14.	Hogan Chart A of Table I, Simple Powers of Numbers, Arithmetic Paper	I	69	IV	34
15.	Hogan Chart B of Table I, Simple Powers of Numbers, Logarithmic Paper	I	70	IV	35
18.	Hogan Drawing illustrating Plff.'s UX 201A tube	I	94	IV	38
19.	Hogan Drawing illustrating Defendant's DV 5 tube	I	94	IV	39
176.	Hogan diagram of vapor pressures of sodium	III	1612	IV	129
186.	Hogan Logarithmic plot of Audion 64-91	III	1744	IV	175
187.	Hogan Logarithmic plot of Kelly data for tube 102-D	III	1745	IV	176
188.	Hogan Logarithmic plot of characteristics of small receiving tube corrected for contact differential	III	1748	IV	177
189.	Hogan plot (Anode Current) 2/3—Anode Voltage Characteristics of Type G Power Tube	III	1749	IV	178
189-A.	Hogan plot of Anode current—anode voltage Characteristics of Type G Power Tube	III	1749	IV	179
190.	Hogan logarithmic plot of plate current—plate voltage of UX-201A Tube (H-20)	III	1750	IV	180
192.	Hogan copy of Deft.'s Exhibit 54-A, with additional lines thereon	III	1755	IV	182
193.	Hogan Logarithmic plot of Type 7510 with nitrogen	III	1758	IV	183
191.	Logarithmic plot of Kelly's data on Tube 105	III	1752	IV	181
163.	Langmuir explanatory diagram	II	1126	IV	45
164.	Langmuir 2/3 power plot diagram	II	1195	IV	45
165.	Langmuir 3/2 power plot diagram	II	1195	IV	47
166.	Langmuir plot of volts on plate and grid against current audion No. 2	II	1198	IV	48
167.	Langmuir explanatory diagram	II	1260	IV	49

PLAINTIFF'S EXHIBITS—CLASSIFIED INDEX—Continued

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
168.	Langmuir explanatory diagram A	II	1267	IV	50
168-A.	Langmuir explanatory diagram A¹	II	1267	IV	51
168-B.	Langmuir explanatory diagram B	II	1267	IV	52
168-C.	Langmuir explanatory diagram B¹	II	1267	IV	53
168-D.	Langmuir explanatory diagram D	II	1267	IV	54
168-E.	Langmuir explanatory Diagram E	II	1267	IV	55
168-F.	Langmuir explanatory diagram F	II	1267	IV	56
219-A.	Langmuir replot of data taken from Defendant's Exhibit No. 295	III	1930	IV	358
219-B.	Langmuir Parabolic Plots of currents taken from Defendant's Exhibit No. 299	III	1930	IV	359
219-C.	Langmuir Parabolic plot of currents taken from Defendant's Exhibit No. 297	III	1930	IV	360
220.	Langmuir. Logarithmic current voltage curve for different pressures of nitrogen	III	1931	IV	361

Documentary, Miscellaneous.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
201-A.	Agreement A, between Hewett and A. T. & T. Co.	III	1763	IV	214
183.	Circular of Sterling Reactivator	III	1638	IV	161
8-A.	Data sheet accompanying DeForest DV 5 Vacuum tube	I	93	IV	27
16-A.	Data sheet enclosed with UV 199 tube	I	92	IV	36
17-A.	Data sheet enclosed with UX 201A Tube	I	93	IV	37
9.	Defendant's Circular	I	51	IV	28
10.	Defendant's Leaflet	I	51	IV	29
177.	DeForest Bulletin B-14 of 1914	III	1632	IV	130
178.	DeForest Bulletin B-15 of 1915	III	1632	IV	134
179.	DeForest Bulletin C-16 of 1916	III	1633	IV	149
180.	DeForest Catalogue L	III	1633	IV	153
181.	DeForest Catalogue B of 1919	III	1633	IV	156
169.	Letter from Alexanderson to Patent Department, General Electric Co., February 5, 1913	III	1452	IV	57
185.	Letter and data sheets furnished by Witness Kelly	III	1738	IV	167
214.	Modification of license agreement dated July 1, 1920 between General Electric Co. and A. T. & T. Co.	III	1786	IV	277
162.	Opinion of Court of Appeals, District of Columbia, in Langmuir v. Arnold, dated June 1, 1925	II	935	IV	41

PLAINTIFF'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
201.	Option Agreement, Dec. 16, 1912, between Hewett and A. T. & T. Co.	III	1763	IV	210
195.	Paper No. 4, Arnold v. Langmuir Interference 40,380	III	1762	IV	203
196.	Paper No. 6, Arnold v. Langmuir Interference 40,380	III	1762	IV	204
197.	Paper No. 9, Arnold v. Langmuir Interference 40,380	III	1762	IV	205
198.	Paper No. 10, Arnold v. Langmuir Interference 40,380	III	1762	IV	206
199.	Paper No. 32, Arnold v. Langmuir Interference 40,380	III	1762	IV	207
200.	Paper No. 85, Arnold v. Langmuir Interference 40,380	III	1763	IV	208
210.	Table of Mechanical Repeater Installations, 1904-1918, in Gherardi deposition	III	1765	IV	261
210-A.	Table of Repeater Installations, 1904-1918, Gherardi deposition	III	1766	IV	262
172.	White test records (Card & 7 sheets)	III	1479	IV	108
173.	White report on relaying of high frequency currents by means of improved audions	III	1483	IV	115

File Wrapper and Contents.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
170.	File wrapper and contents Arnold U. S. Patent No. 1,297,309, March 18, 1919	II	788	IV	59

Notebooks.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
174.	Coolidge Notebook No. 327	III	1506	IV	121
175.	Coolidge Notebook No. 446, Extract from	III	1518	IV	128
216.	Nicolson notebook (Not printed in full)..........	II	801	Not printed	
216-A.	Certain pages of Nicolson notebook	II	801	IV	322
171.	White Notebook No. 462 (Certain pages only)	III	1468	IV	91

Patents, United States.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
213.	DeForest, No. 879,532, Feby. 18, 1908..............	III	1766	IV	273
217.	DeForest, No. 1,201,273, Oct. 17, 1916..........	III	1887	IV	328
212.	Fleming, No. 954,619, April 12, 1910..............	III	1766	IV	269
202.	Hewett, No. 781,001, Jany. 31, 1905................	III	1763	IV	235
203.	Hewett, No. 781,002, Jany. 31, 1905................	III	1763	IV	238
204.	Hewett, No. 749,791, Jany. 19, 1904................	III	1763	IV	241
205.	Hewett, No. 749,792, Jany. 19, 1904................	III	1763	IV	244

PLAINTIFF'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
206.	Hewett, No. 749,793, Jany. 19, 1904	III	1763	IV	247
207.	Hewett, No. 758,650, May 3, 1904	III	1763	IV	250
208.	Hewett, No. 954,434, Apr. 12, 1910	III	1763	IV	252
209.	Hewett, No. 991,304, May 2, 1911	III	1763	IV	255
1.	Langmuir, No. 1,558,436, Oct. 20, 1925	I	35	IV	1
2.	Langmuir, No. 1,244,216 Oct. 23, 1917	I	36	IV	11
3.	Langmuir, No. 1,244,217, Oct. 23, 1917	I	36	IV	16
4.	Langmuir, No. 1,529,597, Mar. 10, 1925	I	36	IV	20
215.	Langmuir, No. 1,558,437, Oct. 20, 1925	III	1820	IV	313
	Publications.				
211.	Philosophical Magazine (1912), Vol. 23, pp. 192-200, "Ionization Produced by Carbon at High Temperatures," by Pring & Parker	III	1766	IV	[illegible]
194.	Physical Review, Vol. 26, No. 4, October, 1925, pp. 436-435, "Probability of Ionization of Gas Molecules by Electron Impacts," by Compton and Van Voorhis	III	1761	IV	185
218.	Certain pages of book of O. W. Richardson, entitled "The Emission of Electricity from Hot Bodies"	III	1891	IV	332
	Physical Exhibits.				
5.	Deforest Type H Rectifier Tube	I	51	—	–
6.	DeForest Type H Audion Tube	I	51	—	–
7.	DeForest DV 5 Vacuum Tube	I	51	—	–
8.	DeForest DV 5 Vacuum Tube	I	51	—	–
182.	DeForest type T audion Tube	III	1633	—	–
16.	Plaintiff's UV 199 Tube	I	92	—	–
17.	Plaintiff's UX 201A Tube	I	93	—	–

PLAINTIFF'S EXHIBIT No. 1.

Oct. 20, 1925. 1,558,436

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS AND PROCESS OF PREPARING AND USING THE SAME

Original Filed Oct. 16, 1913

Fig.1.

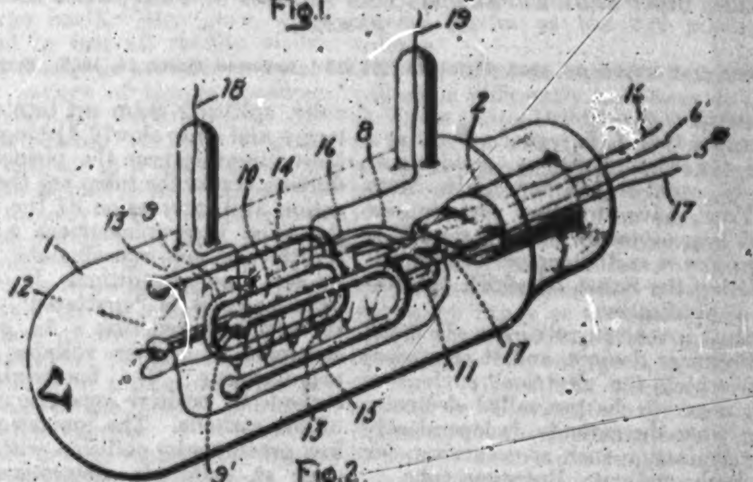

19
18
2
14
6'
5
8
10
16
17
13
9
1
12
11
17
15
13
9'
4

Fig.2.

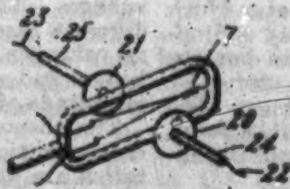

23
25
21
7
20
24
22

Fig.3

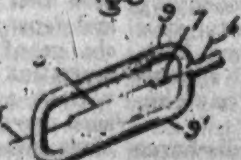


Fig.4.

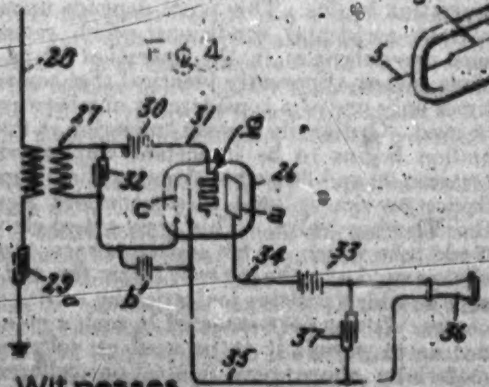
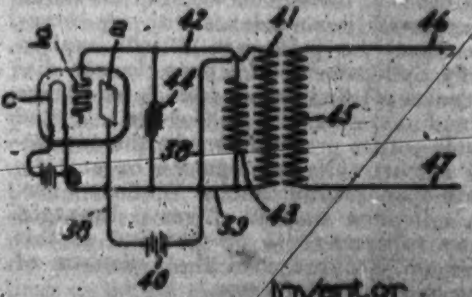

28
27
30
31
a
32
26
c
a
29
b
34
33
37
36
35

Fig.5.


a
a
42
41
46
c
44
45
30
47
38
39
43
40

Witnesses

J. Ellis Glen

Inventor
Irving Langmuir
by Albert G. Davis
His Attorney

Patented Oct. 20, 1925. **1,558,436**

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRICAL DISCHARGE APPARATUS AND PROCESS OF PREPARING AND USING THE SAME.

Application filed October 16, 1913, Serial No. 795,010. Renewed March 14, 1916. Serial No. 84,342.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical Discharge Apparatus and Processes of Preparing and Using the Same, of which the following is a specification.

The present invention relates to electrical vacuum discharge devices, and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization such as occurring, for example, in the ordinary Roentgen tube.

My present invention comprises improvements in electron-discharge apparatus which make possible a high load capacity and operation with the highest voltages but the invention is also applicable and useful for moderate loads and moderate voltages. The novel features of my invention will be pointed out with greater particularity in the appended claims.

Figs. 1 and 2 of the accompanying drawings, Fig. 2 being a partial view, illustrate two types of discharge devices embodying my invention; Fig. 3 is a fragmental view showing a cathode construction, and Figs. 4 and 5 are diagrams of electrical systems illustrating certain applications of my electron discharge tubes.

In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas. In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas a Roentgen X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the vacuous space. If these electrons when moving above a certain velocity collide with gas molecules they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of the electrons and the ions; these phenomena are in general erratic and non-reproducible. The cathode under these conditions is disintegrated, technically it is "sputtered", which causes its rapid destruction. As gas ionization continues at higher voltages a blue glow may appear. The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. These voltages are different for different gases. In the case of gases such as nitrogen, hydrogen, oxygen, argon, helium and neon, they are of the order of magnitude of fifteen to twenty-five volts.

The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device with three electrodes known as the "Audion." This device has been used as a receiver for radio-telegraphy and depends in its operation upon the rapid change of the discharge current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts. Another discharge device previously used to some extent was the Fleming valve. This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the voltages at which positive ionization by collision occurs. It was not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects. No prior hot cathode devices are known to me operating with currents as great as about 5 milliamperes with voltages as high as about 200 volts; indeed no prior discharge devices are known to me operating in a practically stable manner and without substantial positive ionization effects with currents as great as about one-tenth of a milliampere with voltages as high as about forty volts.

In devices made in accordance with my invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas. The cathode is not heated by the discharge itself. Blue glow, glass fluorescence and in fact all readily visible indications of a discharge are ordinarily absent. In most devices of simple construction which embody my invention, the discharge current passing through a given space with the cathode at a sufficiently high temperature with respect to the voltages employed, varies directly with the 3/2 power of the impressed voltages. This 3/2 power law can be readily derived mathematically for a tube in which there is substantially no positive ionization on the assumption that the whole surface of the cathode is at a uniform potential, that the electrons escape from the cathode with negligible velocities and that the walls of the tube do not carry appreciable electric charges.

In most simple devices embodying my invention, these conditions are so well fulfilled that the current does vary in proportion to the 3/2 power of the voltage over wide ranges of voltage above the ionizing voltages. This means that if the logarithm of the current is plotted against the logarithm of the voltage, the resulting plot is a straight line whose slope is 3/2. Or, in many cases it is more convenient to make use of the equivalent relation, that the 2/3 power of the current plotted as ordinates against the anode voltages as abscissæ gives a straight line.

In devices in which there is substantial positive ionization, on the other hand, even when the pressures of gas are so low that only very small currents could be carried by positive ions, the currents begin to increase with voltage more rapidly than according to the 3/2 power law as soon as the anode voltage materially exceeds the ionizing potential of the gas.

In devices embodying my invention which have more than two electrodes, or with special constructions, as where the cathode is a filament, so long that it cannot be considered an equi-potential surface, the 3/2 power law may be more or less masked. However, the effects thus introduced will be readily understood by those skilled in the art, and appropriate methods of identifying the pure electron discharge can easily be found corresponding to the special construction. For example, when such tubes have more than two electrodes and the temperature of the cathode is sufficiently high with respect to the voltages employed, the discharge will usually be characterised by a linear relation between the 2/3 power of the total electron current from the cathode and the voltage applied to any other electrode, the remaining electrodes being kept at constant potential. Another test that can often be made with a three electrode tube is to connect the grid directly to the anode, or to the negative end of the cathode, and observe whether the current varies as the 3/2 power of the voltage.

If for a given cathode temperature the voltage is sufficiently high to cause all of the electrons emitted or liberated at the cathode to be drawn away, then a further increase in voltage produces substantially no change in the current. The current thus determined is called the saturation current, and the range of operation in which the current is substantially independent of the voltage or approaches this condition may be called the saturation range or more briefly designated merely as saturation. If for a given cathode temperature the voltage is not high enough to cause all of the electrons which are emitted or liberated at the cathode to be drawn away, the operation occurs in a range below the saturation range. Operation in this range may be spoken of as operation below saturation.

A change in the temperature of the cathode in a hot cathode device embodying my invention will produce no change in the discharge when the operation is below saturation, even though the ionization voltage is materially exceeded. That is, the current-voltage curve is not changed by a change in the cathode temperature under such conditions.

The discharge in devices embodying my invention is practically independent of the pressure when the pressure is below a certain value which depends upon the size and shape of the device and upon the current and voltage of the discharge.

As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterised by regularity and reproducibility with given conditions. In a device in which the conduction of current is purely electronic and the effect of positive ions is negligible, the conduction of current is governed, over a certain range, on the one hand by the effect of the impressed voltage, which tends to propel the electrons across the vacuous space, and on the other hand by the mutual propulsion of the electrons in the space, which tends to limit or inhibit the current. This last mentioned phenomenon, the current limiting effect of the electric field of the electrons on each other, termed the "space charge effect," is discussed and analysed by me in a paper read before the Physical Society on October 18, 1913, which was abstracted in the Phys-cal Review for November, 1913, and published in full in the Physical Review for December, 1913, and again published in somewhat modified form in the Physikalische Zeitschrift for April 1, and May 15, 1914. It is the basis of the 3/2 power law referred to herein.

The geometric proportions of the device also affect the amount of current which will pass with a given voltage, but as these conditions remain fixed for a given device they may be represented by a constant in an equation expressing the relation between the current and the voltage.

As stated above, the current (I) in the particular device described herein, when operating below saturation, will vary with the 3/2 power of the voltage (V), the equation being:

$$I = aV^{3/2}, \text{ (a being a constant)}$$

As is well known, if we produce a logarithmic graph of any equation in which one variable of the equation varies as a power of the other variable, as for example, an equation of the general form $y = x^n$. (as by plotting logarithms of x as abscissæ and logarithms of y as ordinates) we find that this graph is a straight line. Hence the relation between current and voltage in a device operating below saturation and by pure electronic conduction independent of gas ionization may be expressed by the statement that when with a sufficient electron emission the logarithms of the current values transmitted between cathode and anode are plotted as ordinates against the logarithms of the respective voltages impressed between cathode and anode as abscissæ; the slope of the line obtained does not ordinarily increase for increasing voltage values over a working range of voltages extending materially above the ionization voltages.

A substantial amount of positive ionization ordinarily causes the logarithmic plot of the current with respect to the voltage to bend upwardly and away from the 3/2 power line when the ionizing voltage is materially exceeded. The absence of a bend in the logarithmic plot at voltages somewhat above the ionization voltage is ordinarily a reliable indication that the tube is a pure electron discharge tube, though saturation complete or partial at voltages somewhat greater than the ionization voltages may prevent such a bend in the plot of an ionizing tube.

As above indicated, one of the indications of positive ionization is the occurrence of erratic readings in measuring devices connected in circuit with an electron discharge device under observation. Such erratic readings, of course, will produce a sudden change or discontinuity in the logarithmic graph plotted as above described, and any such irregularities will be more manifest when observed as deviations from a straight line than when the readings are plotted directly.

The effect of positive ionization upon the magnitude of the discharge is especially marked in that region of operation where the current is limited by the space charge effect already discussed, and changes in curvature of the discharge characteristics may occur as indicated unaccompanied by any visible evidence of ionization such as blue glow or the like. At saturation on the other hand, the discharge is ordinarily much less sensitive, and in fact the discharge may actually exhibit naked blue glow effects along with a flat or straight saturation curve.

Devices made in accordance with my invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents, and such devices may be made which will operate without substantial positive ionization at voltages far above the ionization voltages with currents thousands of times greater than the currents at which the devices of the prior art were operable without substantial positive ionization. Devices made and operated in accordance with my invention are capable of transmitting currents materially exceeding one-tenth of a milliampere without causing positive ionization to take any essential part in the operation of the device, though the voltage is materially above the ionization voltages.

Before describing the method of preparing my new type of apparatus, I will describe the structure of the apparatus illustrated by Figs. 1 to 3.

As shown in Fig. 1 the various parts of the apparatus may be mounted in a tube, or envelope 1, upon a pedestal 2, similar to the mount used in incandescent lamps. The cathode 3 is centrally located and may consist of a short straight filament not shown in Fig. 1, but indicated by the position of terminals 5, 6, and shown plainly in Fig. 3. The cathode shown in Fig. 2 consists of a V-shaped conductor. Either form may be used, the particular form of cathode being ordinarily determined by convenience of construction. Preferably the cathode conductor is held taut by a spring 7 to avoid contact of the cathode conductor with the grid by sagging when the metal is expanded at a high temperature. The filament 3 is mounted between two oppositely disposed supports, 9, 9′, in this case constituting a closed loop, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this frame-work is wound a discharge-varying conductor 10, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. By means of this grid 10 potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge.

The supporting framework for the cathode and grid is attached to a rod 11, mounted upon the stem of the tube. Adjacent to the cathode and grid is the anode 12 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 13 upon fork-shaped supports 14 and 15, but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 16 and 17. The grid is indicated in Fig. 1 as being attached to leading-in conductors 18 and 19 at opposite ends, although but one terminal is ordinarily necessary.

In some cases it is desirable to use a plate-shaped anode; Fig. 2 illustrates such an arrangement suitable particularly for rectifying alternating current. The tube itself and other extraneous parts have not been shown in Fig. 2, as they are similar to Fig. 1. The cathode construction has already been referred to and the anodes 20 and 21 also preferably consist of tungsten and may be connected electrically with each other. Current connections are made by conductors 22, 23, the supports 24, 25 being merely indicated. It will be noted that both in Figure 1 and Figure 2 the electrons are afforded a short and direct path from the cathode to the anode and that this path is so related to the position of the walls of the tube as to minimize the tendency for electrons to pass to the walls of the tube. In such a tube electron bombardment of the walls of the tube is avoided, together with the heating of such walls and the secondary emission of electrons therefrom which said bombardment causes. The energy of the discharge is delivered mainly, or entirely, at the anode, anodes, or upon other interior members instead of at the walls of the tube.

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. The heating, especially of solid anodes such as shown in Figure 2, may take place in a suitable vacuum furnace, the temperature preferably being raised to 2,500° C. or even higher. Bombardment is a very effective means of removing occluded gas from anodes.

The bombardment is carried out when the evacuation has proceeded to a high degree by applying a potential between the cathode 3 and the anode 12, Fig. 1, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionization, and as already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon. The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50,000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating voltage. In the case of a plate-shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes.

After the metal has been freed from occluded gas reabsorption of gas will not readily take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacated with less electron bombardment of the anode or anodes.

The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionization by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow, disintegration of the cathode, and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance. It is also true that when the anode has been carefully freed from gas, residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated.

Electron discharge apparatus thus provided with a gas-free pretreated anode or anodes, may be constructed to handle currents at a very high voltage by proper mechanical design of the parts subjected to static strains, suitable proportioning of the parts and so forth as described, for example, in my application Serial No. 795,609 filed concurrently herewith upon which Patent 1,273,783 was granted on July 23, 1918.

The asymmetric conductivity existing between the heated and unheated electrodes of a device of the character described may be utilized for various technical purposes. Reference has already been made to the rectification of current. As shown in Fig. 4 an electron discharge tube may be used for detecting electromagnetic waves in radio-telegraphy. As shown in this Fig. 4 the grid *g* and heated cathode *c* of an electron discharge tube 26 are connected respectively to the terminals of the secondary of a transformer 27, the primary of which is included in the antenna circuit 28. The antenna is grounded through a condenser 29 in the usual manner. The cathode *c* is heated by a local source of energy, as battery *b*. A battery 30 in the grid circuit 31 has its negative terminal connected to the grid *g*. A condenser 32 shunts the secondary of the loosely coupled transformer 27. The inductance of the transformer and the capacity of the condenser are adjusted to make the receiving circuits resonant to the frequency of the oscillations to be received. The oscillations set up by the incoming signals are superimposed upon the negative grid potential and causes a variation of current transmitted between cathode *c* and anode *a* by a local source of energy such as a battery 33 included in the local or plate circuit 34, 35, of the discharge tube. This circuit is connected to an ordinary telephone receiver 36, preferably shunted by means of a condenser 37, whereby the signals are detected.

Fig. 5 illustrates how an electron discharge tube may be used in a system for producing alternating current from direct current. The anode *a* and cathode *c* are connected respectively to conductors 38, 39, one of which includes a local source of energy, such as a battery 40. The terminals of these conductors are connected to an inductive coil 41. The cathode and grid *g* are also connected respectively by conductors 39 and 42 to a second inductive coil 43 which may be in a variable inductive relation to the coil 41. As soon as a flow of current starts in the plate circuit 38, 39, current is induced in the coil 43 of the grid circuit 39, 42. When by reason of this current the grid becomes negatively electrified, the flow of current in the plate circuit is reduced, and as the plate current decreases the grid electrification changes to positive, which again allows the current in the plate circuit to increase. These changes take place with a frequency depending on the electrical characteristics of the circuits. Across the grid circuit 39, 42, of the discharge tube, in some cases is connected a condenser 44, the capacity of which may be varied to control the frequency of the oscillations set up by the system. The oscillations may be transformed to higher or lower voltage by a transformer coil 45 to the terminals of which are connected transmitting conductors 46, 47. The system shown in Fig. 5 is described and claimed in a copending application, Serial No. 797,087, filed October 29, 1913.

Residual gas, left in a tube when it is sealed off or occluded gas driven off from the inner wall of the tube, or from the electrodes, during the use of the tubes, varies in pressure from time to time according to the conditions of operation of the tube and may produce irregularities in the discharge when operating in the saturation region as well as when operating below saturation. The irregularities below saturation are due mainly to the disturbing effect of the resulting positive ions upon the space charge. The irregularities in the saturation region are due to changes in the rate of emission or liberation of electrons at the cathode. It is obvious that the advantages of stable and reproducible operation and freedom from destructive bombardment of the cathode by positive ions, which advantages are severally or collectively to be secured by the means hereinabove described, are not limited to operation below saturation but are also important in operation in the saturation region.

The positive ionization herein referred to is that positive ionization which occurs as the result of collisions between electrons and gas molecules in the space between the electrodes and causes, as by producing changes in space charge, unstable and non-reproducible operation.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the governing or limiting action on the space current due to the electric field of said electrons is substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

2. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization.

3. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

4. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed upon electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the slope of the line obtained by plotting the logarithms of values of said current as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissæ shows no increase for increasing voltage values.

5. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissæ is straight and continuous.

6. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the tube and when the electron emission has any value such that the space current is below the saturation region at such voltages, that said current varies as the three halves power of said impressed voltages.

7. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

8. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, substantially unaffected by positive ionization, the heating effect in the tube due to said current occurring substantially only at one or more of said electrodes.

9. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage

of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts.

10. An electrical discharge device comprising a gas-tight envelope, an electron-emitting cathode, a cooperating anode, and a discharge-varying conductor, the space in said envelope being evacuated to below the pressure at which deleterious gas ionization takes place, constituting a device in which the current passed when operated below saturation and over a working range of voltage materially above the ionization voltages is controlled by space charge substantially unaffected by positive ionization.

11. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts

12. An electrical discharge device, comprising a gas-tight envelope, an electron emitting cathode, an anode deprived of ionizable gas and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that when operated below saturation and materially above the ionization voltages, the current is controlled by space charge substantially unaffected by positive ionization.

13. An electrical discharge device comprising a gas-tight envelope, an electron emitting cathode, a cooperating anode, the space and materials in said envelope being sufficiently free of gas so that substantially no positive ionization occurs when the impressed voltage is as high as 60 volts, and the current over a working range of voltage up to 90 volts varies with the 3/2 power of the impressed voltage.

14. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to 100 volts with currents up to 1 milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said envelope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

15. A device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which no ionizable gas can be evolved at operating voltages up to about 200 volts with operating currents up to about five milliamperes, the space in said envelope being evacuated at a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that with currents up to about five milliamperes at voltages up to about 200 volts, evidences of positive ionization are substantially absent and the current over a working range below saturation varies with the 3/2 power of the voltage.

16. An electrical discharge device comprising a sealed envelope, an incandescent cathode, and a tungsten anode, said anode deprived of ionizable gas disengageable by electron bombardment, and the space in said envelope being evacuated to a sufficiently low pressure so that current flow produces substantially no phenomena of positive ionization when the impressed voltage is as high as 100 volts and the current is as large as 1 milliampere, and the energy of the discharge is delivered mainly upon said anode.

17. An electron discharge apparatus comprising an envelope, an electron emitting cathode, and an anode, said anode being free of gas disengageable by electron bombardment and said envelope being sufficiently free of gas, so that conduction of current can take place in the evacuated space independently of gas ionization at voltages materially above the ionizing voltages with currents of more than one-tenth of a milliampere, and with the energy of the discharge delivered mainly at said anode.

18. An electrical discharge device comprising a sealed envelope, a cathode, means for producing emission of electrons at said cathode independently of the operating voltage, an anode, and discharge varying means independent of the cathode and anode, said device being freed from gas to such extent that the same is operable to transmit current at an impressed voltage at least as high as about 200 volts without evidences of substantial positive ionization.

19. An electrical discharge device comprising a sealed envelope, an incandescent cathode, an anode and discharge-varying means independent of the cathode and anode, the gas residues in said device being so small that the conduction of current is stable and reproducible over a range of voltage materially above the ionization voltages with currents in excess of one milliampere and with the energy of the discharge delivered mainly upon electrodes.

20. An electrical device comprising the combination of a sealed evacuated envelope, a cathode adapted to be independently heated, and an anode within said envelope,

an external circuit connected to said electrodes, and a source of electro-motive force applied to said circuit, the degree of vacuity and the electron emission of the cathode being so related to the potential of said source that the flow of current over a range of voltage materially above the ionization voltage is governed by the electric field of the electrons in the vacuous space and the potential applied to said electrodes, operatively independent of gas ionization.

21. Apparatus for controlling an electric current comprising a vacuum tube, an anode and an electron emitting cathode in the circuit of said current and within said tube, the degree of evacuation of the tube and the relation of its parts being such that for voltages materially above ionization voltage the current is governed or limited by the electric field of the electrons in said tube substantially unaffected by positive ionization, and a third electrode in said tube by which an auxiliary controlling electromotive force may be superposed to modify the effect of said electric field and control said current in a stable and reproducible manner.

22. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

23. A discharge device comprising a tube and electrodes therein, one of which is a cathode, the discharge passing in the main directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltages, that the slope or location of the logarithmic line of current with respect to voltage is not changed by changes in the temperature of the cathode.

24. A discharge device comprising a tube and electrodes therein, one of which is a cathode adapted to be heated and to emit electrons thereby, the discharge passing directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltage, that the plot of the current against the voltage is not changed with changes in the temperature of the cathode.

25. A discharge device comprising a sealed off envelope having therein a cathode adapted to be heated independently of the dicharge and to deliver electrons thereby, and an anode, the inner wall of the envelope and the electrodes being sufficiently free of occluded gas, and the free gas within the envelope being such, so that the finished device is capable of sustained operation below saturation in a stable and reproducible manner with currents of more than one milliampere at voltages materially higher than the ionization voltages and with the energy of the discharge delivered mainly at an electrode or electrodes.

26. A discharge device comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes, the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge, so that the device is capable of passing a sustained discharge of one tenth of a milliampere at forty volts, without developing any substantial positive ionization effects.

27. A discharge device comprising a sealed off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of one milliampere at fifty volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

28. A discharge device comprising a sealed-off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of two milliamperes at one hundred volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

29. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to forty volts with currents up to one-tenth milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said en-

velope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

30. In the process of producing a discharge device, removing the occluded gas from the interior surface of the envelope thereof and from the electrodes to such an extent that the finished sealed-off device will operate, without liberating any substantial amount of gas into the space within the envelope, at voltages materially above the ionization voltage with currents greater than one milliampere and with substantially all the energy of the discharge delivered to an anode or anodes.

31. In the process of producing a hot cathode discharge device, treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein, continuing these operations until the occluded and original free gas is so thoroughly removed as to enable the finished sealed-off device to operate below saturation in a stable and reproducible manner at a voltage above fifty volts and with a current greater than one milliampere and with the energy of the discharge delivered mainly at one or more anodes.

32. The process of producing a discharge device which consists in treating the envelope and enclosed parts thereof to liberate gas therefrom and removing from the envelope gas which is thereby liberated and free gas originally contained in the envelope, the treatment being sufficiently powerful and being sufficiently prolonged and the removal of the liberated and original free gas from the envelope being sufficiently thorough, so that the finished sealed-off device is capable of sustained operation substantially without positive ionization at voltages as high as one hundred volts with currents as great as one milliampere and with substantially the entire energy of the discharge delivered upon the anode or anodes of the device.

In witness whereof, I have hereunto set my hand this 15th day of October 1913.

IRVING LANGMUIR.

PLAINTIFF'S EXHIBIT No. 2.

I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF PREPARATION.

APPLICATION FILED JULY 15, 1914. RENEWED JUNE 25, 1917.

1,244,216. Patented Oct. 23, 1917.

Fig. 2.

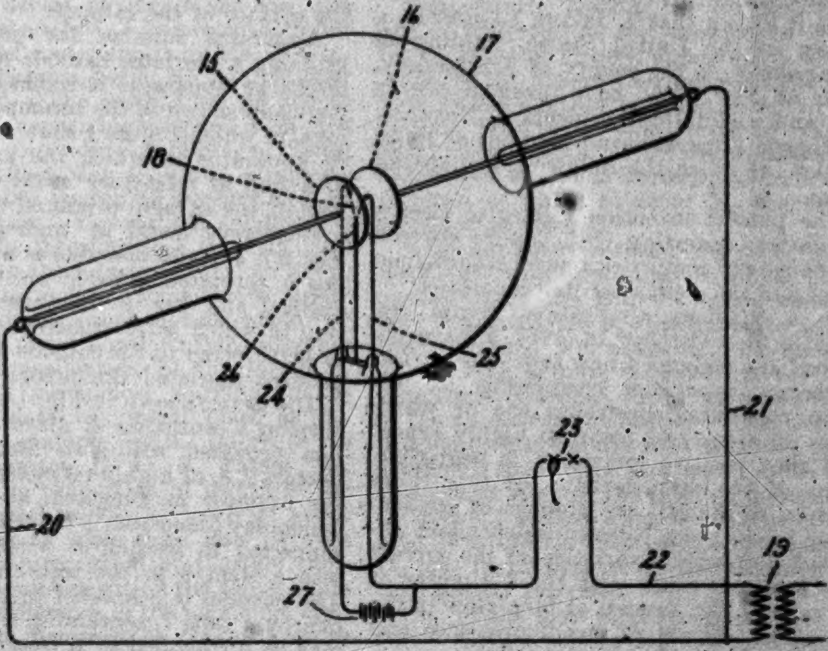
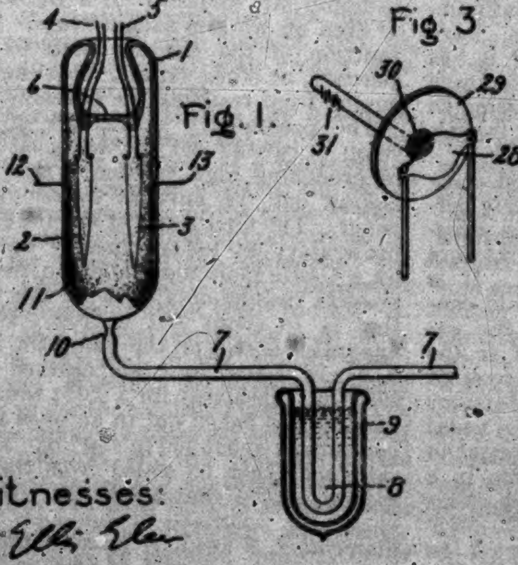

15
16
17
18
26
24
25
21
23
20
22
19
27

Fig. 3

Fig. 1.


4
5
1
6
12
13
2
3
11
10
7
7
9
8
30
29
31
28

Witnesses:
J. Ellis Glen
Anthony Marx

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

12

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS AND METHOD OF PREPARATION.

1,244,216. Specification of Letters Patent. Patented Oct. 23, 1917.

Application filed July 15, 1914, Serial No. 851,085. Renewed June 25, 1917. Serial No. 176,926.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus and Methods of Preparation, of which the following is a specification.

The present invention relates to electrical devices operating with a pure electron discharge and comprises a novel cathode material and the method of its preparation.

In a previous application, Serial No. 795,610, filed October 16, 1913, I have described and claimed a new type of electrical discharge apparatus comprising an envelop containing electrodes one of which emits electrons and being so highly evacuated that positive ionization is negligible. Some of the characteristics of this "pure electron discharge" are absence of conductivity in the space between independent unheated electrodes, a variation of the current over a certain range with the 3/2 power of the voltage, the absence of blue glow in the space, the absence of gas fluorescence and the lack of cathodic disintegration.

Various refractory materials, platinum, carbon, tungsten and molybdenum, have been used as cathode materials and it has been found that the emissivity of electrons of these various materials while differing to some degree is of the same order of magnitude.

I have discovered that the electron emissivity of pure thorium is of an entirely different order of magnitude than the emissivity of refractory materials heretofore used in electron discharge devices. It is not necessary that the electrode should consist entirely of thorium. When, for example, a thorium compound, such as the oxid, has been added during the process of production to one of the highly refractory metals, for example, tungsten, and the metal subjected to a preliminary heat treatment in a high vacuum, the electron emission in a high vacuum is enormously increased. This increased emissivity is not due to the presence of thorium oxid in the manner of the Wehnelt cathode for various reasons hereinafter explained, but according to all indications is a property of metallic thorium on the surface of the cathode.

Apparatus suitable for preparing and utilizing a thoriated cathode in an electron discharge apparatus is somewhat diagrammatically shown in the accompanying drawings, in which Figure 1 shows a simple type of apparatus in which the anode consists of a film of refractory metal on the inside wall of the envelop produced by vaporizing a refractory metal at high temperature; Fig. 2 is a device operable as a rectifier having a thoriated cathode and plate-shaped anodes; and Fig. 3 illustrates a modification in which active thorium material may be transferred to the cathode from an independent thoriated conductor.

The device shown in Fig. 1 comprising an envelop 1 consisting of glass, quartz or the like provided with two filamentary conductors 2, 3, of highly refractory metal, such for example as tungsten, at least one of which, say filament 2, is thoriated. They are connected to leading-in wires 4, 5, sealed into a stem 6 in the well-known manner. The envelop is connected to a vacuum system by a tube 7, containing a trap 8 which may be surrounded by a freezing bath, such as liquid air, contained in a Dewar flask 9 or even an ice and salt mixture. It is the function of the freezing bath to prevent mercury, or other vapors, from the vacuum pumps from reaching the envelop 1.

The preliminary evacuation of the envelop is carried out by the usual methods of producing high vacuum, which includes baking out the envelop to remove water vapor. The final stage of the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means,—that is, to about .001 micron. While the apparatus is still on the pump the filaments 2, 3, are heated to a temperature of about 2900° K. (absolute) for a short time and the envelop 1 is baked out in an oven at a temperature of about 360 to 450° K. The apparatus may then be sealed from the vacuum system at the contraction 10. It is then preferably immersed in liquid air and both filaments 2, 3 aged by heating for about ½ hour to a temperature of 2400 to 2500° K. One of the filaments, for example, filament

3, is then incandesced by a passage of current to a temperature of about 3000° K. which causes rapid vaporization of the metal, thereby producing a gas-free conducting deposit or coating 11 which has been shown on the inner surface of the envelop. Conductors 12, 13 sealed into the envelop make contact with this coating and enable it to be used as an anode for an electrical discharge. A device having a gas-free film anode and the method of its preparation has been described and claimed by me in a copending application, Serial No. 843,569, filed June 6, 1914. The method of producing high vacua by vaporizing tungsten is claimed by me in a co-pending application, Serial No. 838,768, filed May 15, 1914. Pressures much below .001 micron of mercury may be attained thereby. The cathode conductor 2 is prepared by introducing a thorium compound, such as the nitrate of thorium to the oxid of the refractory metal before reduction, or by adding either thorium nitrate or thoria to the metal powder after reduction but before consolidation of the metal by sintering and mechanical working to the solid metal state has taken place as described, for example, with reference to thoriated tungsten in U. S. Patent No. 1,082,933. The proportion of thoria in the unsintered metal usually varies from about ½ to 10% but in some cases may be even greater. The proportion of thorium compound in the cathode within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but with a greater proportion of thorium compound the desired active condition of the filament may be reached and maintained with greater ease than with a lesser amount.

The thoriated cathode 2 is now heated to about 2900° K. for about one minute. The treatment of the filament at a temperature of 2900° has no marked effect on the subsequent electron emission of the cathode when at lower temperature but appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2400° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2300° K. and the treatment at this temperature is usually continued for about one minute, but even outside of this range a marked change is produced. Apparently a concentration of metallic thorium or of some other oxidizable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at a temperature below this forming temperature.

With a filament thus prepared I have obtained at a temperature of about 1300° to 1380° K. substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000° K., that is, about three milliamperes per sq. cm. Preferably a thoriated cathode is operated around 1700° to 1800° K., at which temperatures its life is indefinitely long.

Subsequently heating the filament to a higher temperature, for example, to 2800° K., causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure metal. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2300° K., the active condition is restored.

A similar heat treatment of pure tungsten has no effect on its electron emissivity at incandescence. The active thorium material may be transferred by distillation to an adjacent surface. For example, if the filament 3 consisting of pure tungsten has not been completely destroyed during the preparation of the apparatus, the heating of the cathode to a temperature above 2300° after the preparation of the surface film results in the distillation of some of the thorium material to conductor 3 so that when the conductor 3 is used as a cathode with respect to the anode 11, it is found that its electron emission has been greatly increased.

One of the most striking proofs that the active surface film is not due to the effect of the thoria as in the Wehnelt cathode is furnished by the effect of a minute trace of oxygen on the behavior of the cathode. If in some manner a trace of oxygen is admitted, the electron emission immediately falls as low or even lower than the low value observed when a cathode of pure tungsten is slightly oxidized. In other words, the electron emission becomes very much lower than that of the unoxidized metal. When subsequent to oxidation a trace of hydrocarbon vapor is admitted, the electron emission suddenly rises as though reduction were taking place. If the carbon is in excess, the electron emissivity immediately drops to a low value as though a carbid were formed with the excess of carbon. In an application Serial No. 58,377 filed by me on October 28, 1915, I have more fully described and also claimed a thoriated cathode device containing reducing material.

Cathodes containing only a small amount of thorium compound are deleteriously affected by disintegration of the surface produced by positive ion bombardment and in this respect may be extremely sensitive. In this case it is necessary when using voltages high enough to cause ionization of residual gases to carry the vacuum far beyond the point at which a disruptive discharge no longer takes place, which ordinarily is about $\frac{1}{10}$ of a micron of mercury pressure. The Wehnelt or oxid cathode apparently depends on positive ionization for its activity. At any rate its emissivity is increased by an increase in positive ionization. When large amounts of thorium are present in my improved cathode, it is not so sensitive to positive ion bombardment and it is possible to obtain to a large extent the advantages of a thoriated cathode even in the presence of pressures of gas up to atmospheric pressure.

Another proof that the high electron emission is due to a skin of thorium is the fact that metallic thorium itself, particularly when free from surface oxidation, exhibits a very high electron emissivity for a given temperature as compared with tungsten. Difficulties are encountered with the use of metallic thorium as cathode material due to its relatively low melting point and its susceptibility to oxidation.

At 2000° to 2300° K., the active thorium is slowly diffusing to the surface from the interior of the metal. As the temperature is raised a point is reached where the distillation of thorium from the surface exceeds the rate at which the metal diffuses to the surfaces. It is possible, however, to operate a refractory thoriated cathode at a temperature between 2000° and 2300° K. for a long time without destroying its high electron emission, but operation at a higher temperature is not advisable. A sufficiently great electron emission can be secured through the indicated temperature range with an accompanying saving of energy necessary for heating the cathode.

The apparatus shown in Fig. 2 does not differ essentially from the apparatus shown in Fig. 1, plate-shaped anodes 15, 16 consisting of a highly refractory metal such as tungsten being used instead of the film anode of vaporized metal used in the apparatus shown in Fig. 1. The envelop 17 is baked out and evacuated as already described in connection with Fig. 1. The ionizable gas should be removed from the anodes during the final stages of the exhaust after the pressure has been reduced below about $\frac{1}{10}$ of a micron of mercury by subjecting the anodes to an electron discharge from the cathode 18 whereby ionizable gas is evolved, as disclosed in my co-pending application, Serial No. 795,610 of October 16, 1913. This gas should be removed as fast as liberated and the discharge voltage progressively increased, care being taken not to materially exceed the voltage at which blue glow takes place so as to avoid injury to the cathode. The final stage of the evacuation is produced by vaporizing a tungsten conductor in a side chamber (not shown in the drawing), thereby producing the very high vacuum necessary for the operation of the thoriated cathode. The anodes 15, 16 may be both connected to one terminal of a secondary of the transformer 19, by conductors 20, 21, the cathode being connected to the other terminal by conductor 22, including a load circuit 23. The cathode 18 has been merely indicated by dotted lines as being a V-shaped filament supported by terminal wires 24, 25, and maintained taut at its bight by a spring 26, but it is to be understood that it may have any convenient form. Thorium compound, for example, the oxid, is introduced during the process of manufacture as already described. The apparatus here shown is suitable for the rectification of alternating current when the cathode is maintained at incandescence by a battery 27, preferably at a temperature of 1700 to 1800° K.

It is not absolutely necessary that the thorium should be introduced into the body of the metal during the process of manufacture. As shown in Fig. 3 a cathode 28 located opposite an anode 29 is provided with a film of active thorium material vaporized from the coiled filamentary cathode 30 heated by a battery 31. The cathode 30 may consist either of a thoriated cathode prepared as already described, or of metallic thorium. The inclosing envelop has not been shown, but it is to be understood that these parts are to be operated in the high vacuum already indicated as being desirable. When the coil 30 consists of thoriated wire it is first rendered active by heat treatment at a temperature of 2200° to 2300° K., as already described, and is then heated to a temperature of about 2900° K. to distil off active material, some of which is condensed on the cathode 28. When the coil 30 consists of metallic thorium, it should be heated to a temperature near its melting point to distil some of the thorium over on to the surface of the cathode 28.

As positive ionization is very much decreased at low voltages, it is permissible to have present an inert gas at a pressure of say .01 micron when the voltage impressed between the cathode and anode does not arise above the ionizing potential of the gas. Advantage can be taken of this fact to use an electron discharge device containing a thoriated cathode as a voltage sensitive cut-out device. Below the voltage at which disintegration of the surface begins, a device such as shown in Fig. 1 may be used to pass a current of about $\frac{1}{10}$ of an ampere per sq. cm. when the cathode is at a temperature of about 1700° to 1800° K. When the voltage rises above the critical value, the current immediately drops to a very small value, thus practically interrupting the circuit. The cathode may be restored when the voltage has fallen by again heating it to about 2200° to 2350° K.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In an electrical discharge device, an electrode comprising in part at least oxidizable thorium material, said electrode having at a temperature of about 1300 to 1380° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

2. In an electrical discharge device, an electrode comprising in part at least oxidizable thorium and having when at incandescence in a vacuum so highly attenuated that positive ionization is substantially absent, an electron emission materially greater per unit of surface than tungsten at the same temperature.

3. A cathode for electron-discharge apparatus consisting largely of a highly refractory metal and a surface layer of material having an electron emissivity at a given temperature materially greater per unit surface than said refractory metal independently of and in the absence of positive ionization.

4. In a device operating by pure electron discharge independent of positive ionization, a conductor comprising a refractory metal and a surface film of thorium material vaporizable at a temperature above about 2300° K. and having a greater electron emission when at incandescence in a non-striking vacuum than said refractory metal.

5. In an electrical discharge device, an electrode comprising metallic tungsten and a surface film of thorium material vaporizable at a temperature above about 2300° K. removable from said surface by positive ionization and having an electron emission per unit surface many times greater than pure tungsten at the same temperature.

6. In an electrical discharge device, an electrode comprising metallic tungsten and thoria said electrode having been subjected to a temperature of about 2200 to 2350° K. and having an electron emission a thousand times as great per unit of surface as tungsten in a vacuum too high to permit of positive ionization.

7. In an electrical discharge device, a cathode comprising metallic tungsten and thoria, said electrode having received a heat treatment at about 2000 to 2350° K. and having an electron emission when at incandescence at a given temperature of a higher order of magnitude than pure tungsten at the same temperature.

8. The process of preparing an electrode comprising a refractory metal and thoria for use in a pure electron discharge apparatus which consists in heating said electrode to a temperature adjacent the melting point of said refractory metal and then heating to a temperature of about 2200 to 2300° absolute.

9. The process which consists in heating a conductor comprising tungsten and thoria to a temperature of about 2800 to 2900° absolute and then lowering the temperature to about 2200 to 2300° absolute holding said temperature for a short interval and finally operating said conductor as cathode in a non-striking vacuum at a temperature below 2000° absolute.

10. A cathode for electron discharge apparatus consisting largely of tungsten and containing thorium, said cathode having an electron emissivity, independently of and in the absence of positive ionization, at a given temperature materially greater per unit surface than tungsten at the same temperature.

11. In an incandescent cathode device, an electrode comprising a highly refractory metal and containing oxidizable thorium material, said electrode having an electron emissivity per unit surface many times greater than said refractory metal alone at the same temperature, the electron emissivity of said cathode being lowered by the presence of oxygen and by positive ionization.

In witness whereof, I have hereunto set my hand this 14th day of July, 1914.

IRVING LANGMUIR

Witnesses:
WILLIAM C. WHITE,
HELEN ORFORD.

PLAINTIFF'S EXHIBIT No. 3.

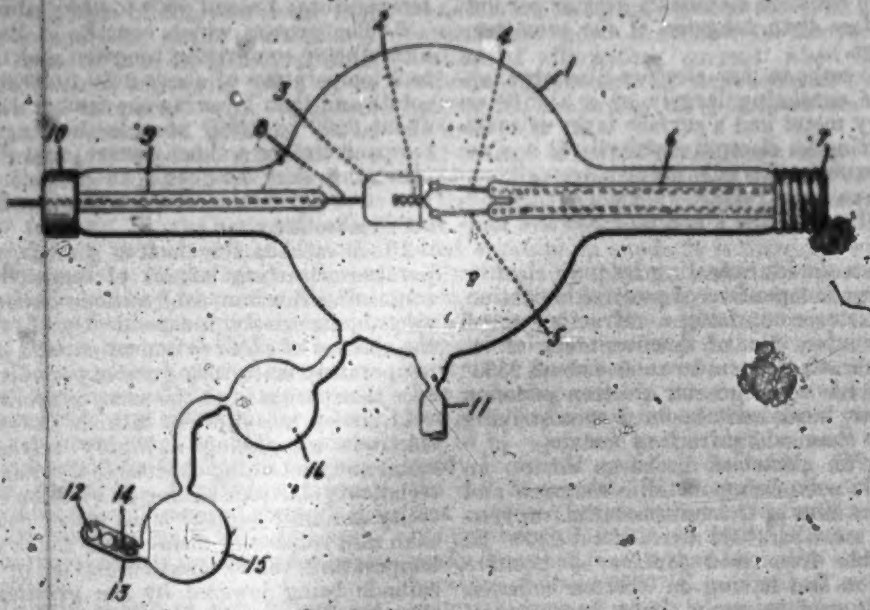
I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME.

APPLICATION FILED OCT. 28, 1913.

1,244,217.

Patented Oct. 23, 1917


2
4
1
C
3
8
10
9
6
7
5
11
16
12
14
13
15

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME.

1,244,217. Specification of Letters Patent. Patented Oct. 23, 1917.

Application filed October 23, 1915. Serial No. 58,377.

To all whom it may concern:

Be it known that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus and Methods of Operating the Same, of which the following is a specification.

The present invention relates to electrical devices having an electrode consisting at least in part of thorium and having at a given temperature an electron emission per unit surface materially greater than the emission of a refractory metal such as tungsten at the same temperature independently of and in the absence of positive ionization. These devices are described and claimed in a copending application, Serial No. 851,095, of July 13, 1914, renewed on June 25, 1917, as application Serial No. 176,926, to which the present application is closely related.

In the preparation of these devices great care must be exercised to remove the last traces of oxygenous gases, particularly water vapor, and precautions must be observed not to evolve water vapor from the bulb walls during the operation of the device.

In accordance with my present invention, I have improved the above described device and also rendered easier the preparation of the same by providing in the envelop a quantity of a vaporizable reagent of low vapor pressure capable of preventing the oxidation of thorium. I prefer to use for this purpose an alkali metal, such for example, as potassium.

The accompanying drawing illustrates one particular form of apparatus to which my invention is applicable, namely, an incandescent cathode discharge device provided with means for introducing the desired reagent.

The device shown in the drawing which may be used for rectifying alternating current, comprises an envelop 1 consisting of a glass not chemically attacked by alkali metal provided with a cathode 2 consisting for example of thoriated tungsten, and a cylindrical or cup-shaped anode 3, also consisting of a highly refractory metal, such for example, as tungsten. A heating current may be conveyed to the cathode by leading-in conductors 4, 5, sealed into a stem 6 in the usual manner and connected to a threaded socket 7 similar to an incandescent lamp socket. The anode stem 8 is also sealed into a glass stem 9 and attached to an external metal cap 10.

The cathode 2 is prepared by adding a thoria compound, such as nitrate of thorium to the oxid of tungsten before reduction of the metal, or by adding either thorium nitrate or thoria to the metal powder after reduction, but before consolidation of the metal powder by sintering and mechanical working to the solid state as described, for example by reference to thoriated tungsten in U. S. Patent #1,082,933. The proportion of thoria in the unsintered metal usually varies from ½ to 10% but in some cases may be even greater. The proportion of thorium compound within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but the favorable conditions will be more easily attained with a greater than with a lesser amount.

The preliminary evacuation of the envelop is carried out by the usual methods of producing a non-striking high vacuum, which includes baking out the envelop to remove water vapor. The final stage of the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means, that is, to about .001 micron. While the apparatus is still on the pump the cathode 2 is heated to a temperature of about 2900° K. (2727° C.) for a short time and the envelop 1 is baked out in an oven at a temperature of about 360 to 450° C.

The substance to be distilled into the envelop, for example, potassium, is indicated at 12 in a small side chamber 13, a small quantity of glass particles, or glass wool, 14 being preferably placed in front of the reducing material. As already indicated all glasses (including the glass wool) used in the apparatus should be unattacked by alkali metal. When the envelop is baked out care should be exercised not to heat the chamber 13 to too high a temperature. The potassium, or other material, is transferred by melting into a communicating chamber 15, after which the chamber 13 may be sealed off. Thereupon, the material is distilled into a second communicating chamber 16 and finally a very small amount is introduced into the main envelop 1, both the chambers 15, 16 being successively sealed off. The redistillation of the reducing material serves to purify it. Although alkali metals have been indicated as preferable for the purposes of my invention, other reducing materials may be used, for example, hydrocarbon compounds. The bulb is finally sealed from the vacuum system at the contraction 11.

The thoriated cathode 2 is now heated to about 2900° K. for about one minute. The treatment of the filament at this temperature appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2400° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2300° K. and the treatment at this temperature is usually continued for about one minute. Apparently a concentration of metallic thorium or of some other oxidizable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at or below this forming temperature.

The presence of the reducing agent in the main receptacle maintains the thorium reduced in spite of traces of water vapor which may be liberated from the glass. In any event the high electron emissivity of the thoriated cathode is more easily secured and maintained in the presence of the reducing agent than without it.

With a filament thus prepared I have obtained at a temperature of about 1800° to 1880° K. substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000° K., that is, about three milliamperes per sq. cm. A thoriated cathode may be operated around 1700° to 1800° K., at which temperatures its life is long, and thermionic current may be obtained many thousands of times greater than obtainable with pure tungsten at the same temperature.

Subsequently heating the filament to a higher temperature, for example, to 2800° K. causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure tungsten. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2300° K. the active condition is restored.

The vapor pressure of potassium, sodium or other alkaline metal at room temperature is so low that objectionable positive ionization of its own vapor during the operation of the pure electron device is negligible and the vapor pressure of the oxidation products of the alkaline metal have no perceptible vapor pressure. For this reason, the alkali metals are to be preferred to carbonaceous compounds as reducing agents in the present device.

The vapor of alkaline metals does not produce an increased emission of a pure tungsten filament thereby furnishing proof that the beneficial effect of the alkaline metal is exerted upon thoria content of the filament and is not due to some ionization phenomena.

Under carefully controlled conditions the benefit of the increased electron emission of a thorium-containing cathode may be secured in a device filled with an inert gas, such, for example, as argon or other monatomic gases, at pressures ranging from a few millimeters of mercury pressure upward, in the presence of potassium or equivalent material for preventing the oxidation of thorium. Care must be exercised to have the cathode at a high enough temperature with reference to the current transmitted so that the vicinity of the cathode is surrounded by free electrons. In other words, the electron emission should be greater than necessary to convey the current thereby preventing a removal of the active thorium material on the surface of the cathode by a bombardment of positive ions.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electrical discharge device comprising electrodes, one of which contains thorium, an inclosing envelop the space within which is evacuated to a pressure so low that positive ionization is substantially absent, and a quantity of a vaporizable reagent capable of preventing the oxidation of thorium in communication with the space within said envelop.

2. In an electrical discharge device, an inclosing envelop, a quantity of alkali metal within said envelop, and electrodes therein, one of which comprises in part at least, oxidizable thorium material, said electrodes having at a temperature of about 1800 to 1880° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

3. In an electrical discharge device, an inclosing envelop, a quantity of potassium within said envelop, and electrodes therein, one of which consists largely of tungsten and containing thorium, said electrode having an electron emissivity at a given temperature materially greater per unit surface than tungsten at the same temperature.

4. An electrical discharge device comprising electrodes, one of which consists of metallic tungsten and a thorium material in an oxidizable state, an inclosing envelop, and a quantity of a vaporizable reagent within said envelop capable of preventing

the oxidation of thorium at an elevated temperature.

5. The process of improving the operation of an electron discharge apparatus containing an electrode operating at incandescence comprising a highly refractory metal and a thorium material which consists in bringing into contact with said electrode the vapor of a reagent preventing the oxidation of thorium at an elevated temperature.

6. The process of improving the operation of an electron discharge apparatus containing an electrode of tungsten and thorium operating at incandescence in a nonstriking vacuum, which consists in bringing into contact with said electrode the vapor of an alkali metal at a pressure too low to cause appreciable positive ionization phenomena.

7. An electrical device comprising the combination of a sealed evacuated envelop, a refractory cathode, means for heating said cathode to incandescence, a coöperating anode and a quantity of potassium within said envelop.

8. An electrical device comprising the combination of an evacuated envelop, a cathode, an anode and a quantity of alkali metal inclosed within said envelop, and means for heating said cathode to incandescence.

In witness whereof, I have hereunto set my hand this 27th day of October, 1915.

IRVING LANGMUIR.

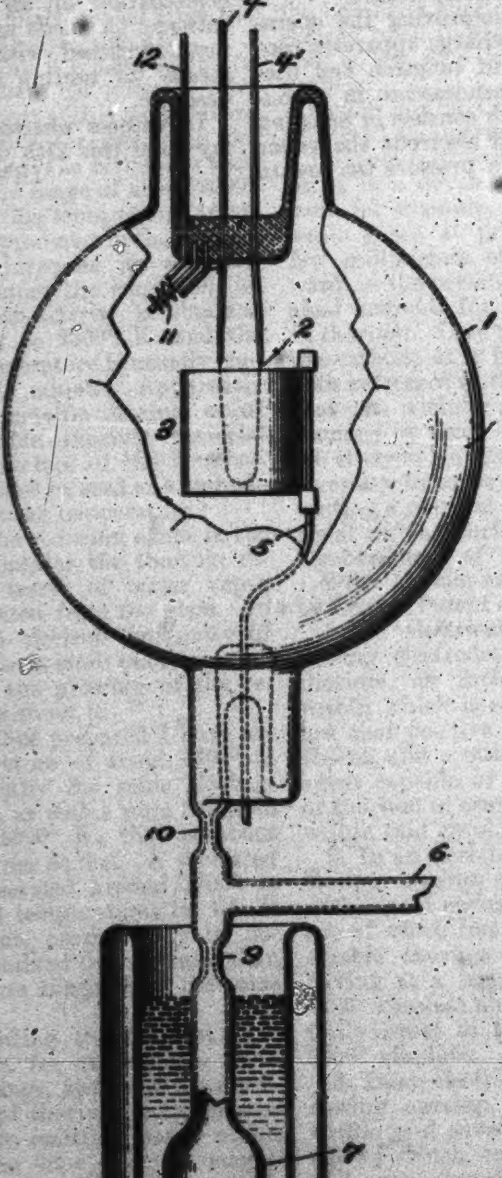
PLAINTIFF'S EXHIBIT No. 4.

March 10, 1925. 1,529,597

I. LANGMUIR

ELECTRON EMITTING DEVICE AND METHOD OF PREPARATION

Filed Aug. 11, 1921



Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

Patented Mar. 10, 1925. **1,529,597**

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-EMITTING DEVICE AND METHOD OF PREPARATION.

Application filed August 11, 1921. Serial No. 491,634.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Emitting Devices and Methods of Preparation, of which the following is a specification.

This invention comprises an improvement in the electron emitting cathodes of the type described in my prior U. S. Patents Nos. 1,244,216 and 1,244,217.

In these patents I have described the preparation and advantages of a vacuum tube containing a cathode adapted to be operated at incandescence and containing distributed throughout its mass thorium (or a compound of thorium) as a constituent. This type of electrode consists of a refractory conducting material, such for example as tungsten, with an addition of a material capable of increasing the electron emissivity of the cathode, such for example as thoria, the latter being subjected to modifications during the preparation of the cathode in the electron discharge device so that the active material in a finished device according to all indications, consists of metallic thorium or at least of a lower oxide of thorium than thoria (ThO_2). The cathode prepared according to the methods set forth in my first Patent 1,244,216 which is commonly known as a "thoriated cathode", is very sensitive to traces of oxidizing gas in the bulb, as for example, small traces of water vapor which may be given off from the walls of the bulb during the normal operation of the device. In order to prevent loss of activity of the cathode, I have described in my second Patent No. 1,244,217, the beneficial results obtained by the admission to the bulb of a small amount of alkali metal, such as potassium or sodium, or of a hydrocarbon compound.

My present invention in one of its aspects is based on the discovery that carbon in a cathode of the thoriated type, when present in a definitely limited amount, will prevent not only reoxidation of active thorium material but what is more important, will act beneficially to reduce thoria to the active state. Although the thoriated cathodes described in my prior patents can be used with satisfactory results, I have found that a further improvement in regularity and stability can be effected by using carbon as hereinafter described, not only as in accordance with my prior patent in restricted quantities, as an oxidation preventing agent, but, as hereinafter described, as an ingredient of a thoriated cathode.

In accordance with another feature of my invention my improved cathode is used in conjunction with a non-carbonaceous reducing agent which is provided in the bulb, as for example, a highly oxidizable metal.

A thoriated cathode may be deleteriously affected by positive ion bombardment, that is, when voltages materially higher than the ionization voltages are impressed between a thoriated cathode and a positive electrode in the presence of ionizable gas, then the beneficial effect of the thorium may be largely or entirely destroyed by positive ion bombardment. Although the alkali metals are entirely satisfactory as agents to remove deleterious gases when the operating temperature of the bulb is only moderately above room temperature, as in the case of radio receiving tubes, these alkali metals have a sufficiently high vapor pressure at the operating temperature of power devices in which cathodes of the thoriated type are used to become ionized at higher voltages and to cause removal of the active film of thorium from the cathode by bombardment. I have found that it is advantageous in many cases to provide a device containing a cathode of the thoriated type with a material having an affinity for gases, such as magnesium, for example, which at the operating temperature of the device, has substantially no vapor pressure. My invention will be pointed out with greater particularity in the accompanying claims and described fully in conjunction with the accompanying drawing which shows somewhat diagrammatically. An apparatus used for carrying out the preparation of an incandescent cathode rectifier.

The rectifier shown in the figure is illustrative of one of the various forms of incandescent cathode devices. It consists of a bulb 1 containing a filamentary cathode 2 into which thoria has been introduced as described in my above mentioned prior patents, and an anode 3, consisting of tungsten, molybdenum or other suitable material. These electrodes are respectively connected to lead wires 4, 4′ and 5 sealed into the walls of the bulb. The bulb is connected to the usual pumping system by means of a tubulature 6. The bulb also communicates with an elongated tube 7 adapted to be surrounded by a freezing mixture contained within a double-walled receptacle 8.

In carrying out my invention, the bulb 1 is first baked out as usual to remove water vapor and is then exhausted. Within the tube 7 is placed a substance adapted to give a low pressure of carbonaceous vapor, as for example, anthracene ($C_{14}H_{10}$) or naphthalene ($C_{10}H_8$).

When the vapor pressure of the substance employed is relatively high, I prefer to reduce the pressure of the hydrocarbon vapor in the bulb 1 by surrounding the tube with a freezing agent contained in the receptacle 8. When employing naphthalene, which has a moderately high vapor pressure, I prefer to reduce the temperature of the containing tube 7 to about —20 to —30° C. to reduce the vapor pressure to about 0.1 to 0.01 microns. The bulb 1 which communicates with the side tube 7, therefore, is filled with hydrocarbon vapor at approximately this pressure. The quantity of hydrocarbon may be controlled by one or more constrictions, such as 9, 10 which may regulate the pressure with or without a freezing agent.

The filament 2, which preferably consists of metallic tungsten, containing about ¾% thoria, is heated to a temperature of about 2300° K. (2000° C.) for a few minutes, in contact with the hydrocarbon vapor. At this temperature the incandescent filament decomposes the hydrocarbon vapor which comes in contact with the incandescent surface of the tungsten and causes the chemical combination with the tungsten of the carbon set free from the naphthalene vapor, with the formation of tungsten carbide (W_2C). The heating is continued for a length of time sufficient to give an increase in resistance of about 15 to 25% of the tungsten filament when cold, or at room temperature. This change in resistance corresponds to the presence of about two-thirds per cent of carbon by weight in the filament.

The carbon content most beneficial will vary with the conditions. In the case of a thoriated tungsten cathode all of the metallic tungsten will be converted to brittle tungsten carbide (W_2C) with a carbon content as high as 3%. Ordinarily a carbon content as high as about 1% is as high as permissible without unduly weakening the cathode. Although the presence of even minute amounts of carbon is highly undesirable in an incandescent lamp, a commercially long life can be obtained in a thoriated cathode containing carbon, as the cathode need be operated only at a relatively low temperature, say at about the operating temperature of an ordinary carbon lamp, the electron emissivity of a thoriated cathode being so much greater than that of an ordinary pure tungsten cathode. The hydrocarbon vapor is removed from contact with the filament either by sealing off the tube 7 at the contraction 9 or cooling the side tube 7 by means of liquid air in the receptacle 8 to a temperature so low that the vapor pressure of the naphthalene is negligible, thereby removing the naphthalene vapor from the bulb 1.

In some cases carbon in a desired proportion may be combined with the cathode prior to the introduction of the cathode into the bulb 1. For example, a thoriated filament may be prepared by squirting tungsten and thoria with a carbonaceous binder in amounts adapted to leave a suitable restricted proportion of carbon in the finished product.

As the next step in the preparation of the device, the anode 3 is deprived of gases by the usual method of electron bombardment; that is, by passing a discharge between the cathode at incandescence and the anode, the exhaust pump in the meantime being operated to remove the vapors and gases which are liberated. During this step some of the carbon is removed by oxidation and evaporation from the cathode but with an original carbon content of about ⅔ of one per cent, enough carbon remains subsequently to furnish a supply of active thorium material by reduction of the thoria.

After the cathode has been provided with a content of reducing agent a non-carbonaceous material capable of combining with water vapor and other deleterious gases may be introduced into the bulb. In some cases this non-carbonaceous reducing agent may consist of alkali metal, such as sodium or potassium. Cæsium may be used to advantage in some cases, especially when some positive ionization is desired in the electron discharge device. Cæsium can be conveniently provided by adding a mixture of cæsium halide and metallic calcium as a paste to some part of the bulb, this method of introducing an alkali metal being claimed in an application, Serial No. 608,311, December 21, 1922, by Ernest E. Charlton.

When not desiring ionization of residual gases or vapors, I prefer to introduce for the reasons given above a reagent having a lower vapor pressure than the alkali metals, as for example, an alkaline earth metal such as magnesium, calcium, strontium, or the like. Conveniently this is done by providing within the bulb a small heating coil 11, consisting of tungsten or other suitable refractory material, and containing a small quantity of the metal to be vaporized. Preferably I employ metallic magnesium. By heating the tungsten filament 11 with current conducted thru the lead wires 4, 12, some of the magnesium is volatilized and deposited on the inner surface of the bulb which is then sealed off at the contraction 10. As during the sealing off process there is a tendency to drive out a small quantity of gas from the heated glass, I prefer to heat up the filament 11 the second time, to volatilize a small additional quantity of magnesium, or the like, in order to combine chemically with what little gas may have gotten into the bulb during the sealing off operation.

The film of magnesium, or other equivalent metal, on the walls of the bulb will combine with any water vapor or oxygen which may be given off by the bulb, or any other parts of the device during its operation, and thereby prevent an oxidization of the active thorium material upon the surface of the cathode.

The tungsten cathode 2 is preferably heated for a very short time to about 2700° K. to volatilize any thorium oxide on its surface.

As a final step, the cathode is "activated", that is, brought into its highly active state by heating to a temperature of about 2200° K. for a few minutes. This results in the reduction of thoria by the carbon and causes the active thorium product to come to the surface of the cathode where it will be effective in increasing the electron emission during the operation of the device. The tube is then ready for operation.

As explained in my prior patents, a temperature materially higher than the activating temperature will result in the thorium being volatilized from the surface of the cathode. A fresh supply can be produced and caused to accumulate upon the surface by again activating or "forming" an electrode at about 2200° K. During normal operation, the cathode is heated to a temperature below about 2200° K. and as high as 2100° K. Under these conditions, the electron emission stays constant.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In an electron discharge device, a cathode body of the thoriated type containing carbon in an amount insufficient to convert all of the metallic constituents of said cathode to a carbide but sufficient to render said cathode less sensitive to the deleterious effect of gases than a cathode body unprovided with carbon.

2. In an electron discharge device, a tungsten cathode of the thoriated type adapted to emit electrons when heated, containing carbon in an appreciable amount but less than three per cent by weight.

3. A cathode adapted to emit electrons at incandescence comprising tungsten, about three-quarters per cent thorium and about two-thirds per cent by weight of carbon.

4. The method of increasing the electron emissivity of an electrode of the thoriated type which consists in introducing carbon into said electrode in amounts insufficient to convert said metal to a carbide, sealing said electrode into a space substantially free from carbonaceous vapors and thereupon activating said electrode.

5. An electric discharge device comprising an evacuated envelope, electrodes therein one of which comprises a refractory metal, thorium oxide and carbon in an amount insufficient to convert said metal to a carbide, and a non-carbonaceous reagent capable of combining with deleterious gases in said envelope.

6. An electric discharge device comprising an envelope, an anode and a cathode of the thoriated type and a non-volatile material, which is capable of reducing thorium oxide, contained in said cathode in such small amounts that the durability of said cathode is not appreciably decreased.

7. An electric discharge device having a cathode comprising metallic tungsten, thorium oxide and carbon combined with said tungsten in an amount materially less than required to convert all the tungsten to a carbide.

8. The method of increasing the electron emissivity of a cathode of the thoriated type which consists in introducing carbon into said cathode in an amount less than about one per cent by weight, heating said cathode in a non-carbonizing and non-oxidizing environment to a temperature at which a carbide of said metal is formed, activating said electrode by heating to about 2200° K. and operating the same under such conditions that bombardment of the electrode by positive ions is inappreciable.

9. The method of increasing the electron-emissivity of a cathode of the thoriated type which consists in introducing carbon into said electrode in an amount less than one per cent by weight, mounting said electrode in a bulb, evacuating the same, volatilizing magnesium in said bulb after evacuation, and activating said cathode by heating to an elevated temperature.

10. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating a conductor comprising refractory metal and thoria in a carbonaceous vapor to a temperature adapted to cause combination of carbon with said conductor, removing said vapor before the amount of carbon introduced into the filament exceeds one per cent, and heating said conductor in a non-oxidizing environment to a temperature at which electron emissivity is markedly increased.

11. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating to incandescence a conductor comprising tungsten and thoria in a carbonaceous vapor until a marked increase in cold resistance occurs by the introduction of carbon, discontinuing the heating before the tungsten has been largely converted to a carbide, and heating said conductor in the absence of said vapor in a reducing environment to produce a surface layer of thorium material having a markedly higher electron emissivity than the original conductor.

12. An electrical discharge device comprising a sealed envelope, electrodes therein which include a cathode of the thoriated type and a substance, having a marked chemical affinity for water vapor, deposited as a film of extensive surface upon the inside of said envelope, said substance having a materially lower vapor pressure than the alkali metals.

13. An electrical discharge device comprising a sealed envelope, electrodes therein one of which is of the thoriated type and a film of magnesium deposited on the inner surface of said envelope.

14. An electron discharge device containing a cathode of the thoriated type, said cathode being provided with a reducing agent sufficient in quantity to promote activation of said cathode, but restricted to an amount which will permit operation of said cathode at a temperature of effective electron emission with a commercially long life.

15. A cathode of the thoriated type for electric discharge devices containing less than about three per cent by weight of carbon.

16. An electric discharge device comprising an envelope, electrodes therein one of which comprises a refractory metal, a material reducible by carbon to a state of higher electron emissivity than said refractory metal at a given temperature, and a quantity of carbon in an amount insufficient to convert said metal completely to a carbide.

17. An electrical discharge device comprising a container, electrodes therein one of which contains less than three per cent of carbon combined therewith and a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of alkaline earth metal deposited in said container out of immediate contact with said electrodes.

18. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of alkaline earth metal deposited as a film on the inner surface of said container.

19. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of magnesium deposited as a film on the inner surface of said container out of immediate contact with said electrodes.

20. An electrical discharge device comprising a container, electrodes therein one of which consists largely of refractory metal and contains an oxide of a metal of high electron emissivity which when rendered active is sensitive to ion bombardment together with a reducing agent, and a quantity of alkaline earth metal, the latter being deposited as a film on the inner wall of said container.

21. An electrical discharge device comprising a glass bulb, electrodes therein one of which consists largely of refractory metal and contains a material capable when activated of substantially increasing the electron emission of the electrode with which it is associated but which is deteriorated by oxidation and positive bombardment, and a film of magnesium coating the inner surface of said bulb.

22. An electrical discharge device comprising a container, electrodes therein, one of which contains as a constituent a material capable of higher electron emission than the main constituent of said electrode but which is sensitive to positive ion bombardment, and to the chemical effect of water vapor under operating conditions, and a film of metal deposited from the vapor state in a vacuum on the wall of said container which metal has a high chemical affinity for water vapor and has a materially lower vapor pressure at the operating temperature of said device than the alkali metals.

23. The method of increasing the electron emissivity of a metallic electrode containing a compound capable upon reduction of materially increasing the electron emissivity of said electrode which consists in introducing carbon into said electrode in an amount insufficient to convert the metal constituting said electrode completely to a carbide and heating said electrode in a non-oxidizing and non-carbonizing environment to a temperature sufficiently high to activate said electrode, and thereupon operating said electrode under conditions which render the effect of positive ion bombardment of said electrode inappreciable.

24. An electrode material for an electrical discharge device consisting of a metal capable of stable operation at an elevated tem-

perature, a compound of a material capable in a reduced state of higher electron emission than said metal, and carbon in a quantity insufficient to deleteriously affect the strength of said material, but being capable of reducing a sufficient amount of said compound to enable said electrode to be more readily activated during use than would be the case in the absence of said carbon.

25. A cathode material for electrical discharge devices consisting largely of a metal capable of operation at an elevated temperature, a reducible compound of a material of high electron emissivity and less than about one per cent of carbon.

In witness whereof, I have hereunto set my hand this 8th day of August, 1921.

IRVING LANGMUIR.

PLAINTIFF'S EXHIBIT No. 5.

DeForest Type H Rectifier Tube.

PLAINTIFF'S EXHIBIT No. 6.

DeForest Type H Audion Tube.

PLAINTIFF'S EXHIBIT No. 7.

DeForest DV 5 Vacuum Tube.

PLAINTIFF'S EXHIBIT No. 8.

DeForest DV 5 Vacuum Tube.

PLAINTIFF'S EXHIBIT No. 8-A.

Data Sheet Accompanying DeForest DV 5 Vacuum Tube.

INSTRUCTIONS FOR USING

De Forest Audion Type DV-5

Filament battery voltage: 6 Volts.
Filament current: .25 Amperes.
Plate Battery Voltage for:
1. Audio Frequency Amplifier,
    (a) Transformer coupled: 90—112½ Volts.
    (b) Resistance coupled: 112½—180 Volts.
2. Radio Frequency Amplifier: 67½—135 Volts.
3. Detector in a regenerative circuit only: 12—22½ Volts.

Resistance of rheostat for operating one DV-5 tube only: 15 ohms.

Resistance of rheostat for operating two or more DV-5 tubes in parallel: 6 ohms.

When "B" battery voltages greater than 90 volts are used on audio frequency amplifiers, the following "C" battery values should be applied:

"C" Battery Voltage	"B" Battery Voltage
1½ Volts	112½ Volts
3 "	135 "
6 "	157½ "
7½ "	180 "

When using the DV-5 as a Regenerative Detector use a Grid Condenser of .00025 mfd capacity and a Grid Leak of from 5 to 10 megohms.

The DV-5 may be used in all positions, but with particular advantage:—

As a Radio Frequency Amplifier in non-oscillating R.F. circuits.

As a Detector in Regenerative Circuits using low "B" battery voltage.

As an Audio Frequency Amplifier in Resistance coupled A.F. circuits.

As an Audio Frequency Amplifier in Transformer coupled A.F. circuits where the transformers are especially designed to handle considerable amounts of power.

As an Amplifier in Reflexed positions of Reflex circuits.

CAUTION

Keep the light in this Audion as dim as possible for clear reception. Most sets contain a "volume control" by which the desired volume can be obtained at low filament voltages.

Keep this "volume control" set near "Maximum." Then regulate the filament control for best reception. This will insure maximum life from De Forest Audions.

Recharge the "A" battery when it becomes necessary to advance the rheostat.

The lowest filament voltage which can be used to give good reception is the proper voltage for operating De Forest DV-5 Audions.

The DV-5 is designed to utilize a high "B" battery voltage. Maintenance of this voltage is absolutely necessary for proper working of any set containing DV-5 Audions.

A set of "B" batteries should never be used after the voltage has fallen below 15% of their original or rated value. As soon as it becomes necessary to light the filament in DV-5 Audions brighter than usual to secure the desired volume, test the "B" batteries. CONTINUED USE OF RUN DOWN "B" BATTERIES WILL RUIN THE AUDIONS.

Never connect new "B" batteries to old or run down "B" batteries. Change the entire set when the "B" voltage gets low.

Never attempt to operate two types of De Forest Audions with the filaments in parallel and controlled from one rheostat. To do so will greatly shorten the life of all of the Audions so used.

IMPORTANT

Handle De Forest Audions carefully. The Audion is a precision instrument requiring great skill and accuracy in its manufacture. It must be handled with as much care as any delicate instrument. Never lay them down on a hard surface but first put down a pad of cloth or other soft material on which to lay them.

Never change connections in or to the set without first removing the Audions.

When taking De Forest Audions out of sockets, or putting them in, ease them into or out of the sockets.

Never change the tubes without first turning the rheostats to "off" position.

Observance of all these precautions will insure long life and continued satisfaction from De Forest DV-5 Audions.

The DV-5 should be mounted in a vertical position. The use of a cushioned support for sockets is strongly recommended.

As a regenerative detector, the grid return should be connected to the positive filament terminal as in diagram 1.

As an Audio Frequency Amplifier the grid return should be connected to the negative "A" battery terminal with the rheostat placed as shown in diagram 2. When "B" battery voltages higher than 90 volts are used, the use of a "C" battery is necessary. The connections are shown in diagram 2.

As a Radio Frequency Amplifier, the grid return should be connected as described in the particular circuit being used.

WARNING: DO NOT INCREASE FILAMENT VOLTAGE ABOVE 5 VOLTS.

This tube is manufactured under U. S. Patents: 6-26-06, 11-13-06, 1-15-07, 10-8-07, 2-18-08, 4-7-08, 9-22-08, 12-20-10, 2-18-16, 10-17-16, 4-3-17, 7-29-19, 8-29-19, 8-3-20, 9-7-20, 5-1-23, and other patents pending.

DIAGRAM No 1
DETECTOR

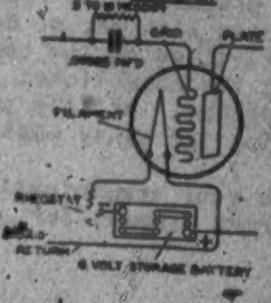
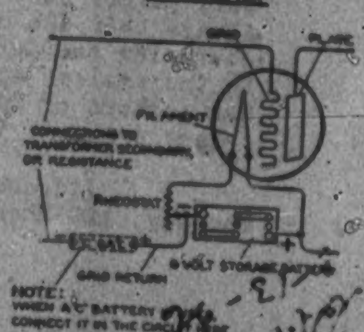


DIAGRAM No 2
A.F. AMPLIFIER


GRID
PLATE
FILAMENT
CONNECTIONS TO TRANSFORMER SECONDARY OR RESISTANCE
RHEOSTAT
C BATT
GRID RETURN
6 VOLT STORAGE BATTERY
NOTE: WHEN A C BATTERY IS USED CONNECT IT IN THE CIRCUIT HERE

DE FOREST RADIO COMPANY
Jersey City, N. J.

Form 172

PLAINTIFF'S EXHIBIT No. 9.

Defendant's Circular.

DE FOREST RADIO COMPANY

TELEPHONE
WEBSTER 5720

CENTRAL AVENUE AT FRANKLIN STREET

JERSEY CITY, N.J.

BROADCAST TO ALL AMATEUR STATIONS
ANNOUNCING THE NEW DE FOREST "H" TYPE TRANSMITTING TUBE

It will be of interest to you to know that we have developed a new power tube which is designed to meet the requirements of the Amateur and Experimental stations in their work on short wave transmission.

The distinct features of this tube are that exceptional output wattage can be obtained without breakdown. Purposely no fixed output rating is being given this tube as its efficiency and function is dependent to a large extent upon power applied, circuit arrangement and wave length.

The tube will be known as the De Forest "H" type power tube. (see enclosed circular for approximate ratings.)

Grid, plate and filament leads are brought out at widely separated places of the tube, ~~well~~ insulated and giving every reasonable assurance against high frequency flashover.

The elements are rigid - Molybdenum is employed in both grid and plate - Each tube is carefully subjected to gas, oscillation, emission, insulation resistance and voltage tests.

The tube performs remarkably well on all wave lengths especially on those of from one meter to two hundred meters.

Those of the experimental and amateur stations which have been supplied with this new oscillator report exceptionally long distance results.

We have established a very low price on this tube, namely $18.00 net, parcel post prepaid. The reason for this price is that as has always been the case with us, we desire to continue as leaders in encouraging the activities of the amateur. The tube will be sold direct to the amateur at the established price. It cannot be bought through our jobbers or dealers. At this price it is necessary to ask that when orders are sent in, the money must accompany the order.

Address your communication to Department "T", De Forest Radio Company, 120 Sherman Avenue, Jer. y City, N. J.

Yours very truly,
DE FOREST RADIO COMPANY
W. C. von Brandt
Manager, Tube Sales

WCvonB:ECB

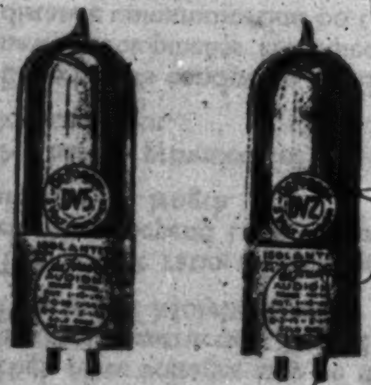
PLAINTIFF'S EXHIBIT No. 10.

Defendant's Leaflet.

DE FOREST Receiving Tubes

with Low Loss Base

Sold by all Dealers



DeForest Audion	Filament Circuit			Plate Voltage		
	"A" Battery Voltage	Filament Terminal Voltage	Filament Current Amps.	R. F. Amplifier	Detector	A. F. Amplifier
DV3	6	5	.25 Max. .24 Min.	67½ to 135	18 to 22½	90 to 100
DV2	6	5	.25 Max. .24 Min.	67½ to 90	18 to 45	67½ to 90

Price $3.00

Long Distance Communication

Established by means of the new

DE FOREST

"H" type Transmitting Tube

Pres

Q.S.T!

Short Wave Transmission a Success with

The New DeForest "H" Transmitting Tube

Your Success on the Lower Waves

depends upon your selection of the proper transmitting tube.

Such a transmitting tube is now produced by the DeForest Radio Company, and will be sold under the designation of the

DeForest "H" Tube

Efficient performance is obtained by the "H" tube on wave lengths of from 1 Meter to 200 *Meters*; in fact, on all wave lengths for which a circuit can be provided.

High frequency flash-over does not break down the tube as all leads are brought out at widely separated places.

High plate voltages may be used without fear of damage to any of the elements. Internal construction is rigid and the best of material is used. Both Grid and Plate are of Molybdenum.

The output ratings given below are approximate, because function and output efficiency depend largely upon the power applied, upon circuit arrangement and upon wave length.

No base is provided for this tube, in order to give it characteristics of a truly low loss oscillator.

Experiments conducted by the DeForest Laboratories indicate definitely that the new developments embodied in this "H" tube will now permit extremely long distance communication on the high frequencies.

TECHNICAL DATA

Plate Voltage	Grid Bias Volts	Filament Volts	Filament Amps.	Plate Current Milli-amps.	Output R. F. Watts	Safe Plate Dis. Watts	Grid Leaks Hartley Circuit Ohms	Size Over-All
1000 to 3000	50 to 500**	10	2.35	40 to 110*	20 to 150**	170	5,000 to 100,000	6x3½"

*Values are with Tube Oscillating **Depends on circuit, grid leak and plate voltage

In order that Amateurs and Experimenters may avail themselves of this high power transmitting tube at a reasonable cost, the DeForest Radio Company will supply these "H" tubes direct from the factory, (instead of through their regular sales channels) upon receipt of *Eighteen* ($18.00) *Dollars. Cash must accompany order.* Tubes will be mailed Parcel Post prepaid.

DeForest Radio Co.
120 Sherman Avenue
Jersey City, N. J.
Dept. T

PLAINTIFF'S EXHIBIT No. 11.

Hogan Fig. 1, Diagram of Two Electrode Tube.

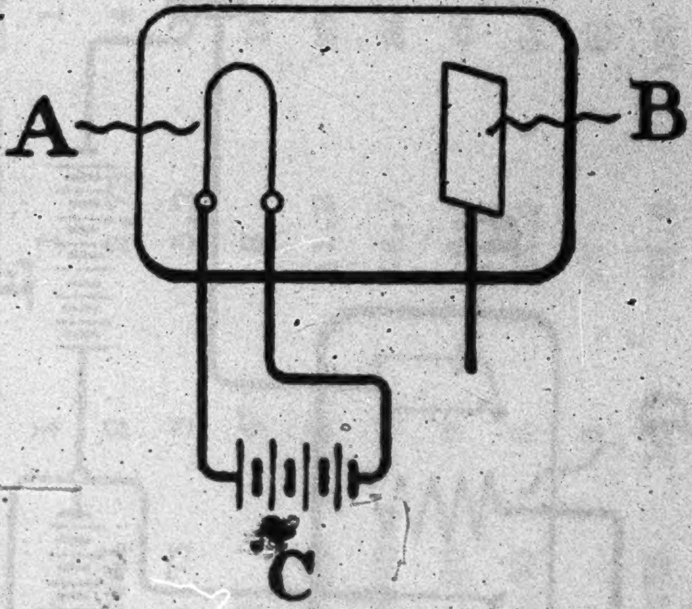


Fig. 1

PLAINTIFF'S EXHIBIT No. 12.

Hogan Fig. 2, Diagram of Three Electrode Tube.

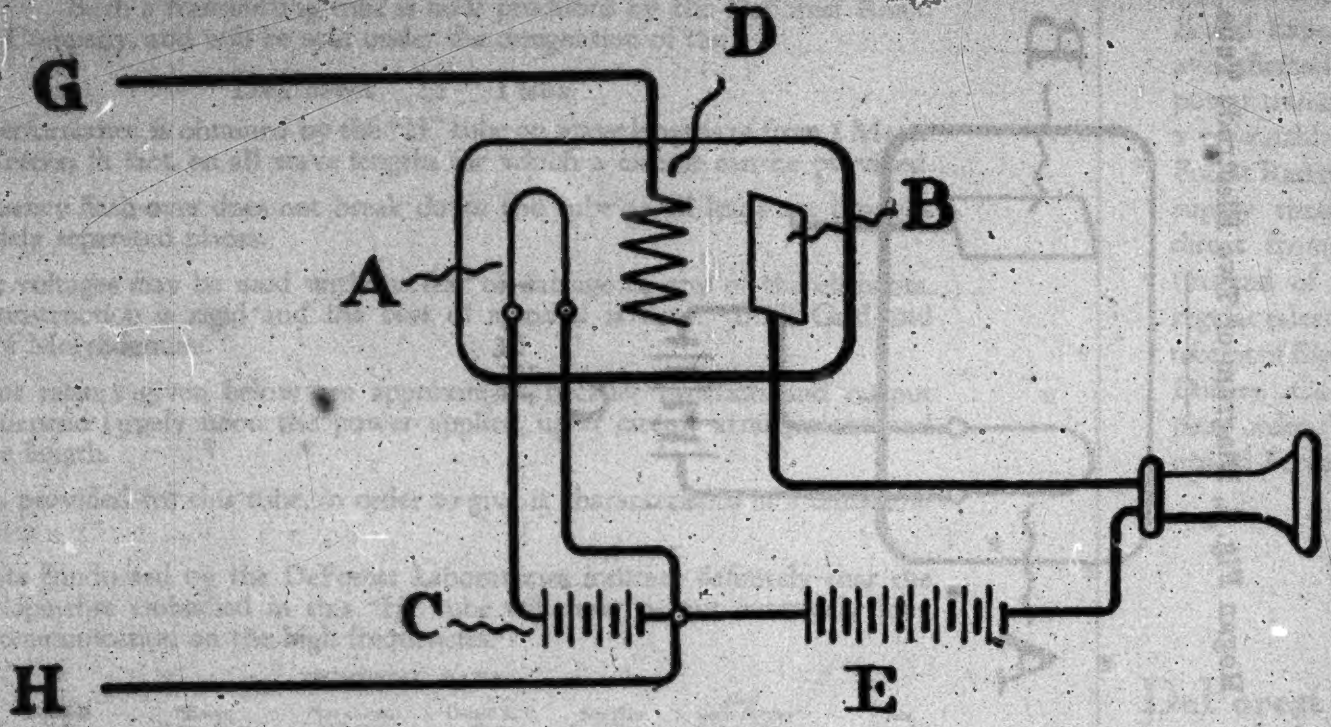


Fig. 2

PLAINTIFF'S EXHIBIT No. 13.

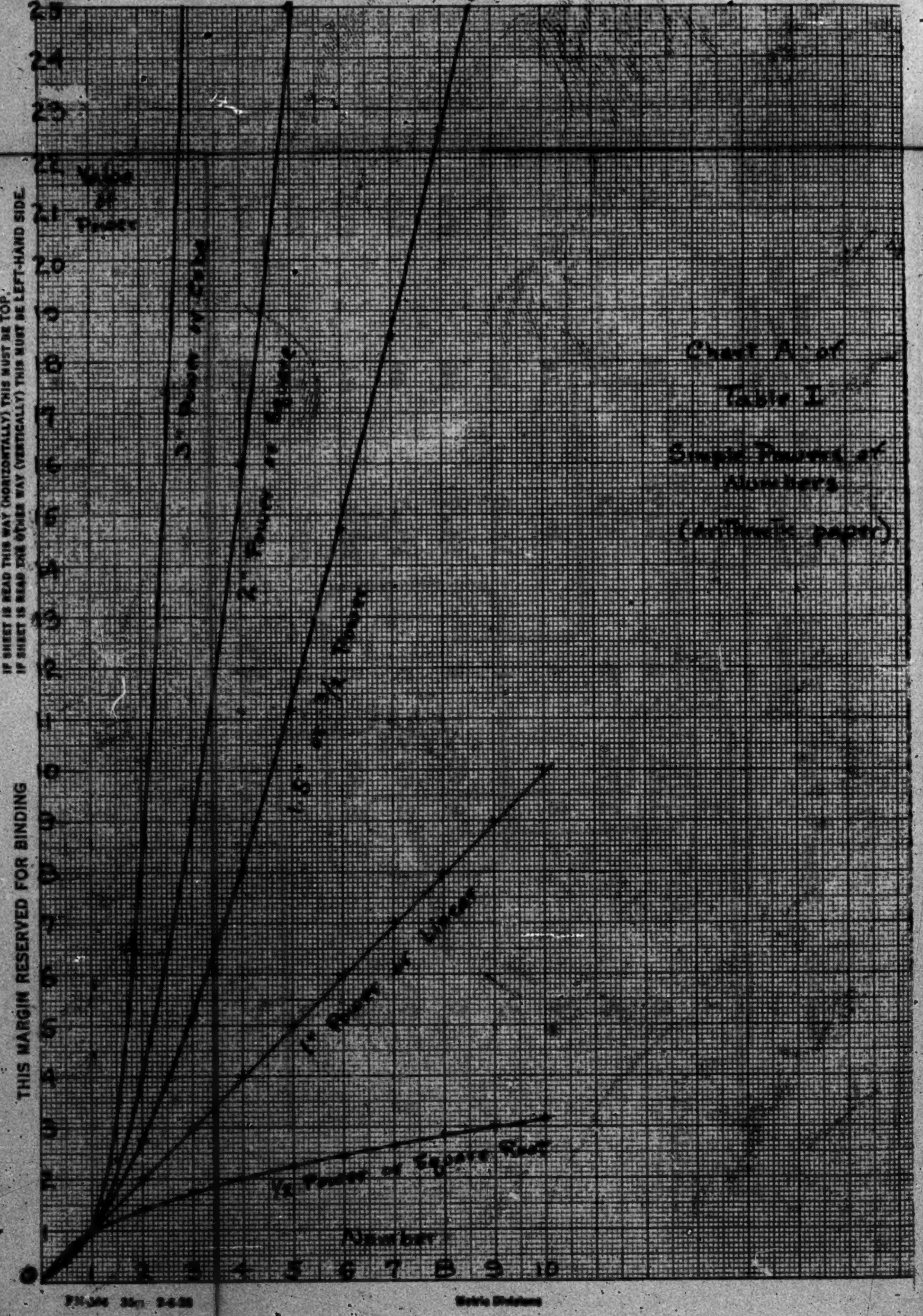
Hogan Table I Showing Power of Numbers.

Table I

Number	Square Root	First Power	3/2 or 1½ Power	Second Power or Square	Third Power or Cube
1	1	1	1	1	1
2	1.41	2	2.73	4	8
3	1.73	3	5.2	9	27
4	2	4	8	16	64
5	2.24	5	11.2	25	125
6	2.45	6	14.7	36	216
7	2.64	7	18.5	49	343
8	2.83	8	22.6	64	512
9	3	9	27	81	729
10	3.16	10	31.6	100	1000

PLAINTIFF'S EXHIBIT No. 14.

Hogan Chart A of Table I, Simple Powers of Numbers, Arithmetic Paper.

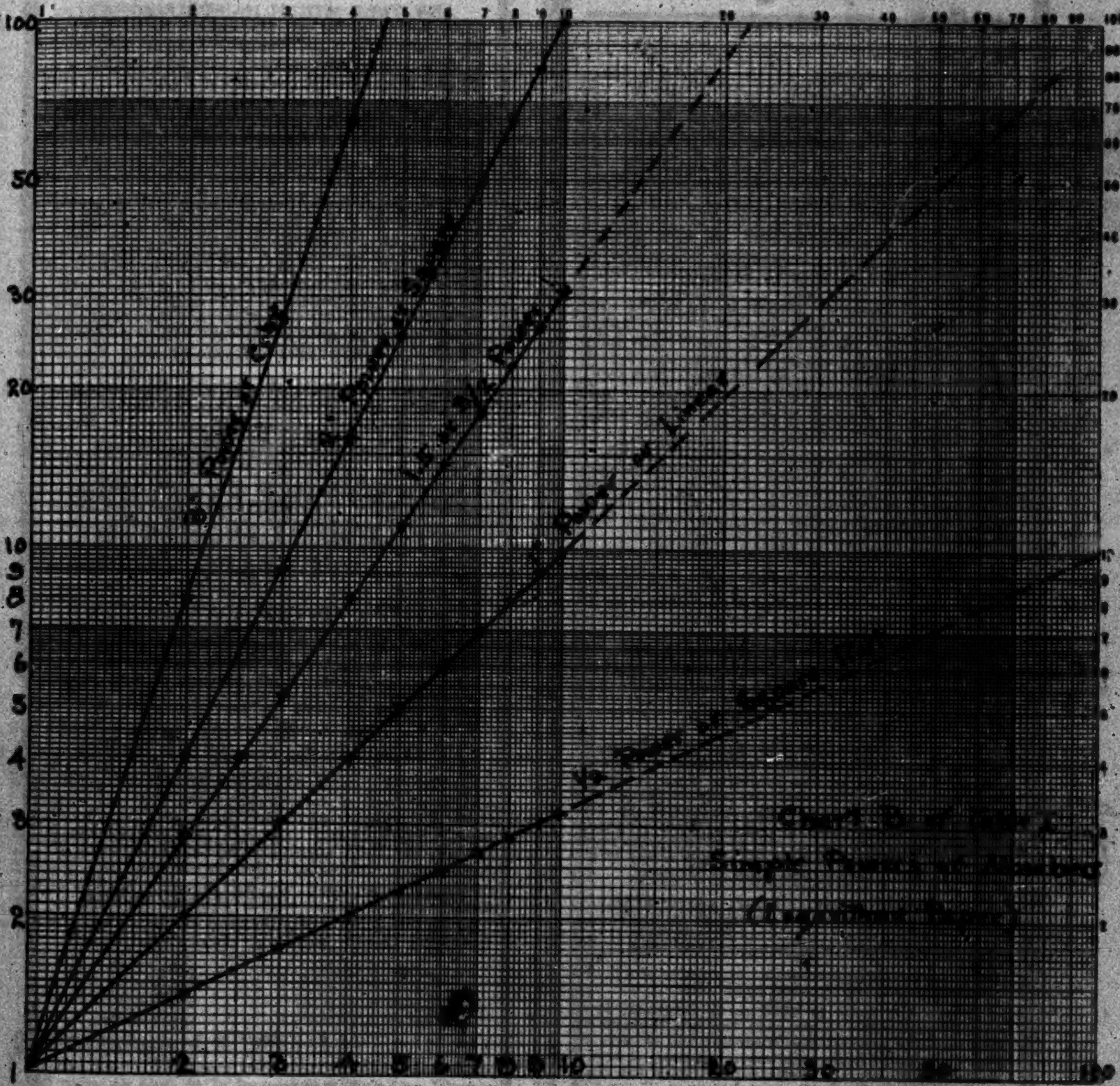


IS MARGIN

TOP.
UST BE LEFT-HA

PLAINTIFF'S EXHIBIT No. 15.

Hogan Chart B of Table I, Simple Powers of Numbers, Logarithmic Paper.

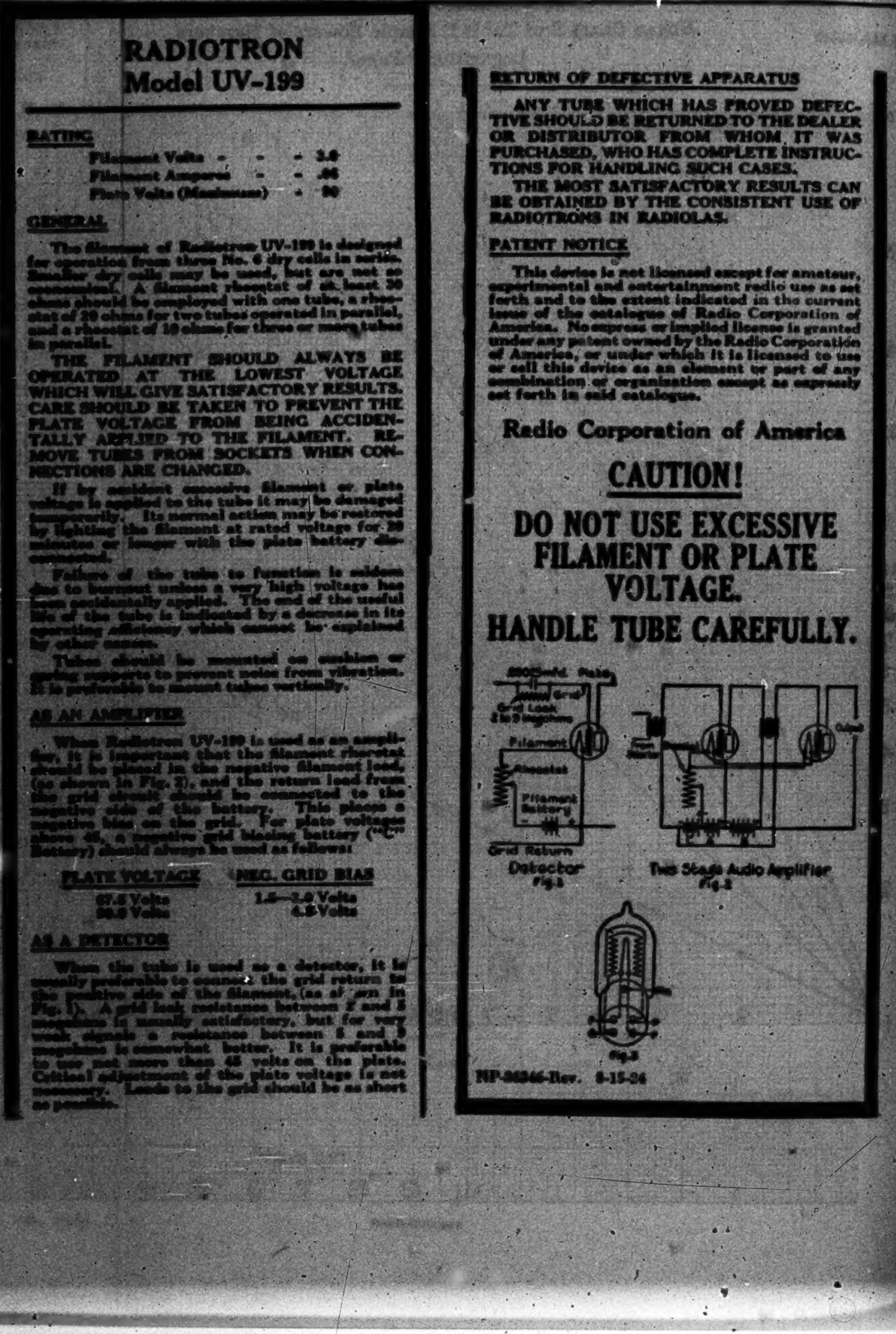


PLAINTIFF'S EXHIBIT No. 16.

Plaintiff's UV 199 Tube.

PLAINTIFF'S EXHIBIT No. 16-A.

Data Sheet Enclosed With UV 199 Tube.



RADIOTRON
Model UV-199

RATING

Filament Volts - - -	3.0
Filament Amperes - -	.06
Plate Volts (Maximum) -	90

GENERAL

The filament of Radiotron UV-199 is designed for operation from three No. 6 dry cells in series. Smaller dry cells may be used, but are not so economical. A filament rheostat of at least 30 ohms should be employed with one tube, a rheostat of 20 ohms for two tubes operated in parallel, and a rheostat of 10 ohms for three or more tubes in parallel.

THE FILAMENT SHOULD ALWAYS BE OPERATED AT THE LOWEST VOLTAGE WHICH WILL GIVE SATISFACTORY RESULTS. CARE SHOULD BE TAKEN TO PREVENT THE PLATE VOLTAGE FROM BEING ACCIDENTALLY APPLIED TO THE FILAMENT. REMOVE TUBES FROM SOCKETS WHEN CONNECTIONS ARE CHANGED.

If by accident excessive filament or plate voltage is applied to the tube it may be damaged temporarily. Its normal action may be restored by lighting the filament at rated voltage for 20 minutes or longer with the plate battery disconnected.

Failure of the tube to function is seldom due to burnout unless a very high voltage has been accidentally applied. The end of the useful life of the tube is indicated by a decrease in its operating efficiency which cannot be explained by other causes.

Tubes should be mounted on cushion or spring supports to prevent noise from vibration. It is preferable to mount tubes vertically.

AS AN AMPLIFIER

When Radiotron UV-199 is used as an amplifier, it is important that the filament rheostat should be placed in the negative filament lead, (as shown in Fig. 2), and the return lead from the grid circuit should be connected to the negative side of the battery. This places a negative bias on the grid. For plate voltages above 45, a negative grid biasing battery ("C" Battery) should always be used as follows:

PLATE VOLTAGE	NEG. GRID BIAS
67.5 Volts	1.5—3.0 Volts
90.0 Volts	4.5 Volts

AS A DETECTOR

When the tube is used as a detector, it is usually preferable to connect the grid return to the positive side of the filament, (as shown in Fig. 1). A grid leak resistance between 2 and 5 megohms is usually satisfactory, but for very weak signals a resistance between 5 and 9 megohms is somewhat better. It is preferable to use not more than 45 volts on the plate. Critical adjustment of the plate voltage is not necessary. Leads to the grid should be as short as possible.

RETURN OF DEFECTIVE APPARATUS

ANY TUBE WHICH HAS PROVED DEFECTIVE SHOULD BE RETURNED TO THE DEALER OR DISTRIBUTOR FROM WHOM IT WAS PURCHASED, WHO HAS COMPLETE INSTRUCTIONS FOR HANDLING SUCH CASES.

THE MOST SATISFACTORY RESULTS CAN BE OBTAINED BY THE CONSISTENT USE OF RADIOTRONS IN RADIOLAS.

PATENT NOTICE

This device is not licensed except for amateur, experimental and entertainment radio use as set forth and to the extent indicated in the current issue of the catalogue of Radio Corporation of America. No express or implied license is granted under any patent owned by the Radio Corporation of America, or under which it is licensed to use or sell this device as an element or part of any combination or organization except as expressly set forth in said catalogue.

Radio Corporation of America

CAUTION!

DO NOT USE EXCESSIVE FILAMENT OR PLATE VOLTAGE.

HANDLE TUBE CAREFULLY.

Detector
Fig. 1

Two Stage Audio Amplifier
Fig. 2

Fig. 3

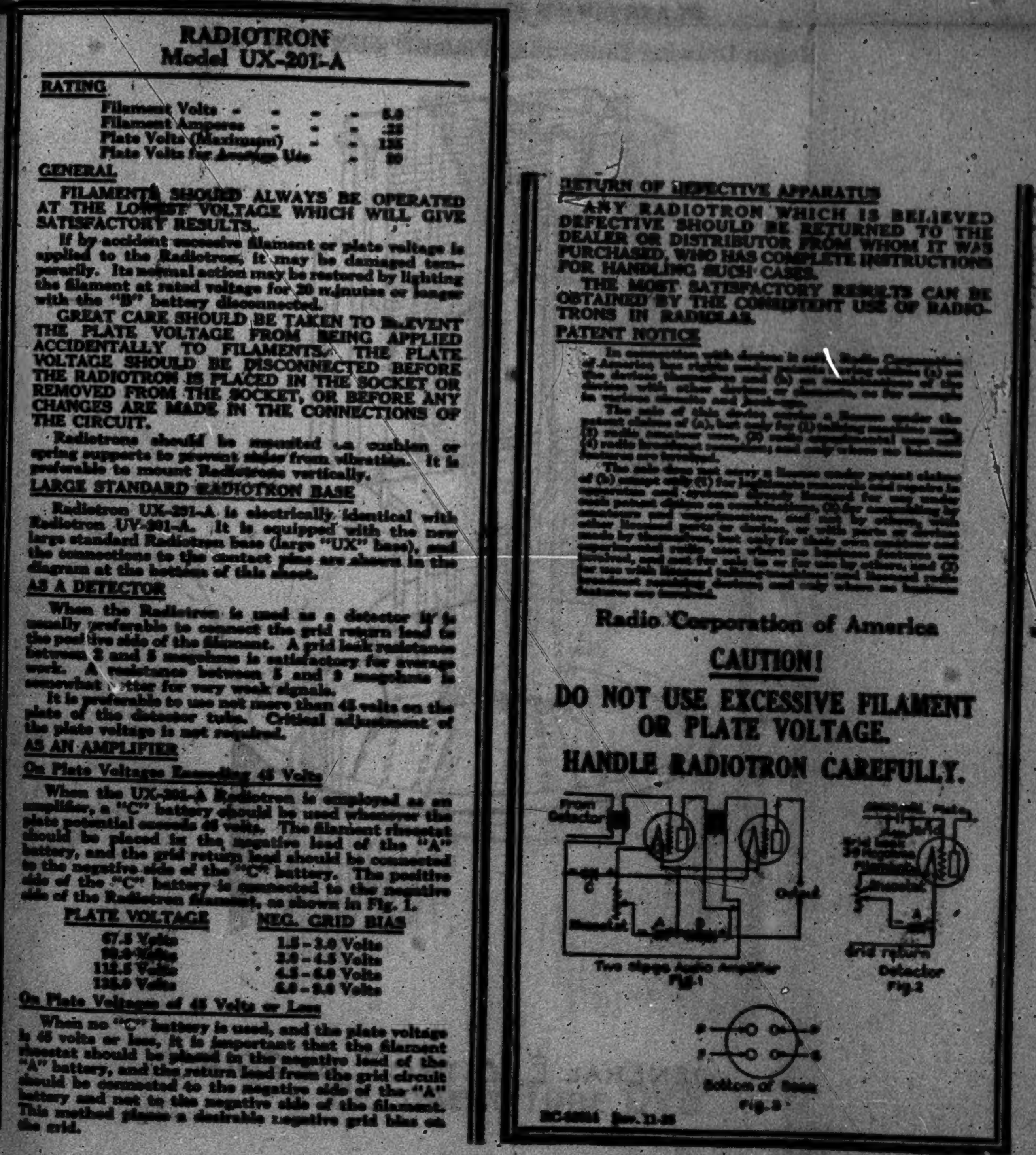
NP-26346-Rev. 8-15-24

PLAINTIFF'S EXHIBIT No. 17.

Plaintiff's UX 201A Tube.

PLAINTIFF'S EXHIBIT No. 17-A

Data Sheet Enclosed With UX 201A Tube.



RADIOTRON
Model UX-201-A

RATING

Filament Volts - - - - -	5.0
Filament Amperes - - - -	.25
Plate Volts (Maximum) - -	135
Plate Volts for Average Use -	90

GENERAL

FILAMENTS SHOULD ALWAYS BE OPERATED AT THE LOWEST VOLTAGE WHICH WILL GIVE SATISFACTORY RESULTS.

If by accident excessive filament or plate voltage is applied to the Radiotron, it may be damaged temporarily. Its normal action may be restored by lighting the filament at rated voltage for 20 minutes or longer with the "B" battery disconnected.

GREAT CARE SHOULD BE TAKEN TO PREVENT THE PLATE VOLTAGE FROM BEING APPLIED ACCIDENTALLY TO FILAMENTS. THE PLATE VOLTAGE SHOULD BE DISCONNECTED BEFORE THE RADIOTRON IS PLACED IN THE SOCKET OR REMOVED FROM THE SOCKET, OR BEFORE ANY CHANGES ARE MADE IN THE CONNECTIONS OF THE CIRCUIT.

Radiotrons should be mounted on cushion or spring supports to prevent shock from vibration. It is preferable to mount Radiotrons vertically.

LARGE STANDARD RADIOTRON BASE

Radiotron UX-201-A is electrically identical with Radiotron UV-201-A. It is equipped with the new large standard Radiotron base (large "UX" base), and the connections to the contact pins are shown in the diagram at the bottom of this sheet.

AS A DETECTOR

When the Radiotron is used as a detector it is usually preferable to connect the grid return lead to the positive side of the filament. A grid leak resistance between 2 and 5 megohms is satisfactory for average work. A resistance between 5 and 9 megohms is somewhat better for very weak signals.

It is preferable to use not more than 45 volts on the plate of the detector tube. Critical adjustment of the plate voltage is not required.

AS AN AMPLIFIER

On Plate Voltages Exceeding 45 Volts

When the UX-201-A Radiotron is employed as an amplifier, a "C" battery should be used whenever the plate potential exceeds 45 volts. The filament rheostat should be placed in the negative lead of the "A" battery, and the grid return lead should be connected to the negative side of the "C" battery. The positive side of the "C" battery is connected to the negative side of the Radiotron filament, as shown in Fig. 1.

PLATE VOLTAGE	NEG. GRID BIAS
67.5 Volts	1.5 – 3.0 Volts
90.0 Volts	3.0 – 4.5 Volts
112.5 Volts	4.5 – 6.0 Volts
135.0 Volts	6.0 – 9.0 Volts

On Plate Voltages of 45 Volts or Less

When no "C" battery is used, and the plate voltage is 45 volts or less, it is important that the filament rheostat should be placed in the negative lead of the "A" battery, and the return lead from the grid circuit should be connected to the negative side of the "A" battery and not to the negative side of the filament. This method places a desirable negative grid bias on the grid.

RETURN OF DEFECTIVE APPARATUS

ANY RADIOTRON WHICH IS BELIEVED DEFECTIVE SHOULD BE RETURNED TO THE DEALER OR DISTRIBUTOR FROM WHOM IT WAS PURCHASED, WHO HAS COMPLETE INSTRUCTIONS FOR HANDLING SUCH CASES.

THE MOST SATISFACTORY RESULTS CAN BE OBTAINED BY THE CONSISTENT USE OF RADIOTRONS IN RADIOLAS.

PATENT NOTICE

In connection with devices it sells, Radio Corporation of America has rights under patents having claims (a) on the devices themselves and (b) on combinations of the devices with other devices or elements, as for example in various circuits and hook-ups.

The sale of this device carries a license under the patent claims of (a), but only for (1) talking machine uses, (2) radio amateur uses, (3) radio experimental uses and (4) radio broadcast reception; and only where no business features are involved.

The sale does not carry a license under patent claims of (b) except only (1) for legitimate renewals and repairs in apparatus and systems already licensed for use under such patent claims on combinations, (2) for assembling by amateurs and experimenters, and not by others, with other licensed parts or devices, or with parts or devices made by themselves, but only for their own amateur and experimental radio uses where no business features are involved, and not for sale to or for use by others, and (3) for use with licensed talking-machines and licensed radio broadcast receiving devices, and only where no business features are involved.

Radio Corporation of America

CAUTION!

DO NOT USE EXCESSIVE FILAMENT OR PLATE VOLTAGE.

HANDLE RADIOTRON CAREFULLY.

Two Stage Audio Amplifier
Fig. 1

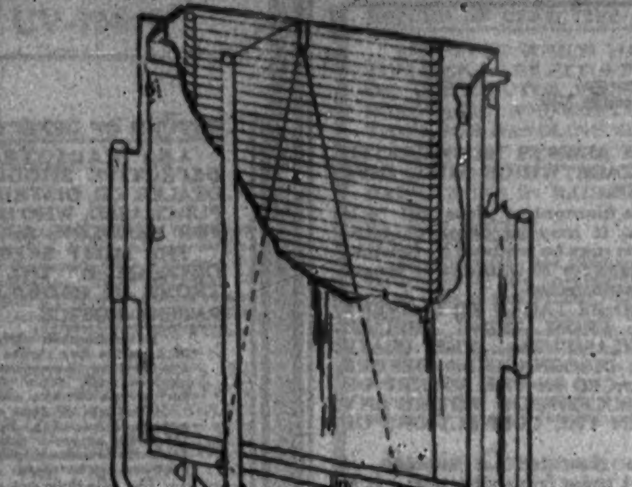
Detector
Fig. 2

Bottom of Base
Fig. 3

RC-[illegible] Rev. 11-26

PLAINTIFF'S EXHIBIT No. 18

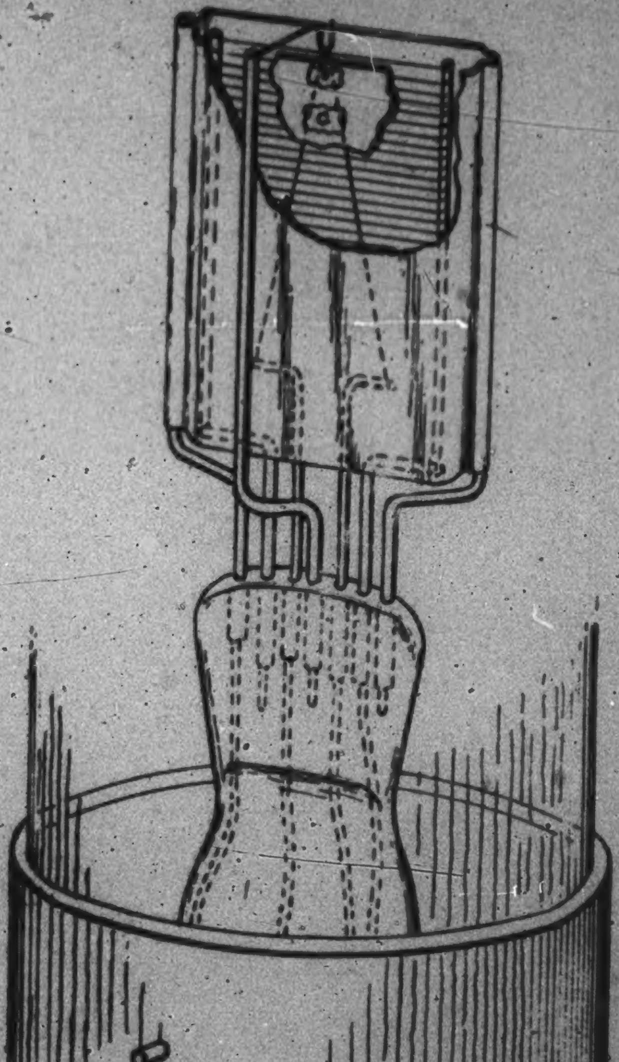
Hogan Drawing Illustrating Plaintiff's UX 201A Tube.



GENERAL ELECTRIC TUBE 201A

PLAINTIFF'S EXHIBIT No. 19.

Hogan Drawing Illustrating Defendant's DV 5 Tube.



DE FOREST TUBE DV5

[NOTE: FOR PLAINTIFF'S EXHIBITS NOS. 20 TO 161 INCLUSIVE, SEE INTERFERENCE RECORD]

PLAINTIFF'S EXHIBIT No. 162.

In the Court of Appeals of the District of Columbia

IRVING LANGMUIR, Appellant, vs. HAROLD D. ARNOLD.	No. 1680. Patent Appeal

OPINION OF THE COURT
(Filed June 1, 1925)

(Before MARTIN, Chief Justice, and ROBB and VAN ORSDEL, Associate Justices)

Appeal from a decision of an Assistant Commissioner of Patents in an interference proceeding awarding priority to the junior party, Arnold, and reversing concurrent decisions of the Examiner of Interferences and the Board of Examiners-in-Chief.

The invention is a thermionic tube adapted to be used as a relay in long distance telephone systems, as a detector or amplifier in wireless systems, or as a rectifier of alternating currents. The issue is expressed in thirteen counts, of which the 1st, 7th and 13th, here reproduced, will serve as examples:

> "1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

> "7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when volt-

> ages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltage, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous."
>
> "13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner."

The attitude of the junior party, appellee here, when this interference was declared, is significant. He filed a motion challenging the patentability of the issue and sought and obtained permission to take evidence in support of that motion. The result was the taking of voluminous testimony by the parties on this issue, which by stipulation is in the record here. The Law Examiner, to whom this question was initially referred, sustained the patentability of the issue and his decision is controlling here. We therefore start our inquiry in this appeal with the established fact that, so far as this proceeding is concerned, the issue is patentable; in other words, that something more than mere mechanical skill was involved in the result achieved.

The Examiner of Interferences, in an exhaustive opinion, awarded priority to the senior party, Langmuir. The Board, on appeal, directed attention to the fact that, structurally considered, the tubes of both parties outwardly are substantially identical with the Fleming valve and the DeForest audion of the prior art; that the invention has been referred to as a "thing compact of glass and metal". The Board then pointed out that this definition, although correct as far as it goes, is inadequate because it applies equally well to the prior art devices, and that to this definition should be added the qualification that the device "operates with a *pure* electronic discharge above the voltage of positive ionization and below saturation", and proceeded: "But how is one to know whether the discharge is purely electronic? In other words, how is one to know whether a tube embodies merely the prior art devices or the invention of the issue? * * * For example, count 1 specifies that the envelope of the tube is evacuated to such a degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts. Thus the count distinguishes from the prior art, not by features of structure, but by a characteristic which is manifest while the device is operating at or above a certain voltage."

Later in its decision the Board suggested that the question to be determined was, who of the parties "first knowingly and understandingly conceived and produced such a tube"; that Arnold, the junior party, did not claim to have conceived the invention prior to November 1, 1912, or to have reduced it to practice prior to the 29th of that month; that Langmuir, on the other hand, alleged conception, disclosure, sketches, written description and successful operation prior to September 1, 1912, followed in November of that year by the successful operation of other devices embodying the invention. The Board then carefully reviewed the testimony in support of Langmuir's contentions and found that he had conceived the invention of counts 1 to 11, inclusive, as early as September 1, 1912, and had reduced the same to practice by November 19th of the same year; that, as to counts 12 and 13, Langmuir had conceived prior to April 8, 1913, and had reduced to practice by April 15th of that year; that Arnold conceived and reduced to practice the invention of all of the counts except counts 1 and 11 on April 25, 1913, and that counts 1 and 11 were not reduced to practice until after Langmuir's filing date.

The attitude of the Assistant Commissioner toward the case was that of the junior party upon the declaration of the interference, namely, that the patentability of the issue was doubtful. He says: "The line between the prior art and the issue is attenuated and if there is patentability, it must be as set out in the decision of the Law Examiner on the motion, and I do not understand either party to attack that decision here. Arnold alleges that when he made the invention, he thought he was following the prior art and not producing something patentable, and an undercurrent of that attitude seems to tinge his whole case. This is why he filed so late." Proceeding from that postulate, the Assistant Commissioner has accepted as controlling on the question of conception and reduction to practice, on behalf of Arnold, testimony of a vague and general character and which failed to satisfy the lower tribunals, as it also has failed to satisfy us. The decisions of those tribunals are so clear and satisfying that we are content to rest our opinion upon the reasoning there given.

It results that the decision is reversed and priority awarded Langmuir.

Reversed.

CHAS. H. ROBB,
Associate Justice.

Endorsed: No. 1680 Patent Appeal. Irving Langmuir, Appellant, vs. Harold D. Arnold. Opinion of the Court per Mr. Justice ROBB. Court of Appeals, District of Columbia. Filed June 1, 1925. HENRY W. HODGES, Clerk.

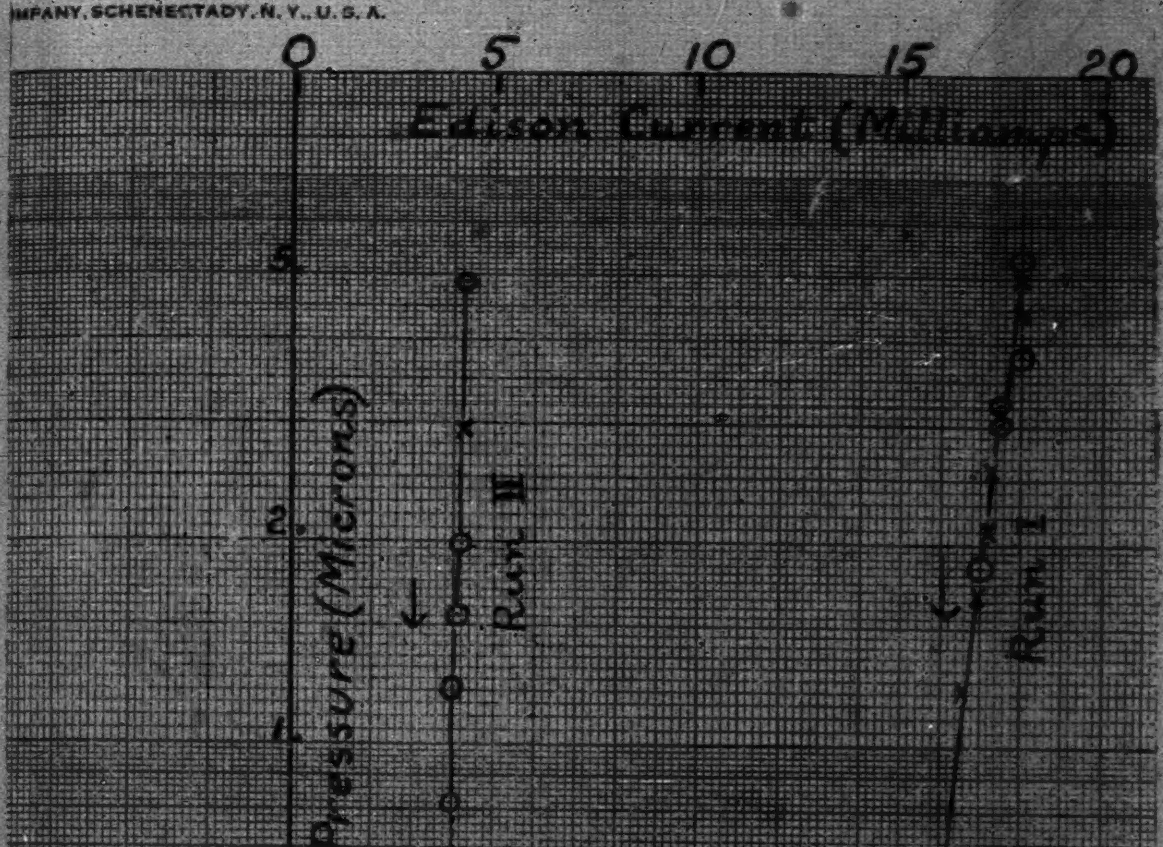
A true Copy.

Test: HENRY W. HODGES,

[SEAL] Clerk of the Court of Appeals of the District of Columbia.

PLAINTIFF'S EXHIBIT No. 163.

Langmuir Explanatory Diagram.

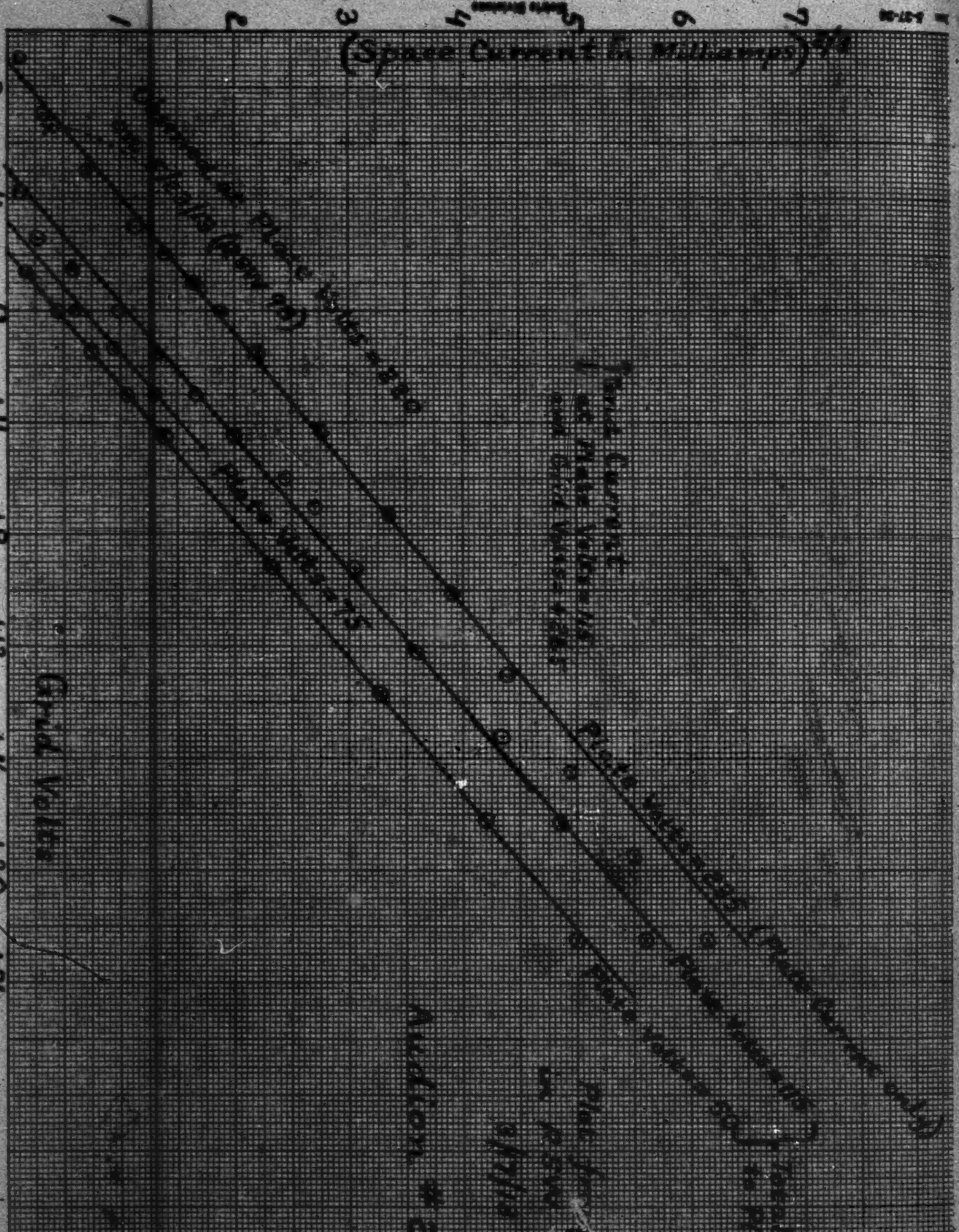


Exp't 291
pages S-1177-8

Aug. 21, 1912.

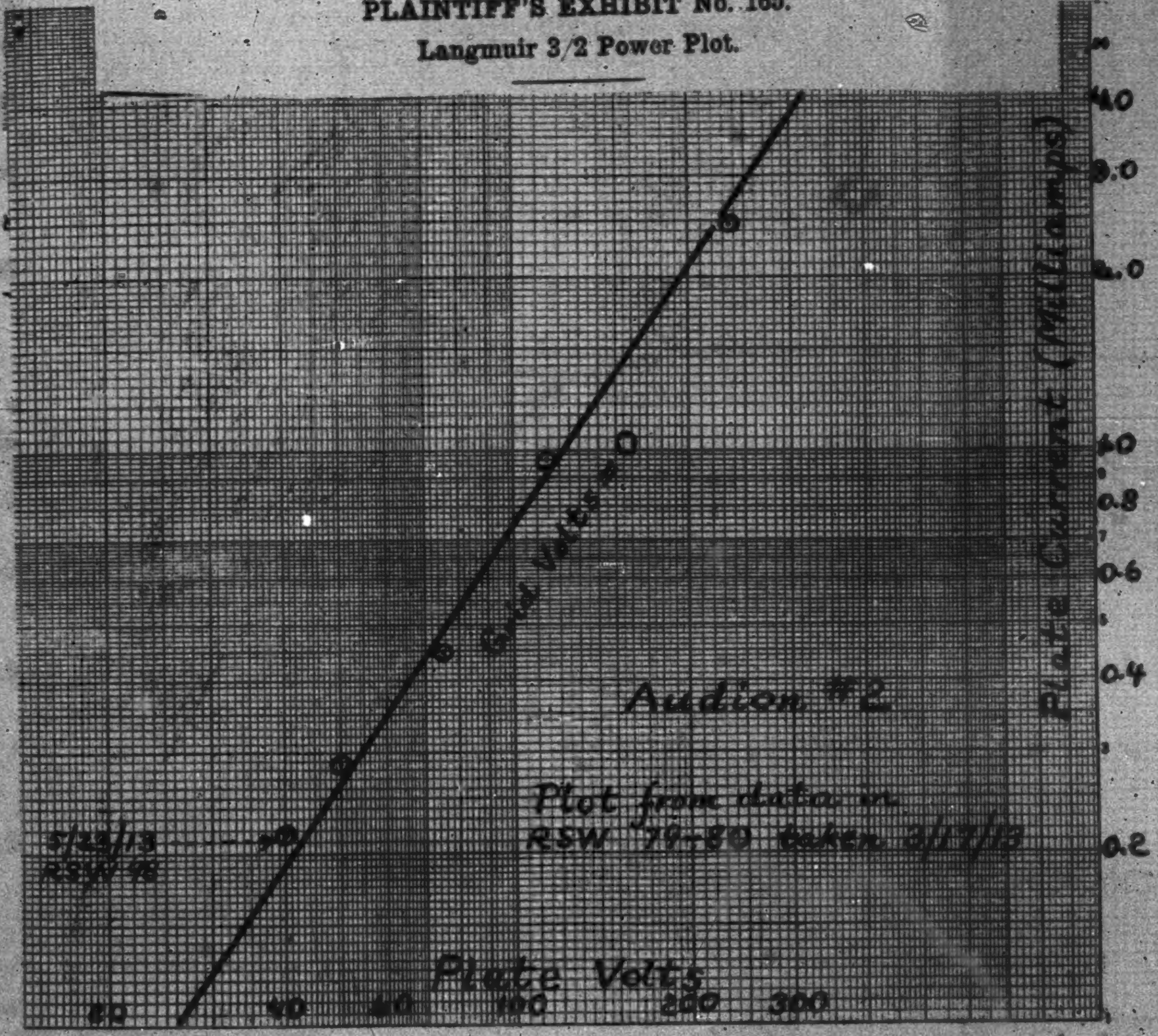
PLAINTIFF'S EXHIBIT No. 164.

Langmuir 2/3 Power Plot.



PLAINTIFF'S EXHIBIT No. 165.

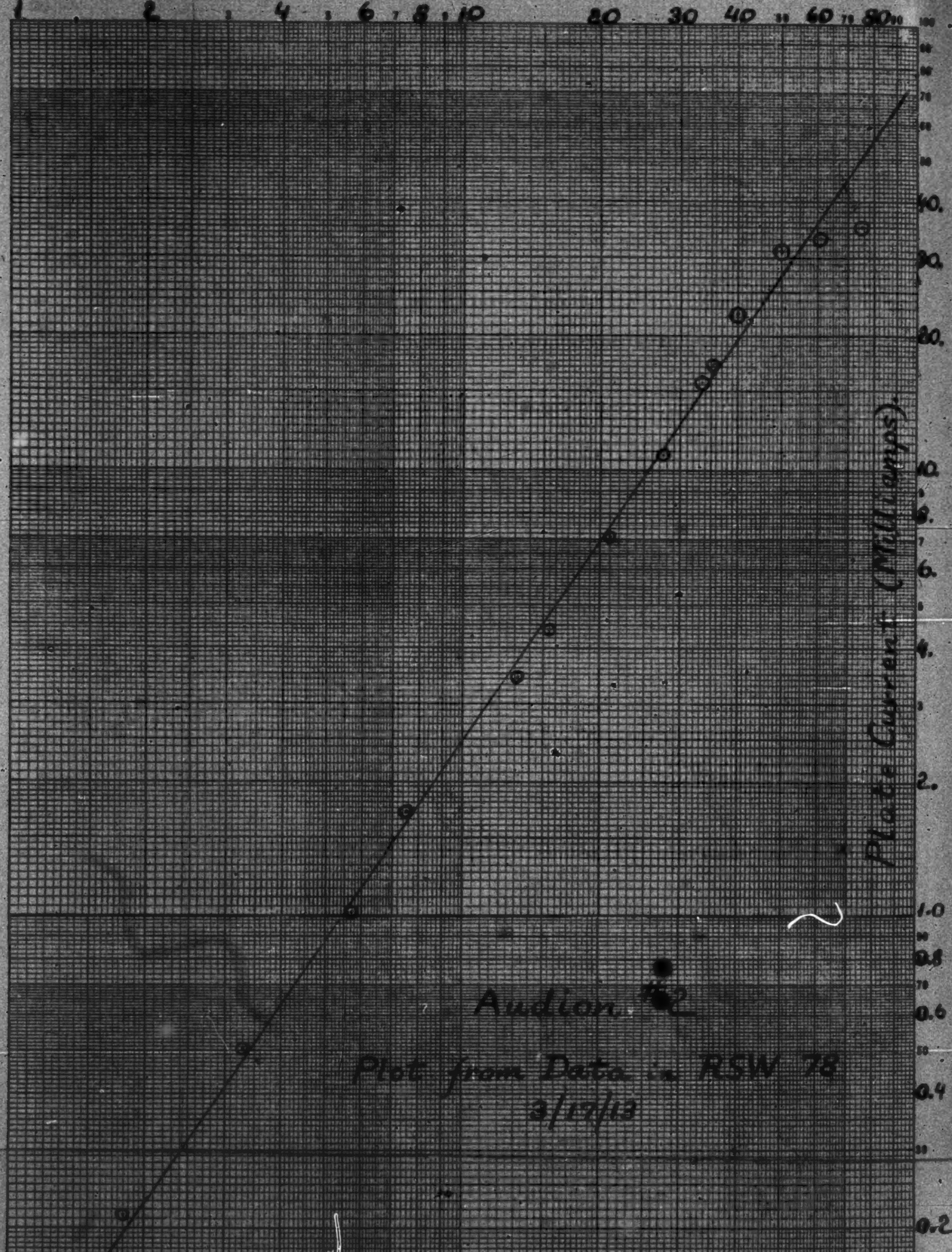
Langmuir 3/2 Power Plot.



IS MARGIN

Langmuir Plot of Volts on Plate and Grid Against Current Audion No. 2.

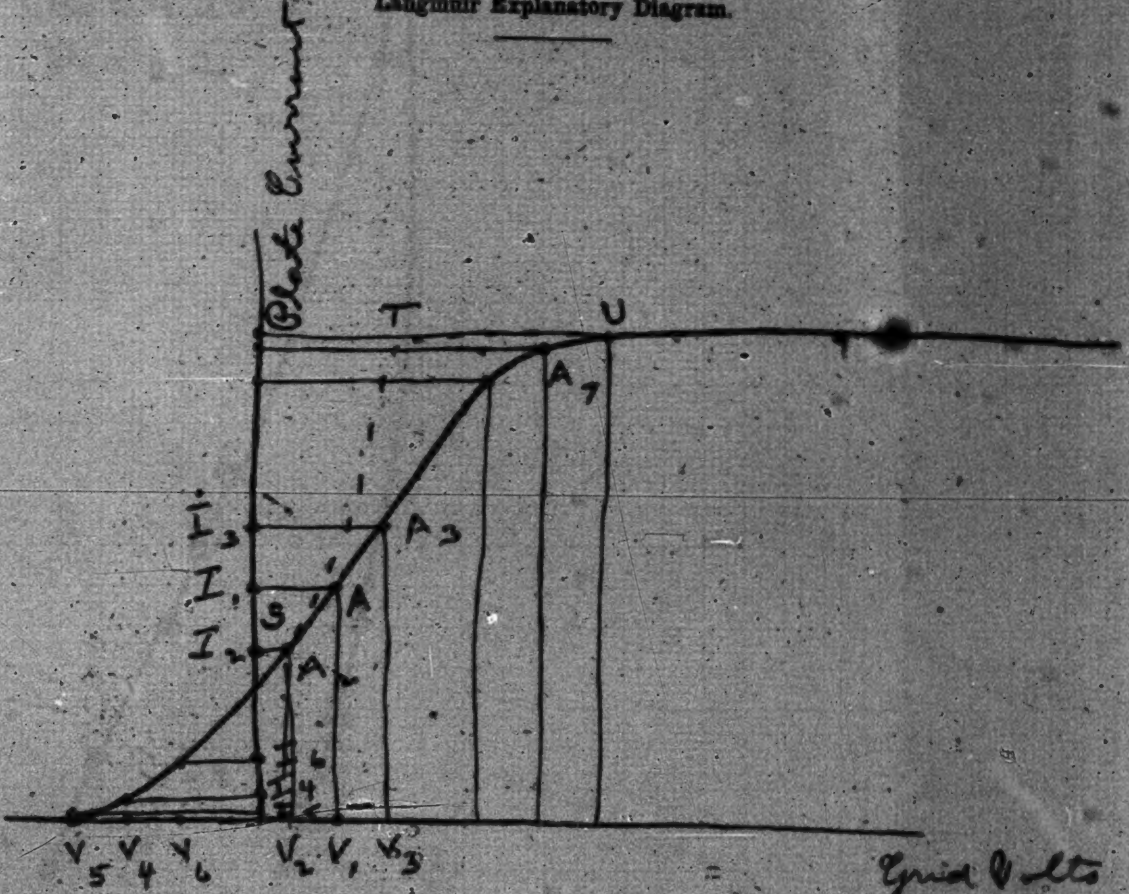
BE TOP.
JST BE LEFT.



Audion #2

Plot from Data in RSW 78
3/17/13

PLAINTIFF'S EXHIBIT No. 157.
Langmuir Explanatory Diagram.

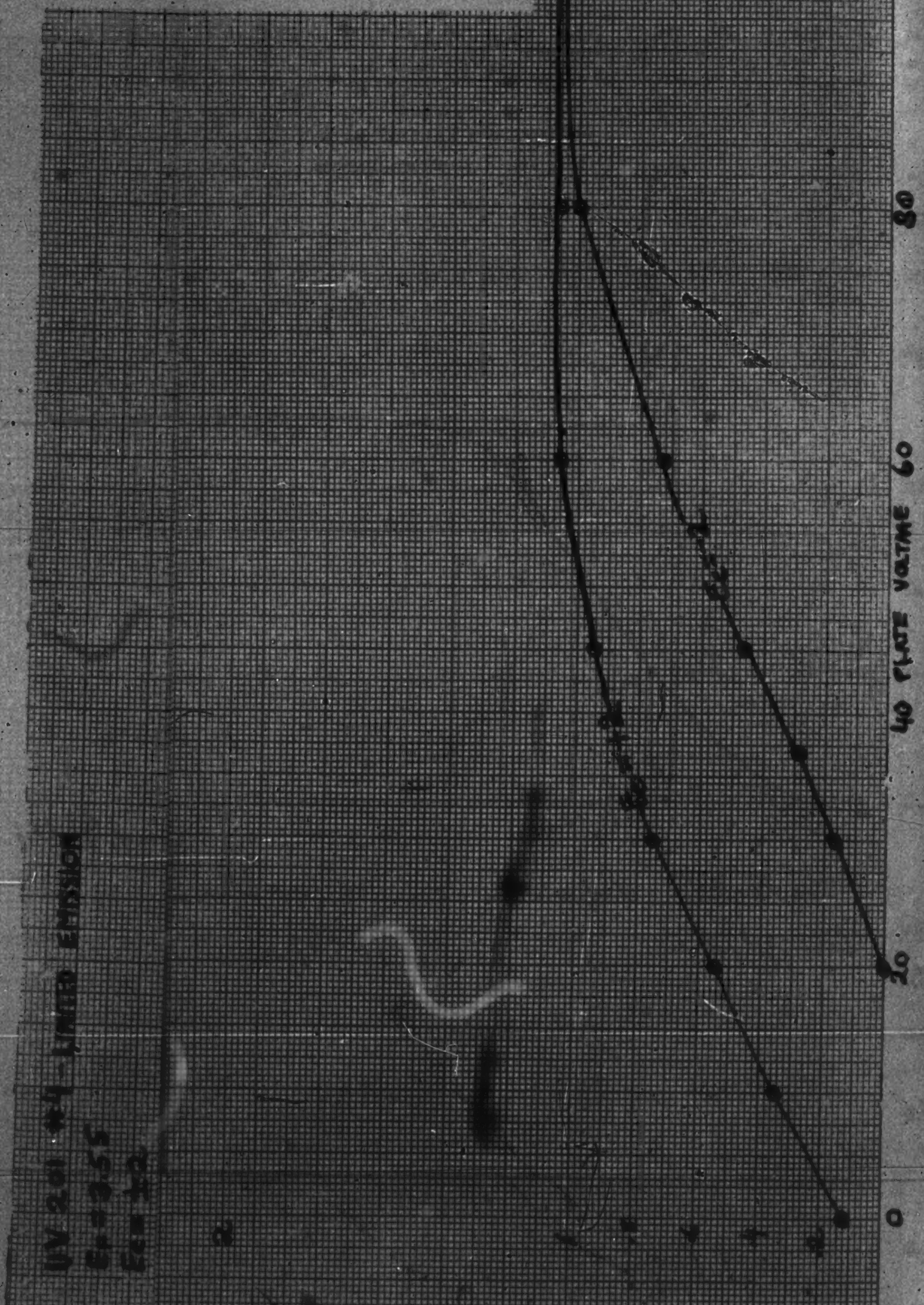


Detector depends on curvature.

Amplifier " " slope.

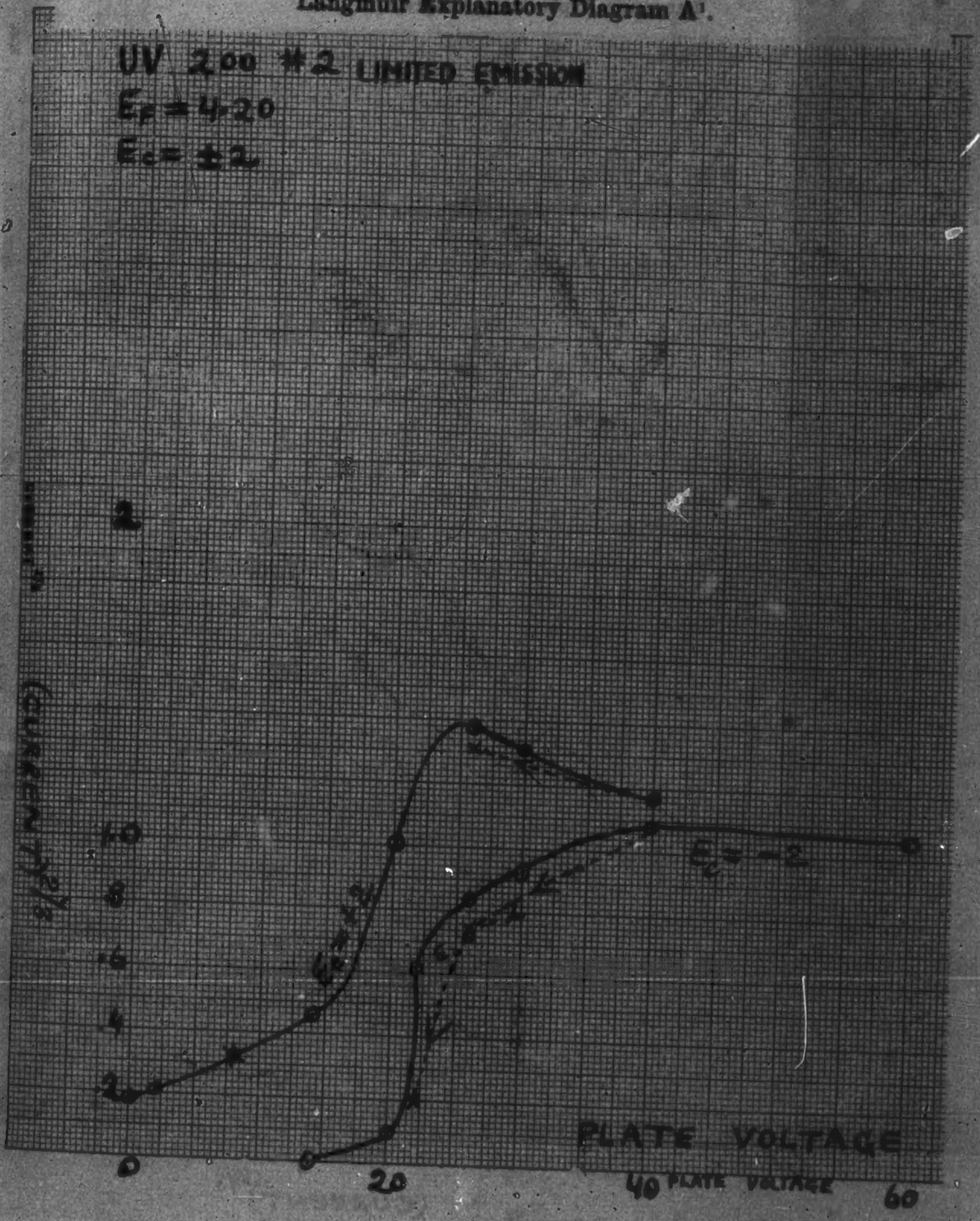
PLAINTIFF'S EXHIBIT No. 168.

Langmuir Explanatory Diagram A.



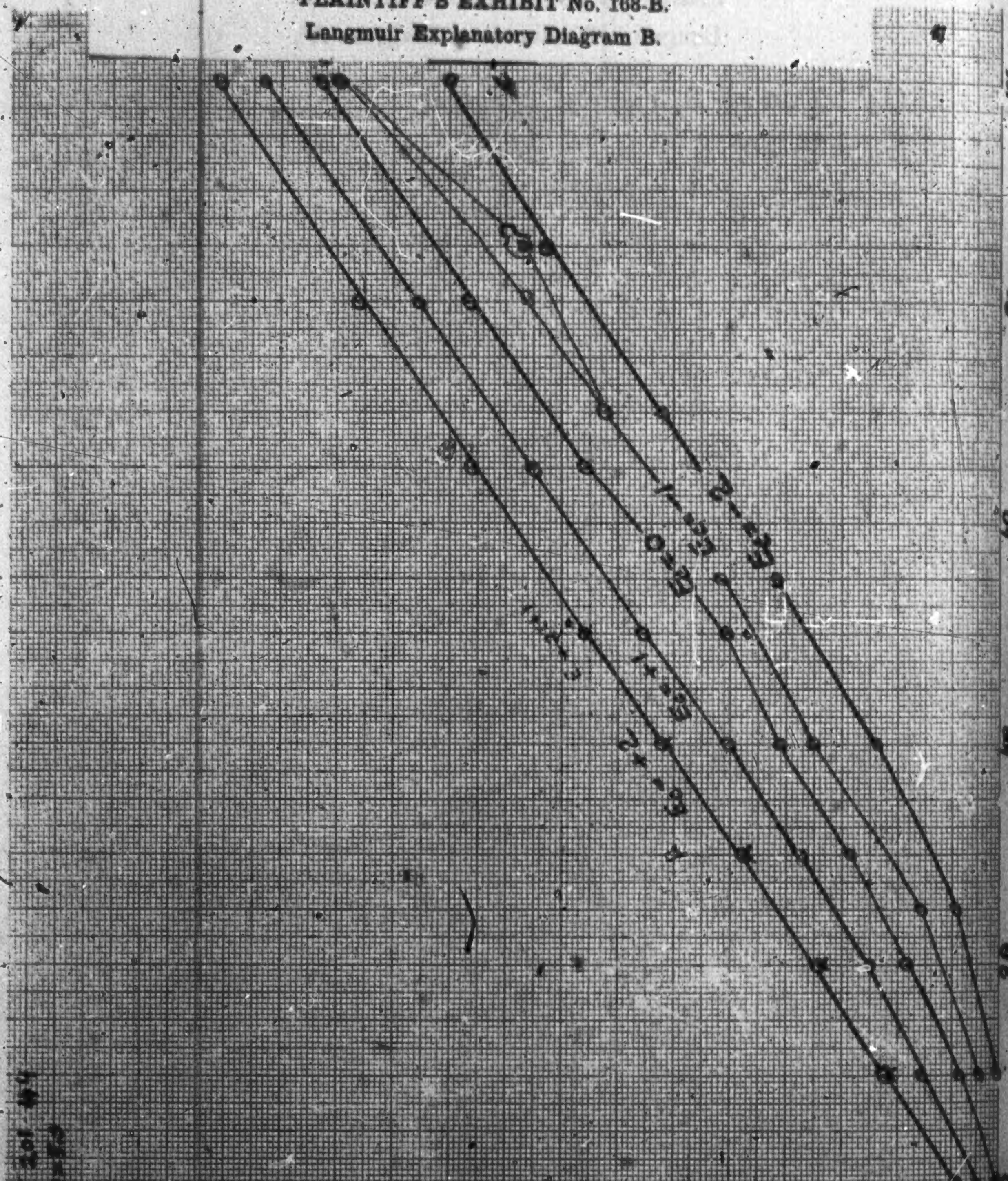
PLAINTIFF'S EXHIBIT No. 168-A.

Langmuir Explanatory Diagram A^1.



PLAINTIFF'S EXHIBIT No. 168-B.

Langmuir Explanatory Diagram B.

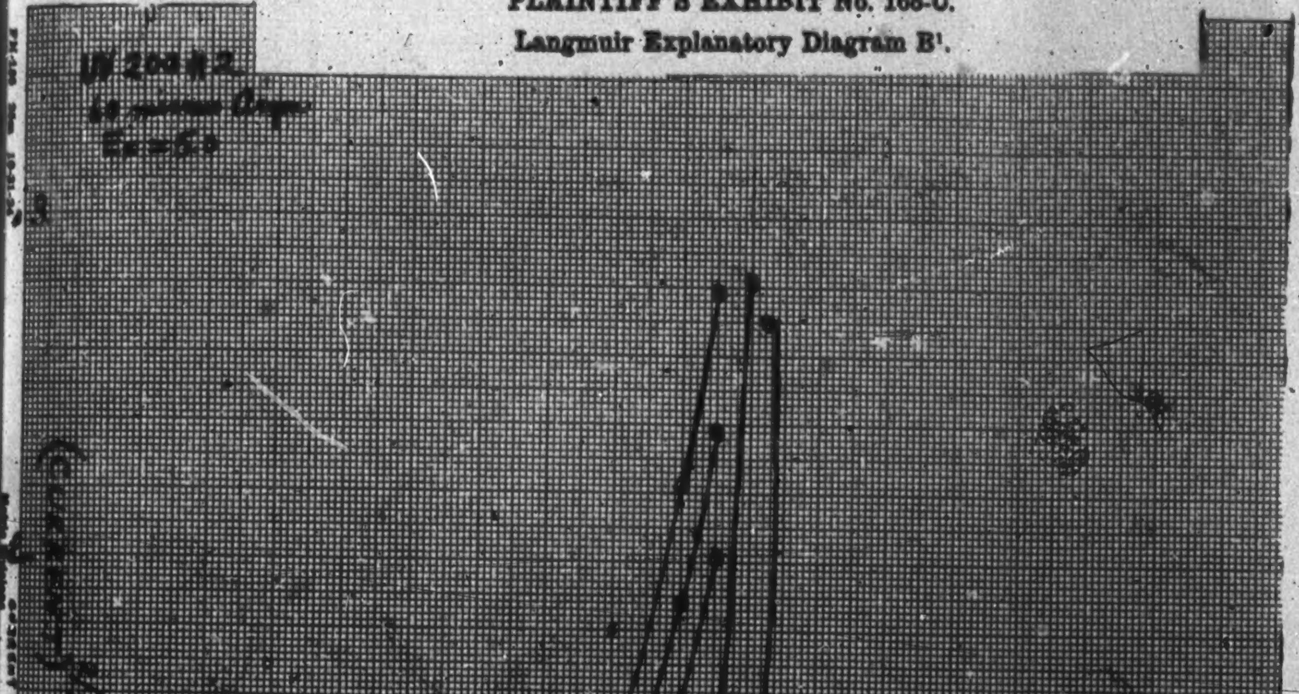


FN-156 25m 10-31-34

Metric Divisions

PLAINTIFF'S EXHIBIT No. 168-C.

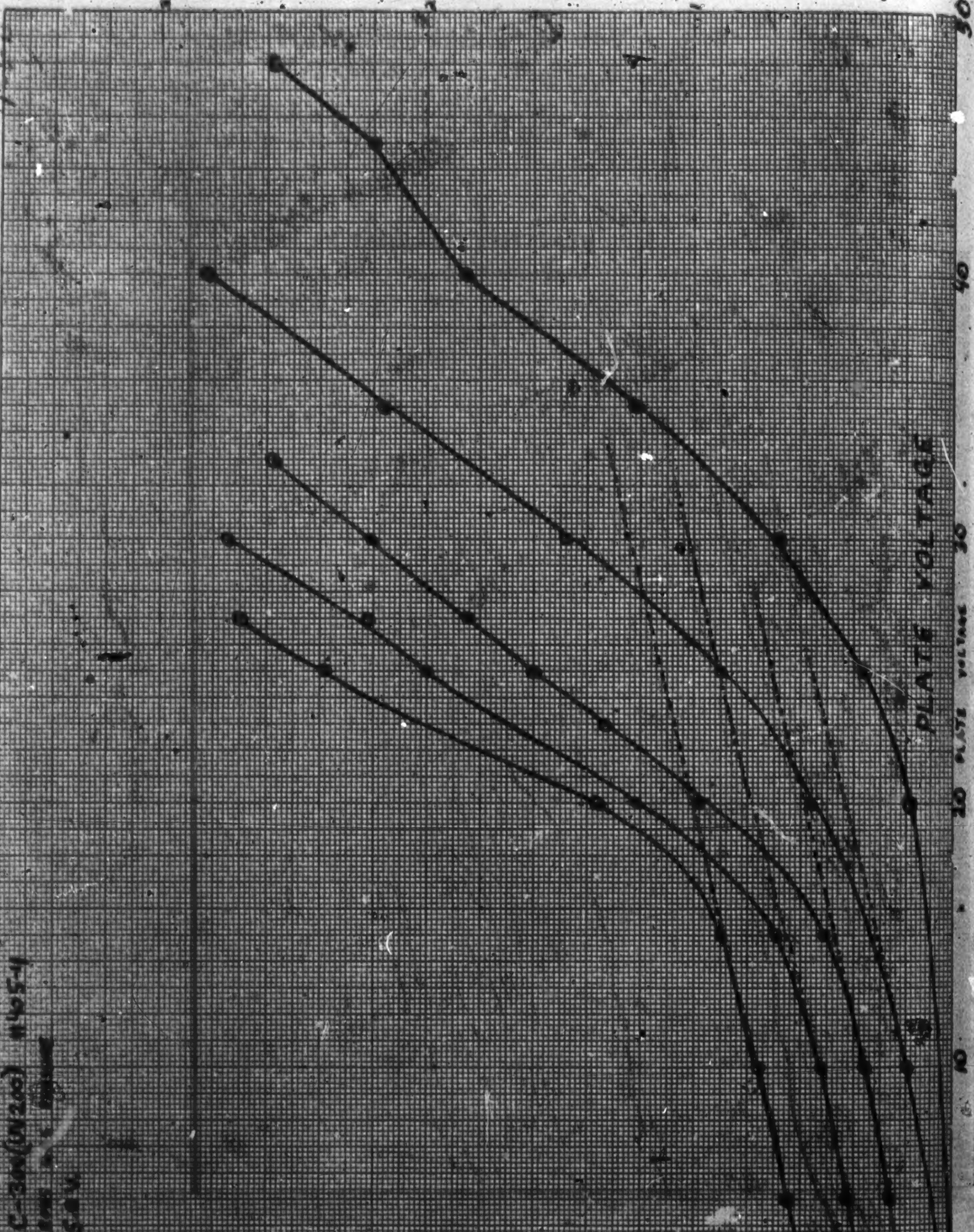
Langmuir Explanatory Diagram B¹.



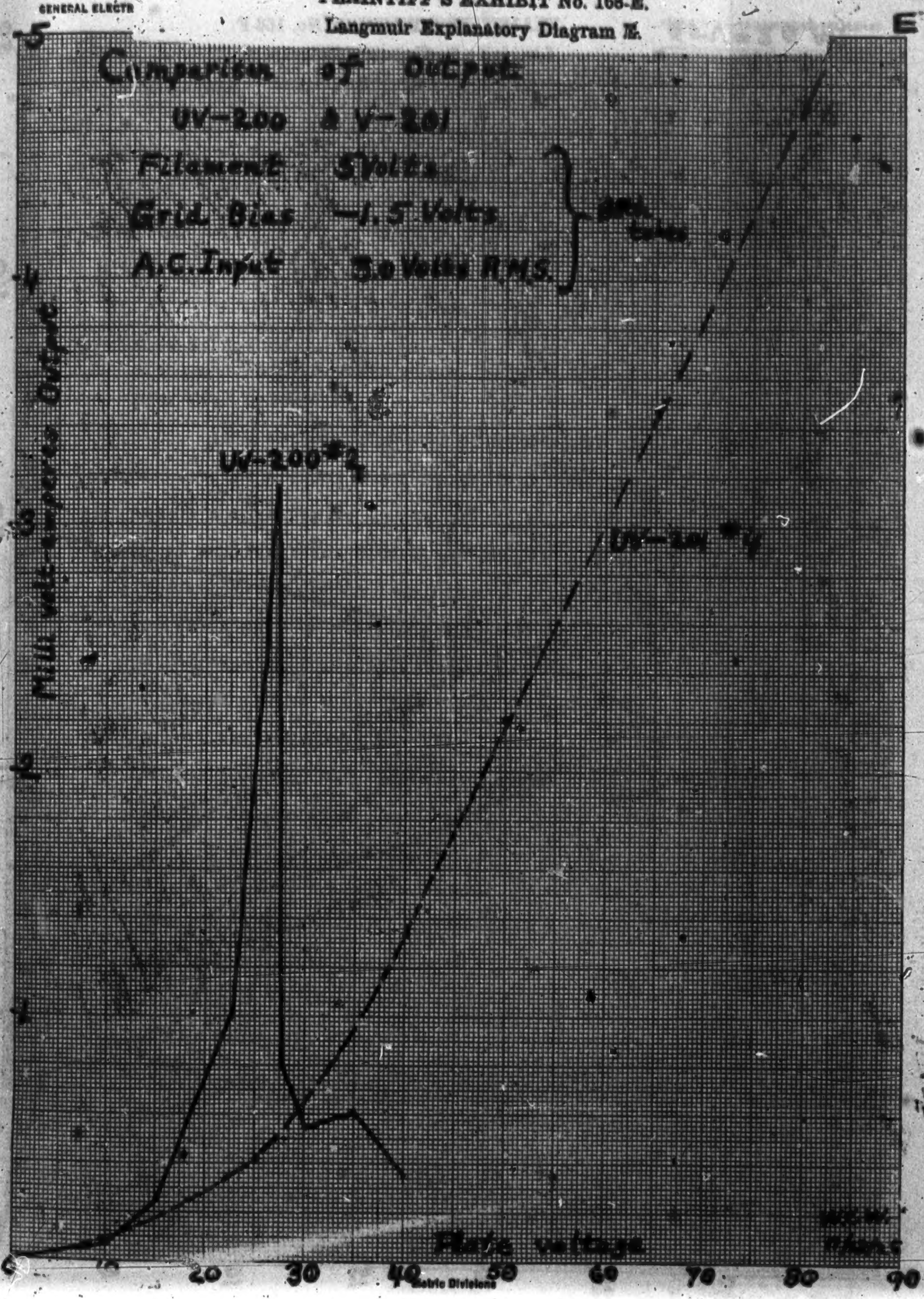
GENERA

PLAINTIFF'S EXHIBIT No. 168-D.

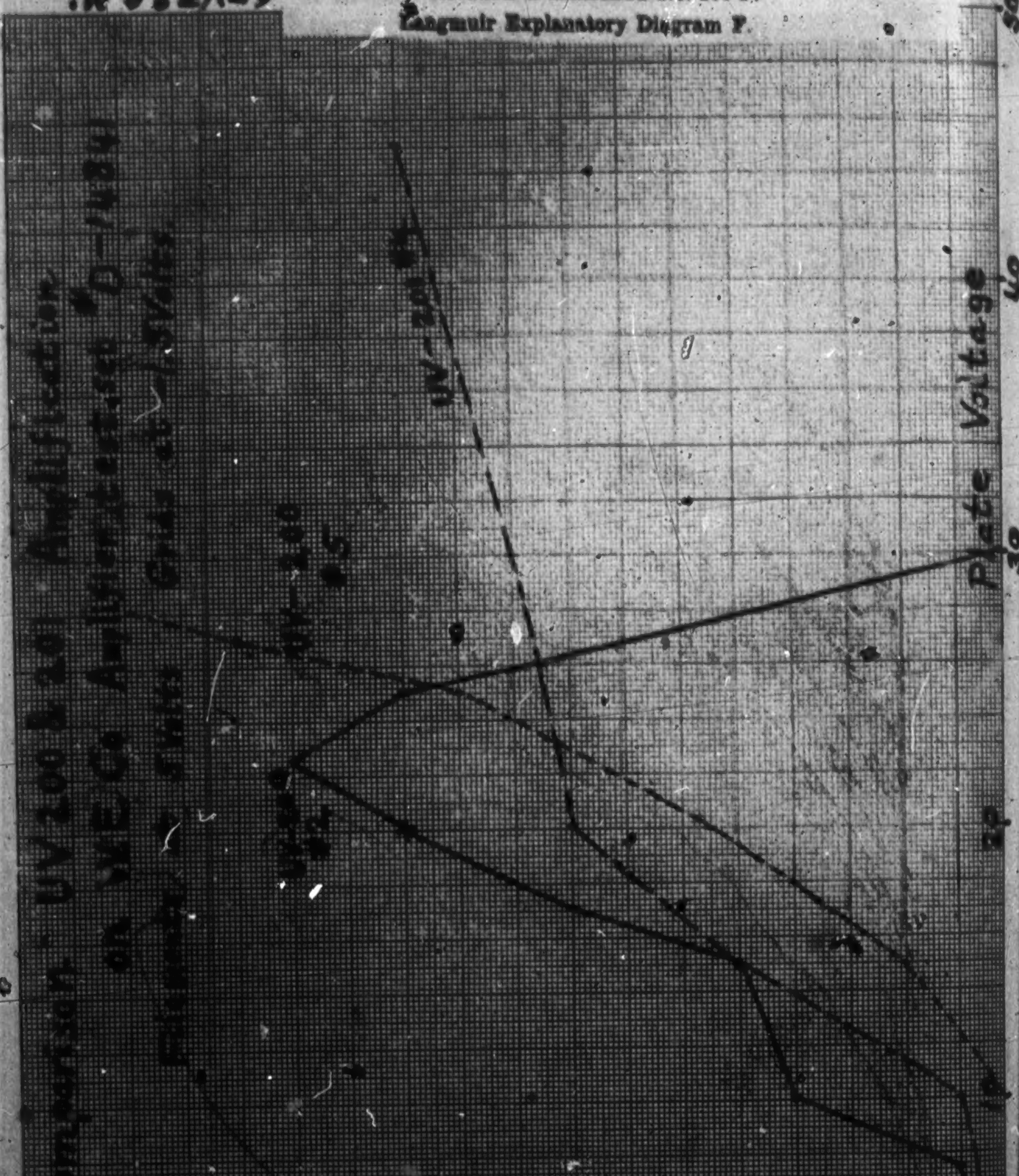
Langmuir Explanatory Diagram D.



PLAINTIFF'S EXHIBIT No. 168-E.
Langmuir Explanatory Diagram E.



PLAINTIFF'S EXHIBIT No. 168-F.
Langmuir Explanatory Diagram F.



ERAL ELECTRIC COMPANY
EXECUTIVE CORRESPONDENCE

PLAINTIFF'S EXHIBIT No. 169.

Subject:
Location:
Referring to:
Attention of:

Patent Case 17605 Feb 7/13

Schenectady, N. Y. Feb. 5, 1913.

Miss H. Orford,
Patent Department.

Dear Miss Orford:

As a matter of record of conversation with Mr. Hawkins and Dr. Coolidge on Jan. 9th, please docket a case for me on the use of an X-ray tube as an amplifier for high frequency current for wireless telegraphy. In the incandescent rectifier which is sometimes used as a detector, relay action is obtained by introducing the controlling potential on a grate grid which is placed in the flow of the radiating energy. The controlling potential has the effect of starting and stopping the flow and this principle may be app lied on a large scale as an amplifier for sending purposes.

I have a patent used sometime ago covering broadly the use of this principle in combination with telephone for sending wireless telephone messages.

This particular construction of the X-ray tube suggested to me the possible advantages of deflection, rather than stopping the flow of energy by providing two targets and deflecting the flow of energy from the antenna circuit to the local circuit. The deflection may be produced either by electro-magnet which is controlled by the telephone or by an electrostatic potential.

A. Allen Orford
17605f
Feb 7/13

Yours very truly,

E.F. Alexanderson

PLAINTIFF'S EXHIBIT No. 170.

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper, Contents and Drawing, in the matter of the

Letters Patent of

Harold D. Arnold, Assignor, by Mesne Assignments to Western Electric Company, Incorporated,

Number 1,297,309. Granted March 18, 1919,

for

provement in Manufacture of Vacuum-Tube Devices.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this third day of November in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

ATTEST: Willis B. Magruder
Chief of Division.

Thomas E. Robertson
Commissioner of Patents.

60

NUMBER (Series of 1915). 62259

1915

(EX'R'S BOOK) ~~207-3-8~~ 143-3½-7

DIV. ~~37~~ 16

PATENT No. 1297309

Name Harold D. Arnold, by mesne assignments

Assor. to Western Electric Company, Incorporated, ~~of New York, N.Y.~~

a corp. of ~~Illinois~~ New York

191— filed

of East Orange,

County of

State of New Jersey

Invention Manufacture of Vacuum Tube Devices

PARTS OF APPLICATION FILED.

	ORIGINAL	RENEWED
Petition	Nov. 18, 1915	, 191
Affidavit	" " 1915	, 191
Specification	" " 1915	, 191
Drawing	✓ ✓ 1915	, 191
Photo Copy	, 191	, 191
First Fee Cash	$15 Nov 18, 1915	, 191
" " Cert.	, 191	, 191
Appl. filed complete	Nov. 18, 1915	, 191
Examined and Passed for Issue	Dec. 13, 1918	, 191
	C. D. Cookins Ex. Div. 16	Ex. Div.
Notice of Allowance	Dec. 16, 1918	, 191
	By Commissioner	By Commissioner
Final Fee Cash	$20, Feb. 14, 1919	, 191
" " Cert.	, 191	, 191
Patented	MAR 18 1919	, 191

Division of App. No.

Attorney DeWitt C. Tanner and John G. Roberts,

~~165 West St., New York, N.Y.~~

920 Broadway

Associate Attorney

(No. of Claims Allowed 4), Title as Allowed Manufacture of Vacuum Tube Devices (0321)

(U. 250-27)

62.2 61 L

DIV [illegible]

NOV [illegible] 10

To the Commissioner of Patents:

Your petitioner HAROLD D. ARNOLD

citizen of the United States, residing at East Orange in the County of Essex and State of New Jersey, whose post-office address is 140 South Munn Avenue, East Orange, New Jersey, prays that Letters Patent may be granted to him for the improvement in MANUFACTURE OF VACUUM TUBE DEVICES, set forth in the annexed specification; and he hereby appoints DE WITT C. TANNER (Reg. No. 4325) and JOHN G. ROBERTS (Reg. No. 9084) of No. 463 West Street, New York, New York, severally, his attorneys, with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith; and requests that communications from the Patent Office in connection with this application be addressed to said JOHN G. ROBERTS.

Harold D. Arnold

Case 15

TO ALL WHOM IT MAY CONCERN:

Be it known that I, HAROLD DE FOREST ARNOLD, a citizen of the United States, residing at East Orange, in the County of Essex and State of New Jersey, have invented certain new and useful improvements in the MANUFACTURE OF VACUUM-TUBE DEVICES, of which the following is a full, clear, concise, and exact description.

This invention relates to the manufacture of vacuum tube devices, and more particularly it relates to a method of exhausting air and other gases and vapors from the glass bulbs or containers which enclose the electrode elements of thermionic repeaters, such as audions, and similar devices in which extremely high vacua are desired.

Its objects are an effectively complete elimination of the gases occluded by the walls of the containing vessel, and by the electrode elements and other metallic surfaces enclosed therein; a removal of such gases or any other gases from the containing vessel, and a resulting product characterized by stability and uniformity of operation.

To these ends this invention provides for the attachment of the vessel to be exhausted to any suitable vacuum pump and for the application of heat to the exterior of such vessel during the process of evacuation. It further provides for the heating of one or more of the enclosed electrodes by the passage of an electric current therethrough, and for the production in said vessel of an electron discharge which may be made to bombard and heat another electrode through the application of a suitable potential difference between the said electrode and the source of said discharge.

A more complete understanding of the method of this invention will be obtained by consideration of the attached drawing, which illustrates an apparatus arrangement suitable for producing the high vacua desired in thermionic devices of the audion type. It will, of course, be appreciated that the method herein disclosed is equally applicable to the production of high vacua in any device having an electrode or electrodes capable of producing an electron discharge.

In the drawing, a plurality of thermionic repeater elements 2, each having the customary filamentary cathode 3, grid 4 and anode 5, are enclosed in an oven 6 which may be electrically heated by a resistance element 7 connected to a suitable source of current 8. The glass containing-vessels 9 of the elements 2 have tubular extensions 10 connected to a main tube 11 leading to an exhaust apparatus 12, such, for example, as a Gaede molecular pump, connected to a source of motive power 13. The terminals of the electrode elements 3, 4 and 5 are brought out through suitable apertures 14 in one of the walls of the oven 6, so as to be readily available for test purposes and for the application of any desired electromotive force. A suitable number of windows 15 are provided in the front of the oven 6 so that the appearance of the tubes 2 being exhausted may be observed during the process. The filaments 3 are connected in series with a source of current 16 and a variable resistance 17. The process of exhausting the vessels 9 is as follows: The pump 12 is started and the temperature of the oven 6 is gradually raised until it has reached approximately 350° C. The purpose of this heating is to drive out the gases occluded by the walls of the vessel 9. After the temperature of the oven has risen to about 250° C., the filaments 3 are brought to incandescence by current supplied from the source 16, which current is raised to a value approximately 10% greater than the current normally to be used in the operation of the completed device. A potential difference is thereupon successively applied to the terminals of the electrodes 4 and 5 by means of a test clip 20 connected through the potentiometer 21 to a direct current source 22 of about 220 volts output. The filament 3 being

connected to the negative terminal of the source 22 as shown, and the test clip 20 being connected to the positive terminal of the source 22, there will result an electron discharge from the cathode 3 to the electrode 4 or 5, to which the test clip 20 is temporarily connected. This potential difference is made sufficiently high, through adjustment of the potentiometer 21, to cause an electron discharge of sufficient volume to heat the electrode 4, to which the test clip 20 is attached, even to incandescence, which heating is effective to drive out any gases which may be occluded by said electrode.

The electron discharge, which passes from the cathode 3 to either electrode 4 or 5 when a potential difference is established therebetween, partially ionises whatever gas may be in its path. When gas in sufficient quantity is thus ionised, there will result a blue glow in part or all of the vessel 9, which may readily be observed through one of the windows 15. The intensity of this blue glow depends upon the amount of gas present and upon the current and potential difference impressed between the cathode 3 and electrode 5. For a given current and potential difference therefore, this blue glow will gradually become fainter as the gas within the vessel becomes more attenuated, until the glow finally disappears.

A visible indication of the sufficiency of evacuation is therefore available, and, for example, in exhausting the bulbs of thermionic repeaters, such as are employed in telephone work, it has been found that a sufficiently high vacuum has been obtained if the blue glow no longer appears, when approximately 175 volts potential difference is impressed between the cathode 3 and the anode 5. When this point has been reached, the tubes are allowed to cool gradually and are sealed off of the pump 12 and given an aging run, which consists in applying the normal heating current to the filaments 3 and impressing the customary operating potential difference between the cathode 3 and anode 5. It has been found that after an aging run of from fifteen to twenty hours duration, for example, the repeaters have reached a stable condition and may be relied upon to give constant and uniform results.

In case the thermionic device to be exhausted is equipped with a grid 4 of very fine mesh, as in the case of a repeater designed for voltage amplification, it may be difficult to obtain a current to the electrode 5 sufficient to heat it properly. In such an event, it has been found desirable to apply an additional positive potential from a source 23, for example of perhaps 60 volts output, to the grid electrode 4 at the same time that the positive potential from source 22 is being applied to the anode 5. This increases the flow of electrons to the anode 5, and as some current will also flow between the filament 3 and grid 4, the voltages may be adjusted so as to heat both electrodes 4 and 5 at the same time.

With some tubes the early part of the process may be accelerated by applying to both the grid electrode 4 and the anode 5 the same large potential as that which later in the process is applied to the anode only.

WHAT IS CLAIMED IS:

Ins A

1. The method of producing a high vacuum in a thermionic discharge tube, which consists in establishing an electron discharge within said tube during the process of evacuation and causing said discharge to bombard an electrode element within said tube, thereby heating said electrode and driving out the gases occluded thereby.

Sub. C'

Insert B'

Per B

1ª ~~2.~~ The method of producing a high vacuum in a thermionic discharge tube containing a plurality of electrodes, which Ⓑ' ~~consists in~~ heating one of said electrodes to incandescence and simultaneously establishing an electron discharge between said electrode and a second electrode, whereby said second electrode is heated and its occluded gases are expelled.

Ins A

3. The method of producing a high vacuum in a thermionic discharge tube, which consists in applying heat to the exterior of said tube during the process of evacuation and in establishing an electron discharge within said tube and causing said discharge to bombard and heat an electrode within said tube and to drive out the gases occluded thereby.

Per C

Ins A

Insert C'

2. ~~4.~~ The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, ~~in heating one of said electrodes to incandescence~~ which consists, in establishing an electron discharge between ~~two of said electrodes whereby one of said electrodes is~~ C' heated during the process of evacuation, and in assisting the passage of said discharge by means of a potential differ- third electrode.

Ins A

3ª ~~5.~~ The method of producing a high vacuum in a thermionic discharge tube containing three electrodes ~~in heating one of said electrodes to incandescence~~ which consists in establishing an electron discharge between ~~one of~~ said electrodes and the other two electrodes during the process of evacuation, whereby said two electrodes are heated by bombardment and their occluded gases are driven off.

In Witness Whereof, I —— hereunto subscribe my —— name this fifteenth day of November A. D., 1915.

Harold D. Arnold

~~Witnesses:~~

State of — New York ——
COUNTY OF — New York —— } ss.

—— HAROLD D. ARNOLD —— the above named petitioner, being duly sworn, deposes and says that he is a —— citizen of the United States, and resident of —— East Orange —— in the County of —— Essex —— and State of —— New Jersey —— and that he —— verily believes himself —— to be the original, first, and sole —— inventor of the improvement in —— MANUFACTURE OF VACUUM TUBE DEVICES —— described and claimed in the annexed specification; that he —— does not know and does not believe that the same was ever known or used before his —— invention or discovery thereof; or patented or described in any printed publication in the United States of America or any foreign country before his —— invention or discovery thereof; or more than two years prior to this application; or in public use or on sale in the United States for more than two years prior to this application and that no application for foreign patent has been filed by him —— or his —— legal representatives or assigns in any foreign country.

Harold D. Arnold

Sworn to and subscribed before me this 15th day of November 1915 }

Notary Public.

NOTARY PUBLIC,
NEW YORK COUNTY No. 287,
NEW YORK REGISTER No. 7245.

69

Div. 37 Room 107
Address only
"The Commissioner of Patents,
Washington, D. C."
and not any official by name.

D-200

Paper No. 2. 26

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.
W.G.---M.Y.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON Apr. 25, 1916.

U. S. PATENT OFFICE
APR 25 1916
MAILED

John G. Roberts,
463 West St.,
New York City.

Please find below a communication from the EXAMINER in charge of the application of

H. D. Arnold; Manufacture of Vacuum Tube Devices, Nov. 18, 1915; #62,259.

Thomas Ewing
Commissioner of Patents.

The claims are rejected on British patent #15,788 of 1914, accepted Oct. 1, 1915 (three sheets of drawing); also on

Snook, 1,166,792; Jan. 4, 1916; filed Oct. 8, 1912; Class 176-2.

W. S. Ruckman
Examiner.

See Law Ex.
re affidavits

Cl. 1

70

3a

UNITED STATES PATENT OFFICE
Division 37, Room 107

In re application of
HAROLD DeF. ARNOLD,
Serial No. 62,259
Filed Nov. 19, 1915

Manufacture of Vacuum Tube Devices.

COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:-

This amendment is in response to the Office action of April 25, 1916. Please amend the application as follows:

✓ Cancel claims 1 and 3 and renumber the remaining claims as 1, 2 and 3:

✓ In present claim 2, line 3, after "consists" insert --in heating one of said electrodes to incandescence,--; cancel line 4, and substitute the following: --said heated electrode and a second one of said electrodes whereby said second electrode is--.

c

✓ Present claim 3, line 3, after "consists" insert --in heating one of said electrodes to incandescence,--; line 4, cancel "one of said electrodes" and insert --said electrode--.

REMARKS

Rejection of present claim 1 upon the patent to Snook is thought to be an error, for Snook does not use an electrode which can be heated to incandescence in the manner explained in this application. Snook shows two cold electrodes k and a, one of which may be heated by bombardment to a certain degree, but certainly not to such a temperature as is understood by the term "incandescence". Applicant has in mind and clearly explains in his application that one electrode is to be heated to incandescence by an electric current and as a result of this high heating will give off its occluded gas and at the same time will constitute a source of electrons which may then be driven to a second electrode to heat and bombard this second electrode in such a manner as to drive off its occluded gas. No such process is intimated or is even possible in Snook's arrangement.

It is thought that present claim 2 is allowable in the form in which it was submitted, but in order to more fully distinguish from the patent to Snook, the claim has been limited by including the step of heating one of the electrodes to incandescence. It is to be emphasized that this claim sets forth a process particularly adapted for use in a vacuum discharge tube where one electrode may act as a serious barrier to the establishment of a fairly large electron stream to a third electrode. The claim points out that the step for overcoming the difficulty consists in applying a potential difference between the source of discharge, which is now defined as the incandescent electrode and thereby establishing an electron stream or discharge between said incandescent electrode and the impeding electrode. With this explanation as to this claim 2, it is thought that the calim will be found allowable.

Claim 3 has been amended to distinguish from Snook by inserting the step of heating one of the electrodes to incandescence, and as pointed out in connection with claim 1, this electrode is then caused to give up its occluded gas and at the same time to become an electron source, making it possible to establibh an electron discharge between said electrode and the other two electrodes.

(Serial No. 62,259)

An affidavit executed by Harold D. Arnold is attached hereto overcoming the British patent 15,788 of 1914 as a reference so far as these claims are concerned. An affidavit executed by Russell F. Trimble is also attached, verifying the statements made by Arnold in his affidavit.

Allowance of the application, as now amended, is respectfully requested.

Respectfully,

HAROLD DeFOREST ARNOLD,

By J G Roberts
Attorney

463 West Street,
New York, April 23, 1917.

PIW:JT

MAIL ROOM
APR
24

UNITED STATES PATENT OFFICE

In re application of
Harold D. Arnold,
Serial No. 62,259,
Filed November 18, 1915

Manufacture of Vacuum
Tube Devices

AFFIDAVIT

County of New York,
State of New York. ss.

HAROLD D. ARNOLD being duly sworn, deposes and says:

That he is of legal age and a citizen of the United States; that he is the applicant named in the application, above identified; that he made the invention set forth in the claims in said application prior to October 1, 1915; and that the invention had been used extensively by himself and those assisting him in the laboratories of the Western Electric Company, Incorporated, prior to said date of October 1, 1915; that he does not know and does not believe that the invention has been in public use in this country for more than two years prior to his application, and that the said invention has never been abandoned.

Harold D. Arnold

Subscribed and sworn to before me this 23rd day of April, 1917.

Notary Public

PIW:JO

UNITED STATES PATENT OFFICE

In re application of)
Harold D. Arnold)
Serial No. 62,259) Manufacture of Vacuum Tube Devices
Filed November 18, 1915)

AFFIDAVIT

State of New York)
) ss.
County of New York)

RUSSELL FAY TRIMBLE, being duly sworn, deposes and says:

That he is of legal age and a citizen of the United States; that he has been in the employ of the Western Electric Company, Incorporated, since and prior to January 1913; that since said date of January 1913, he has been in charge of a large part of the work relating to the evacuation of vacuum tube devices; that prior to October 1, 1915 it was a usual and common expedient in the laboratories of the Western Electric Company, when evacuating such devices, to have one electrode (in the form of a filament) heated to incandescence and to have a second electrode connected to said first electrode by means of a source of potential, the second electrode being connected to the positive terminal of the source, whereby an electron discharge was caused to flow from said filament to said second electrode. The purpose of this was to bombard and heat the second electrode in such a manner and to such an extent as to cause it to give off occluded gases. This method of evacuating vacuum tubes was followed by myself and my assistants, and was done at the suggestion and under the instructions of Harold D Arnold, under whose direction I was working.

W Gay Fritts

Subscribed and sworn to before me this 23rd day of April, 1917.

Notary Public

PIW-FJ
JT

APPROVED.
Under Order 3335.

P A Hostetler
Law Examiner.
May 28-1917

76

Div. 16 Room 109

Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

2-900
F.H.

Paper No. 4

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON June 6, 1917.

Mr. John G. Roberts,
465 West Street,
New York, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

H. D. Arnold, S. No. 62,259, filed Nov. 18, 1915,

Manufacture of Vacuum Tube Devices.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Apr. 24, 1917.

Claim 1 is rejected as not setting forth a method for producing a vacuum as the operation set out is insufficient to produce a vacuum. Further, the operation set out is a step described in the evacuating process described in patent No. 1,166,792, Enock, of record. See page 4, lines 31 to 60 of the reference. This claim is accordingly rejected on patent No. 1,166,792, cited.

Claims 2 and 3 appear to be allowable.

Wm. A. Kinnan
Examiner, Division XVI.

RWL

77

Case 15

5

B

UNITED STATES PATENT OFFICE.

Division 16 Room 102

In re application of

Harold DeForest Arnold

Serial No. 62,259

Filed November 18, 1915

Subject.

Manufacture of Vacuum Tube Devices

THE COMMISSIONER OF PATENTS,
Washington, D. C.

B

Sir:

In reply to the Office action of June 8, 1917, please amend as follows:

✓ Claim 1, line 3, cancel "consists in" and substitute --comprises performing the following steps during the process of evacuation, i. e.--; line 4, after "and" insert --simultaneously--.

B¹ Per C ✓

Add the following claims:

B² Per C

--4. The method of producing a high vacuum in a thermionic discharge tube having a filamentary cathode which consists, during the process of evacuation, in passing an electric current through said cathode to heat the same independently of electron bombardment and in heating another electrode in said tube by a space current between said cathode and said electrode.

5. The method of producing a high vacuum in a thermionic discharge tube having a cathode and an auxiliary electrode which consists, during the process of evacuation, in passing an

(Serial No. 62,259)

~~electric current through said cathode to heat the same independently of electron bombardment and in heating said auxiliary electrode by bombardment from said cathode.--~~

REMARKS

Claim 1 has been amended to define a method for producing a vacuum and this has been done in terms which differentiate from the references of record by specifying that one of the electrodes is heated to incandescence and that simultaneously an electron discharge is established between said electrode and a second electrode.

It is thought that claims 4 and 5 should be allowed as the patent to Snook does not disclose a cathode which is heated independently of bombardment by an electric current passing therethrough. In applicant's case two or more electrodes may be kept hot, while the tube is pumped out, one being heated by bombardment and the other being heated independently of bombardment. This individual control of the heating of the electrodes appears novel with applicant and it is submitted that the claims 4 and 5 should be allowed.

Reconsideration and allowance are therefore respectfully requested.

Respectfully,

HAROLD DeFOREST ARNOLD,

By J.G. Roberts
Attorney

463 West Street,
New York, March 1st 1918

Div. 16 Room 112 ABS. [illegible]

Address only "The Commissioner of Patents, Washington, D. C.," and not any official by name.

Paper No. 6

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON June 18, 1918.

John G. Roberts, Esq.,
463 West St.,
New York, N.Y.

Please find below a communication from the EXAMINER in charge of the application of

Harold D. Arnold, Ser. No. 62,259, filed Nov. 18, 1915,
Manufacture of Vacuum Tube Devices.

James T. Newton
Commissioner of Patents.

6-231

This action is in response to amendment filed Mar. 15, 1918.

Claims 1, 4 and 5 are rejected on any one of the following references;-

COOLIDGE,	1,203,495,	Oct. 31, 1916,	(250-36);
"	1,211,091,	Jan. 2, 1917,	"
"	1,211,092,	Jan. 2, 1917,	"

Attention is called especially to: page 2, lines 81 to 86, of patent 1,203,495; to page 2, lines 26 to 50, of patent 1,211,091, and to page 2, lines 6 to 15, of patent 1,211,092, all cited above.

Claims 2 and 3 appear allowable.

If, by the date of applicant's next action, this application will have been pending three years or more, it will come within the Commissioner's order respecting delayed applications, and the amendment cannot be entered without the special approval mentioned therein. For these reasons, applicant is urged to place the application in condition for final action.

JSF

Examiner, Division 16.

Case 15

UNITED STATES PATENT OFFICE

In re application of
HAROLD D. ARNOLD
Serial No. 62,259
Filed Nov. 18, 1915

Subject: Manufacture of Vacuum Tube Devices

16

THE COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

Please note that the address of DeWitt C. Tanner and myself, as attorneys of record in the above application, will be, until further notice, 920 Broadway, New York, N. Y.

Respectfully,

J. G. ROBERTS

Date: September 9, 1918.
920 Broadway, New York, N. Y.

Case 18 81

8 C

UNITED STATES PATENT OFFICE.

Division 16 Room 112

In re application of

Harold DeForest Arnold

C

Serial No. 62,259

Filed November 18, 1915

Subject

Manufacture of Vacuum Tube Devices

THE COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

In reply to the Office action of June 18, 1918, please amend the above entitled application by cancelling all the claims and substituting therefor the following:-

41. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes and establishing an electron discharge between said heated electrode and a second one of said electrodes, whereby said second electrode is heated during the process of evacuation, and in assisting the passage of said discharge by means of a potential difference applied between the source of said discharge and the third electrode.

// C'

2. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes to cause it to emit

(Serial No. 62,259)

electrons, in establishing an electron discharge between said heated electrode and the other two electrodes during the process of evacuation, whereby said two electrodes are heated by bombardment and their occluded gases are driven off.

3. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energising said cathode to cause it to emit electrons, in establishing an electron discharge between said cathode and said other electrodes during the evacuation, and in maintaining said grid at a potential different from that of said cathode during said discharge.

4. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energising said cathode to cause it to emit electrons, and in maintaining said grid and anode at a positive potential with respect to that of said cathode during evacuation.

REMARKS

By reason of the amendments to allowed claims 2 and 3, these have been rewritten, and in their present form, as claims 1 and 2, differ but slightly from the form in which they were allowed. The principal difference is that the limitation as to heating one of the electrodes to incandescence has been

(Serial No. 62,259)

broadened to state that the electrode is heated, without regard as to whether this is to the point of incandescence or not. It is thought that these claims will still be allowable.

Claims 3 and 4, added by this amendment, are specific to the type of tubes which is to be evacuated, and to the potentials which are applied between the electrodes during evacuation.

Claim 4 is more specific than any of the others in that it recites that the grid is maintained at a potential which is positive with respect to the cathode during the evacuation.

This case is now believed to be in condition for allowance.

Respectfully,

HAROLD DeFOREST ARNOLD,

By WGRoberts
Attorney

920 Broadway,
New York, November 17. 1918.

WEB:T

84

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D.C.

LBG 2—181 **Serial No.** 62259

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Dec. 16, 1918

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

Harold D. Arnol[illegible] Assor. by mesne assigts. to Western Electric Company, Incorporated, a corporation of New York

Sir: Your APPLICATION for a patent for an IMPROVEMENT in

Manufacture of Vacuum Tube Devices

filed Nov. 18, 1915 , has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

James T. Newton
Commissioner of Patents.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

Mr. John G. Roberts,
#920 Broadway,
New York, N. Y.

Case 15

20

ck j

UNITED STATES PATENT OFFICE.

In re application of

Harold D. Arnold

Serial No. 62,259

Filed November 18, 1915

Allowed December 16, 1918

Subject: Vacuum Tube Devices

THE COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

The enclosed check for $20.00 is in payment of the final Government fee on the above named application.

Respectfully,

J. G. ROBERTS,

Attorney for Applicant.

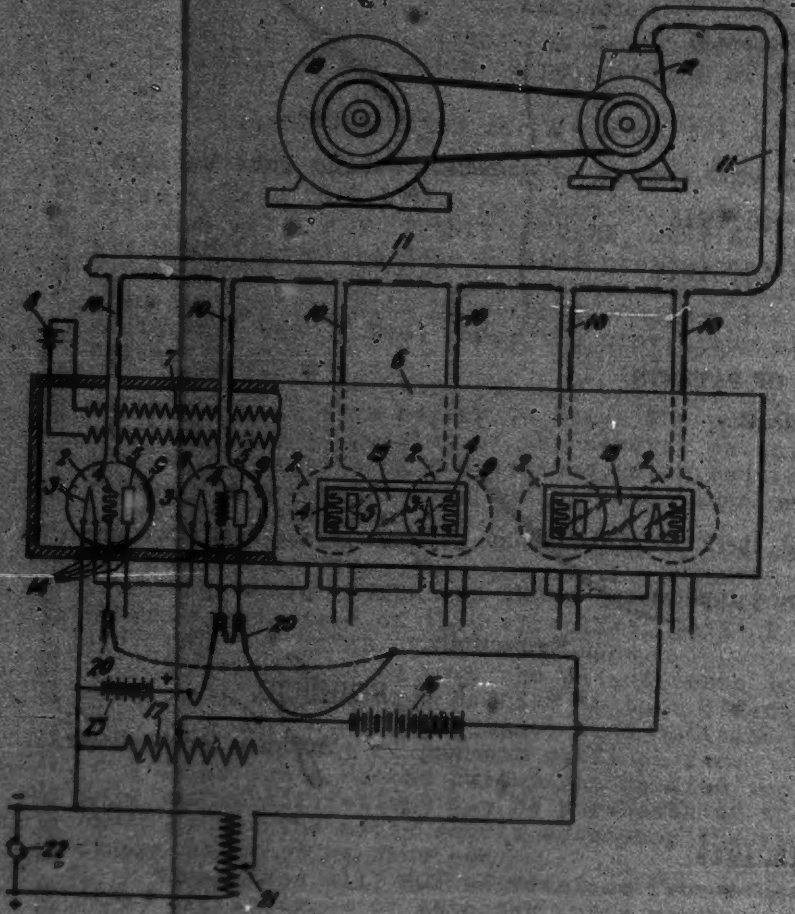
Date: February 13, 1919
920 Broadway,
~~463 West Street,~~
New York, N. Y.

Form No. [illegible]
LETTER TRANSMITTING
FINAL FEE

88

H. D. ARNOLD.
MANUFACTURE OF VACUUM TUBE DEVICES.
APPLICATION FILED [illegible]

1,297,809. Patented Mar. 18, 1919.


13
12
11
11
8
10
10
10
10
10
10
7
6
2
3
4
5
9
14
20
20
+
21
17
16
-
22
24

Inventor:
Harold D. Arnold
by A. C. Kennet. Att'y.

full pat ordered

UNITED STATES PATENT OFFICE.

HAROLD D. ARNOLD, OF EAST ORANGE, NEW JERSEY, ASSIGNOR, BY MESNE ASSIGNMENTS, TO WESTERN ELECTRIC COMPANY, INCORPORATED, A CORPORATION OF NEW YORK.

MANUFACTURE OF VACUUM-TUBE DEVICES.

1,297,309. Specification of Letters Patent. **Patented Mar. 18, 1919.**

Application filed November 18, 1915. Serial No. [illegible].

To all whom it may concern:

Be it known that I, Harold De Forest Arnold, a citizen of the United States, residing at East Orange, in the county of Essex and State of New Jersey, have invented certain new and useful Improvements in the Manufacture of Vacuum-Tube Devices, of which the following is a full, clear, concise, and exact description.

This invention relates to the manufacture of vacuum tube devices, and more particularly it relates to a method of exhausting air and other gases and vapors from the glass bulbs or containers which inclose the electrode elements of thermionic repeaters, such as audions, and similar devices in which extremely high vacua are desired.

Its objects are an effectively complete elimination of the gases occluded by the walls of the containing vessel, and by the electrode elements and other metallic surfaces inclosed therein, a removal of such gases or any other gases from the containing vessel, and a resulting product characterized by stability and uniformity of operation.

To these ends this invention provides for the attachment of the vessel to be exhausted to any suitable vacuum pump and for the application of heat to the exterior of such vessel during the process of evacuation. It further provides for the heating of one or more of the inclosed electrodes by the passage of an electric current therethrough, and for the production in said vessel of an electron discharge which may be made to bombard and heat another electrode through the application of a suitable potential difference between the said electrode and the source of said discharge.

A more complete understanding of the method of this invention will be obtained by consideration of the attached drawing, which illustrates an apparatus arrangement suitable for producing the high vacua desired in thermionic devices of the audion type. It will, of course, be appreciated that the method herein disclosed is equally applicable to the production of high vacua in any device having an electrode or electrodes capable of producing an electron discharge.

In the drawing, a plurality of thermionic repeater elements 2, each having the customary filamentary cathode 3, grid 4 and anode 5, are inclosed in an oven 6 which may be electrically heated by a resistance element 7 connected to a suitable source of current 8. The glass containing-vessels 9 of the elements 2 have tubular extensions 10 connected to a main tube 11 leading to an exhaust apparatus 12, such, for example, as a Gaede molecular pump, connected to a source of motive power 13. The terminals of the electrode elements 3, 4 and 5 are brought out through suitable apertures 14 in one of the walls of the oven 6, so as to be readily available for test purposes and for the application of any desired electromotive force. A suitable number of windows 15 are provided in the front of the oven 6 so that the appearance of the tubes 2 being exhausted may be observed during the process. The filaments 3 are connected in series with a source of current 16 and a variable resistance 17. The process of exhausting the vessels 9 is as follows: The pump 12 is started and the temperature of the oven 6 is gradually raised until it has reached approximately 350° C. The purpose of this heating is to drive out the gases occluded by the walls of the vessel 9. After the temperature of the oven has risen to about 250° C., the filaments 3 are brought to incandescence by current supplied from the source 16, which current is raised to a value approximately 10% greater than the current normally to be used in the operation of the completed device. A potential difference is thereupon successively applied to the terminals of the electrodes 4 and 5 by means of a test clip 20 connected through the potentiometer 21 to a direct current source 22 of about 220 volts output. The filament 3 being connected to the negative terminal of the source 22 as shown, and the test clip 20 being connected to the positive terminal of the source 22, there will result an electron discharge from the cathode 3 to the electrode 4 or 5, to which the test clip 20 is temporarily connected. This potential difference is made sufficiently high, through adjustment of the potentiometer 21, to cause an electron discharge of sufficient volume to heat the electrode, to which the test clip 20 is attached, even to incandescence, which heating is effective to drive out any gases which may be occluded by said electrode.

The electron discharge, which passes from the cathode 3 to either electrode 4 or 5 when a potential difference is established there-between, partially ionizes whatever gas may be in its path. When gas in sufficient quantity is thus ionized, there will result a blue glow in part or all of the vessel 9, which may readily be observed through one of the windows 15. The intensity of this blue glow depends upon the amount of gas present and upon the current and potential difference impressed between the cathode 3 and electrode 5. For a given current and potential difference therefore, this blue glow will gradually become fainter as the gas within the vessel becomes more attenuated, until the glow finally disappears.

A visible indication of the sufficiency of evacuation is therefore available, and, for example in exhausting the bulbs of thermionic repeaters, such as are employed in telephone work, it has been found that a sufficiently high vacuum has been obtained if the blue glow no longer appears, when approximately 175 volts potential difference is impressed between the cathode 3 and the anode 5. When this point has been reached, the tubes are allowed to cool gradually and are sealed off of the pump 12 and given an aging run, which consists in applying the normal heating current to the filaments 3 and impressing the customary operating potential difference between the cathode 3 and anode 5. It has been found that after an aging run of from fifteen to twenty hours duration, for example, the repeaters have reached a stable condition and may be relied upon to give constant and uniform results.

In case the thermionic device to be exhausted is equipped with a grid 4 of very fine mesh, as in the case of a repeater designed for voltage amplification, it may be difficult to obtain a current to the electrode 5 sufficient to heat it properly. In such an event, it has been found desirable to apply an additional positive potential from a source 28, for example of perhaps 60 volts output, to the grid electrode 4 at the same time that the positive potential from source 22 is being applied to the anode 5. This increases the flow of electrons to the anode 5, and as some current will also flow between the filament 3 and grid 4, the voltages may be adjusted so as to heat both electrodes 4 and 5 at the same time.

With some tubes the early part of the process may be accelerated by applying to both the grid electrode 4 and the anode 5 the same large potential as that which later in the process is applied to the anode only.

What is claimed is:

1. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes and establishing an electron discharge between said heated electrode and a second one of said electrodes, whereby said second electrode is heated during the process of evacuation, and in assisting the passage of said discharge by means of a potential difference applied between the source of said discharge and the third electrode.

2. The method of producing a high vacuum in a thermionic discharge tube containing three electrodes, which comprises heating one of said electrodes to cause it to emit electrons, in establishing an electron discharge between said heated electrode and the other two electrodes during the process of evacuation, whereby said two electrodes are heated by bombardment and their occluded gases are driven off.

3. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energizing said cathode to cause it to emit electrons, in establishing an electron discharge between said cathode and said other electrodes during the evacuation, and in maintaining said grid at a potential different from that of said cathode during said discharge.

4. The method of evacuating a vacuum tube having cathode, anode and grid electrodes, which comprises energizing said cathode to cause it to emit electrons, and in maintaining said grid and anode at a positive potential with respect to that of said cathode during evacuation.

In witness whereof, I hereunto subscribe my name this fifteenth day of November, A. D. 1915.

HAROLD D. ARNOLD.

1915

CONTENTS:

1. *Application* 1 *papers.*
2. Rejection APR 5 1916
3. Amendment A Affid APR 24 1917
4. Rejection June 5, 1917
5. Amendt. B Mar. 15-1918
6. Rejection- June 18- 1918
7. Chang of Address Sep 12-1918
8. Amendt. C Nov. 25-1918
9.
10.
11.
12.
13.
14.
15.
16.
17.
18.
19.
20.
21.
22.
23.
24.
25.
26.
27.
28.
29.
30.
31.
32.
33.
34.
35.
36.
37.
38.
39.
40.
41.
42.
43.
44.
45.
46.
47.
48.
49.
50.

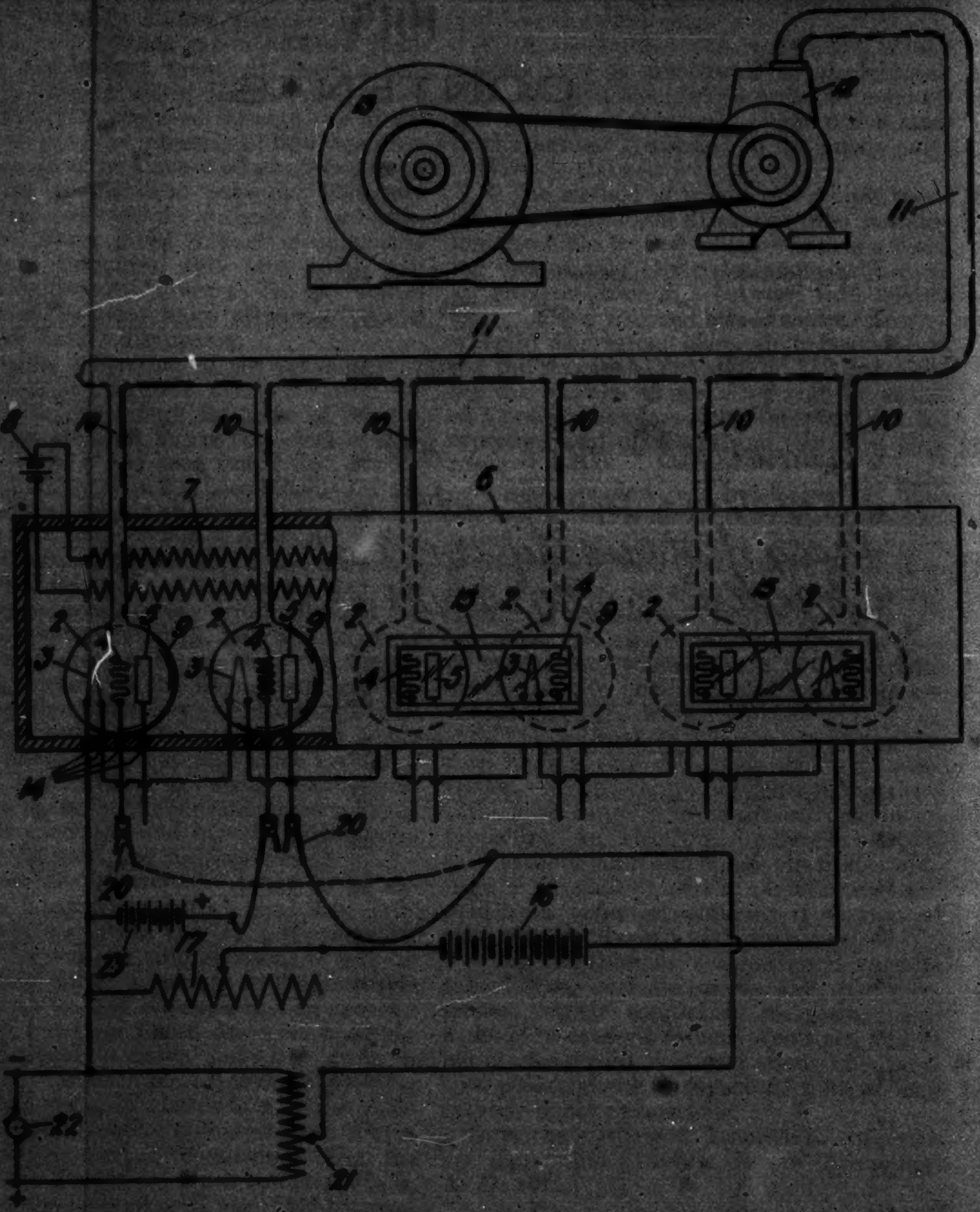
90

H. D. ARNOLD.

MANUFACTURE OF VACUUM TUBE DEVICES.

APPLICATION FILED NOV. 13, 1915.

1,297,309. Patented Mar. 18, 1919.


13
12
11
11
10
10
10
10
10
10
8
7
6
2
3
5
9
2
4
3
5
9
2
15
2
4
9
2
15
2
14
20
20
23
17
16
22
21

Inventor:
Harold D. Arnold
by Att'y.

= Mar. 12, 1918

PLAINTIFF'S EXHIBIT No. 171.

White Note Book No. 452.

Mon. Feb. 10 '13

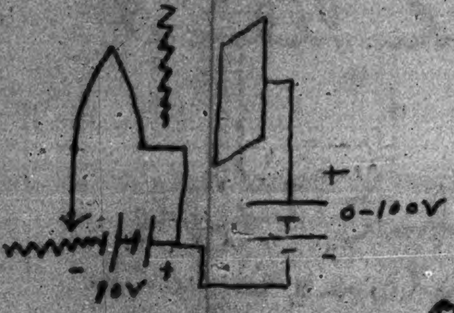
Cleaned up a quantity of mercury for Dr. Story. Air blown thru it for a number of hours.

Have decided that trouble with vacuum system is with gage column so will take it down and have a new pipe section put in and give whole a good cleaning

Spent afternoon in conversation with Dr Langmuir in regard to some experiments I am to try with the De Forest audion.

Thurs. Feb. 13 '13

assembled apparatus and made some tests on the De Forest Audion.



Mc Kay and Orange calibrated the audion filament. current temp. relation given on C.S.W. 20.

Fri Feb 14 13
to
Tues Feb 25 '13

away from lab on account illness.

Small rotary converter for vacuum gage has been fitted with steel rings and metite brushes.
It runs much smoother and should last a long while.

Thurs Mar 13 to Sat Mar 15
Completed vacuum system and exhausted an all tungsten audion.
Treatment given on R.S.W.77

Filament color matched by Orange and Mackay:
at 1.025 amps and 4.05V Temp was 2452°C Then from curves of ideal filament current-temperature curve drawn as on C.S.W.25.

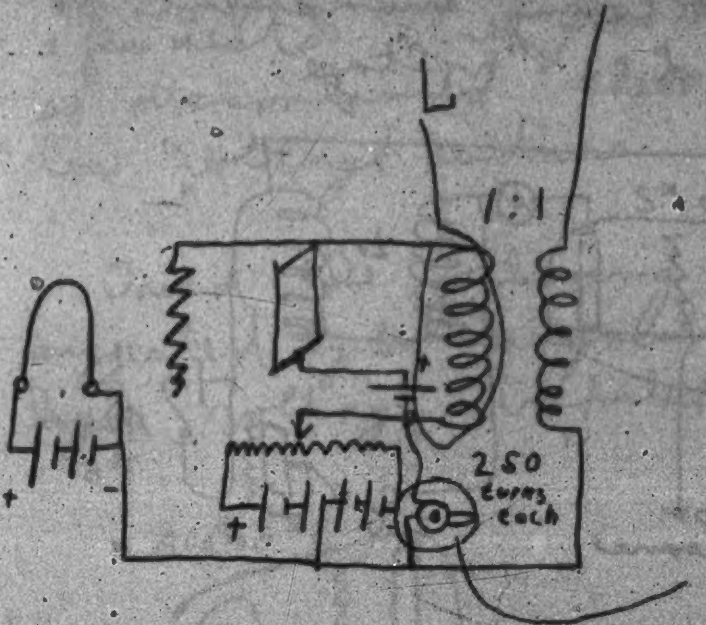
lines at very low plate voltages and high + grid voltages the curves are distorted due to fact that grid current is large in comparison with plate current

In both these sets of tests filament kept at 1.05 amps 2480°C which is above saturation on all voltage up to about 200.

From data of these two tests drew curves showing relation between grid E.M.F. and plate E.M.F. these are straight lines as long as plate current is large in comparison to grid current. These curves drawn for different currents.

In commencing tests for the day it was necessary to run filaments for quite a time to get results consistent with previous day's results. at first results were 5 to 10% high.

Tried to use # 2 as a wireless receiver using a buzzer for sender. Could get no results.

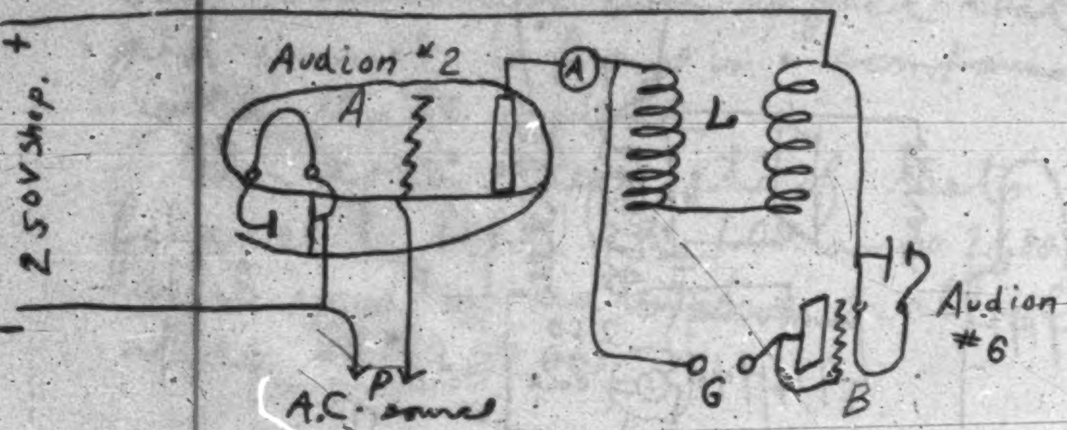


When filament is at about 1 amp a low pitch sort of rattling is heard as filament temperature is raised this raises in pitch till at about 1.3 amps it is a sort of squeal. Magnetic lines of force have the same pitch raising effect when ~~[illegible]~~ parallel to filament.

There is also ~~a~~ decided microphone effect.

Dr Langmuir suggested a D.C. transformer.

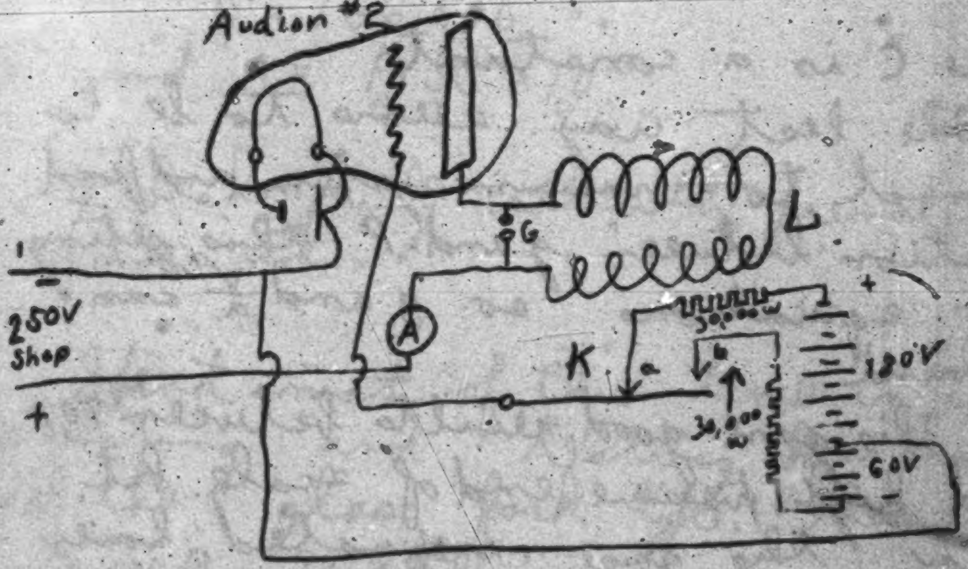
8/9/13 Used the following arrangement to step up d.c. voltage.



L is an inductance consisting of the primaries of two 200 watt 6600/100 V pot. transformers connected in series. Various A.C. sources were tried 40 ~ shop at 25 V and a special 100 ~ alternator at about 30 V

The idea being to charge up the inductance while the grid of #2 is + the E.C. doing this then in next part of cycle when grid is − the E.C. is suddenly shut off, thus allowing the coil L to discharge across gaps G Audion #6 being used as a rectifier. The higher voltage thus obtained would just about jump the smallest gap we could arrange so potential was probably about 350-400 Volt. after a few tests blue glow began to appear so discontinued these tests on these low voltage audions.

Tried the following arrangement suggested by Dr Langmuir to get single high voltage impulses


Audion #2
K
G
L
−
250V
Shop
+
A
+
30,000 ω
K
a
b
30,000 ω
180V
60V
−

The key K being used to change the sign of the grid potential very suddenly Sparks of 0.3 mm could be produced from the 250V shop.
About 25 mil-amps was passed thru L when grid was +
The high resistances were used

Calibrated another gage of the Moore type for Mr Perkins. Tried it by volume and diam. measurement but unsatisfactory

We know that relation should approximately be

$$C + g = \frac{pV}{ag} \quad \text{see pg 40}$$

where C is a constant

The best way seems to be to connect to a vacuum system and find relation between g and P, thus getting two equations so g and $\frac{V}{a}$ can be found

This gave good results between 70μ and high pressure end of scale but below this gage indicated lower pressure than equation ~~good~~ gave.

Wired up a 10K.V.A. 40,000V transformer with regulator (induction) and resistance in secondary, to be used on high voltage audion relays ect.

April 28 to May 10

Made some tests on audion #2 to get total currents obtained from filament. See RSW79.

Tried to find Q and A for this filament

It is a 2.7 mil, 14.05 mm long area
∴ = 3.03 mm^2

Q = 166,500

and A = 19.55×10^{15}

Q checks fairly well with previous results A does not.

Spent most of this time in constructing and testing four audions of the glass fork type. These are Nos 6, 7, 8, 9.

Construction data given on pgs 48, 54, 55.

Principle construction troubles were:

Winding of first grid, this overcome by practice and more careful handling of wire. Breaking of fork due

L = .0000592 henrys

For this coil the field at any point along the axis as relative to the field in plane of coil is given on C.S.W. 45 Here inverted values of relative field strength are plotted against distance along axis from plane of coil. For instance at 100 cm along axis field is only $\frac{1}{133}$ of its value at center of coil

Then tested out Mr. Alexanderson theory of geometrical tuning using two audions in series. The results of this test are described in a report. Particulars given on RSW 100-103

Evidently this feature is little effected by geometrical construction

Dr. Langmuir thinks this is due to fact that electrons leave filament at different velocities according to Maxwells distribution law so that a certain E.M.F. range is necessary to cover this range of velocities

Tried slipping audion #2 into a solenoid, capable of giving quite a powerful field.

Under certain conditions noted RSW98 the grid Eg vs E.C. curve took on form shown on CSW50. Having a sharp discontinuity, in all cases the magnetic lines parallel to the filament caused decrease in E.C. and if field was strong enough entire stoppage of it

This flat portion may be of great value as the sensitiveness must be extremely great, which was tested out as follows.

Mon. May 26 '13

Worked on report of high frequency geometrical tuning with audions.

Tues May 27 '13

Tested out all other available audions inside of a solenoid but #2 was the only one which gave the discontinuity effect. Suspect the effect is due to positive ionization because

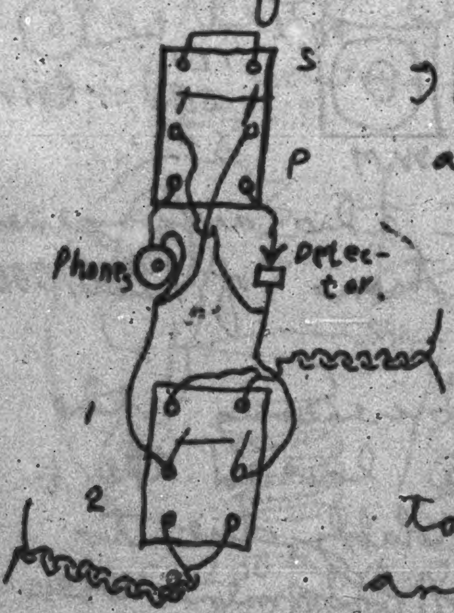
1st After operating a while there is a lag between grid E.M.F critical values depending on whether it is being raised or lowered past the point

2nd For no apparent reason the effect will sometimes mysteriously disappear and later just as mysteriously appear again.

3rd This audion #2 is the only one which shows effect and is the only one we have which has shown blue

Mr Brooks is starting a wireless receiving station in Bldg 4 and I have given him one of our audions to use. (#8) So far he has not used it to receive messages although it responds to the buzzer as well as a galena detector he is using.

Rogers has rigged up a silicon detector in connected with a couple of D.P. D.T. switches



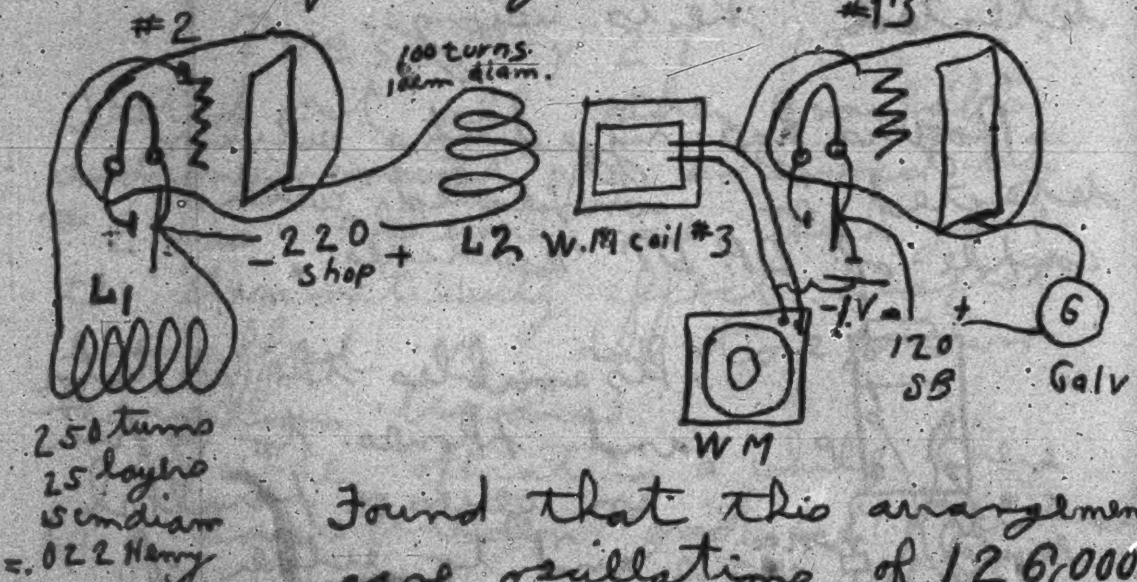
This enables the detector and phones to be put in series or parallel and to either of two circuits.

The detector seems to work fairly consistently

With this arrangement tested ~~out~~ audion # 2 as a multiplier of oscillations.

Dushman has found that when an inductance is placed in grid circuit oscillations are set up which are amplified in the plate circuit, tried to detect these oscillations on one of our small audions #2.

Used following connections


#2
100 turns. 10cm diam.
-220 shop +
L2
W.M coil #3
#13
L1
-1V+
120 SB
+
G
Galv
WM
250 turns
25 layers
15cm diam
=.022 Henry

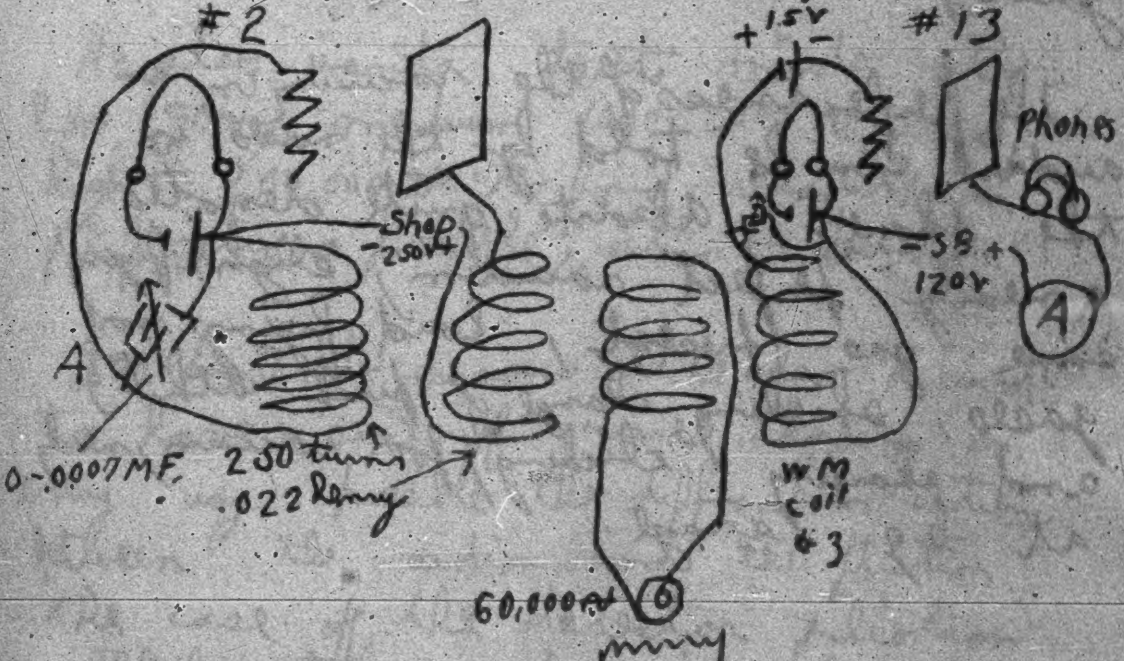
Found that this arrangement gave oscillations of 126,000 cycles per second.

Also found that increasing the filament temperature lowered the frequency. This is probably due to change in position of filament when heated causing change in capacity of audion

Increase of plate voltage

second and will neutralize the result being zero only 1000th of a second so that the effect in the phones will that of a 1000 cycle current which is easily heard. This arrangement should improve the sensitiveness of the detector for here the whole variation is made use of and not just the assymetry.

For tests the following arrangement was used on the first trial


#2
Shop
-250v+
A
0-.0007MF.
250 turns
.022 henry
60,000~
G
+1.5v-
#13
Phones
3
-SB+
120v
A
WM
coil
#3

easily according to A.B.C. Allies:

Add a solution of Sodium Hypophosphite to one of copper sulphate in the cold add HCl, filter and wash precip. then wash precip in grain alcohol, result is CuH.

The same difficulty however will be experienced in freeing from contained gases,

The perfectness of the vacuum in an audion can be told by the noises in the phone. Absolute quite denotes a nearly perfect vacuum, slight frying some gas present, loud frying more gases, shrieking change of pitch with Eg and chopping clicking, poor vacuum, nearly at b-g. stage.

Dec 22 to Dec 29 1913

Had a talk with Dr Langmuir he wants some pieces of apparatus made up to demonstrate pliotrons
1st a detector outfit
2nd an amplifier "
3rd a telephone relay.

Several amplifiers should be made up so that tuning in geometrical progression may be illustrated.

He also wants tests made with low (60v) medium 1000-2000 v and high 200,000 v to find relations amplifications possible, without tuning.

For patent reasons it is also desired to have a series of curves showing in every way possible the difference in action between the audion and the pliotron the case of the detector pliotron will be taken up separately.

PLAINTIFF'S EXHIBIT No. 172.

White Test Records.
(Card and 6 Sheets.)

#2 OK 4/10/13

Glass fork type
2.7 mil fil 14.05 cm
1.5 mil hand wound grid
5 mil zigzag plate.
2 m from grid
70 mil. grid fork.
Grid lead thru stem

Audion #2

2.7 mil W. filament Do not run above 1.2 Amps.

°C Abs.	Amps
2000	.71
2100	.775
2200	.845
2300	.917
2400	.99
2480	1.05
2600	1.14

filament takes about 4 V at 2450°

Plate and grid insulation good to 250 V.

Conditions become constant after running fil 5 min at 2500°C.

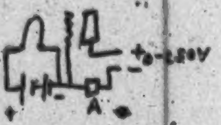
Tungsten Wire Audion. R.S.W. 77

Date	Time	Press μ	Temp	
3/13/13	4.00	Started cold exhaust		
	5.15	.2	Room	
3/14/13	8.00	1.7	Room	Started oven
	8.30	6.5	330	
	8.40	8.0	350	
	9.05	9.	350	turned on pump.

Left pumping and at 350° till 11.15
got down to .2μ plate hot.

12.00	.10	room
1.30	.10	"

Flashed plate filament well
and filament one sealed off at .05μ



Audion #2

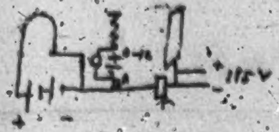
RSW78

K-.0158

Date	Lamp amps	°C ab	Plate volts	Edison Meter	I Milamps
3/17/13	.67	1942	30	.05	.00079
	.78	2105		2.45	.0387
	.82	2163		7.5	.1184
	.96	2358		13.6	.215
	.72	2017		.2	.00316
	.75	2061		1.1	.0174
	.81	2148		4.7	.0742
	.88	1956	70	.05	.00079
	.73	2036		.65	.0103
	.76	2076		2.1	.0332
	.78	2105		4.8	.0758
	.8	2135		9.0	.142
	.81	2148		11.2	.177
	.82	2163		12.6	.199
	.83	2178		16.4	.259
	.92	2304	30	10.6	.1674
	1.015	2433	"	16.4	.259
Iron grid	<1.25	<2725	30	0	0
"	.72	2116	70	.1	.00158
"	.85	2206	70	.55	.00869
"	1.0	2412	"	1.1	.0174
"	1.1	2545	"	1.6	.0253

115 V grid to - fil.

Amp. Lamp	°C Abs	Plate volts	Edison meter	I milamps	K=1.07
.8	2135	115	.28	.3	
.9	2275	to 120	3.	3.21	
1.	2412		13.5	14.45	
.95	2345		6.5	6.95	
1.05	2480		26.0	26.	K=1
.85	2206		.5	.535	
>1.05	2500	1.8	.2	.214	K=1.0
		3.3	.47	.503	
		5.7	.95	1.02	
		7.5	1.6	1.714	
		13.2	3.2	3.425	
		15.5	4.1	4.39	✓
		21.0	6.6	7.06	
		27.5	10.1	10.8	
		33.5	14.6	15.6	
		35.3	16.2	17.35	
		40	22.2	22.2	K=1
		50	31.	31	
		75	35	35	
		61	33	33	Grid [illegible]



Audion #2

RSW 79

x x x

				K=1.07			K=.0158	
Date	Lamp Amps	C Abs	Plate volts	Edison Meter	Current Milamps	Grid volts	Grid meter	I milliAmp
3/17/13	1.051	2480	115	.9	.963	±0	-.25	.00395
				1.37	1.467	+1.5	-2.3	-.0363
				1.9	2.02	+3.0	-6.7	.106
				2.65	2.61	+4.5	-11.8	-.1865
					K=1		K=1.07	
				3.6	3.6	+6.	-.2	-.214
				4.1	4.1	+7.	-.33	-.353
				4.8	4.8	+9.2	-.47	-.503
				6.	6.	+12.2	-.8	-.856
				7.7	7.7	+15.2	-1.15	-1.23
				9.	9.	+18.3	-1.5	-1.605
			"	11.	11.	+22.5	-2.	-2.14
			0	0	0	±0	-2.25	K=.0158 -.0355 with plate free
			115	.45	K=1	-1.5	0	0
				1.3	1.3	-2.8	0	0
				2.5	K=.0158 .0395	-4.3	0	0
				.2	.00316	-5.8	0	0
				0	0	>-6.8	0	0
	1.05		50	5.	K=.0158 .079	-1.4	0	0
				.25	.00395	-2.9	0	0
				0	0	-4.3	0	0
				.27	K=1.07 .289	0.0	-.55	K=.0158 [illegible]
				.55	.589	+1.4	-3.45	.0545
				.9	.962	+3.0	-8.9	.141
				1.3	1.39	+4.5	-16.0	.253
				2.9	K=1. 2.9	+9.2	-.59	K=1.07 .631
				4.6	4.6	+13.7	-1.2	1.285
				6.2	6.2	+18.2	-2.13	2.28
				7.7	7.7	+22.5	-3.2	3.43
			75	1.25	K=1.07	+3	-7.9	K=.0158
				.8		+1.4	-2.8	
				.42		±0	-.35	
						-1.4	0	

Fil I	Fil K	Total EC ma	I EC ma .0158
.7	1990	1.1	.0194
.65	1912	.2	.00316
.75	2060	10.6	.0674
.8	2135	.6	1.07 .642
.85	2206	1.9	2.033
.90	2275	5.0	5.35
.95	2345	10.5	11.23
1.0	2411	22	1.02 22

l = 1.405

1.05 milli

+E.M.F. on grid required to cause 0 E.C. to Plate

Plate E.M.F.	-Grid EMF
110	6.2
80	5.0
60	4.2
40	3.3
20	2.7
8.3	2.00
0	1.7

~~On [illegible] Audion~~

~~0 2.25~~

~~On large plate~~

~~0 3.25~~

See RSW 82

R.S. W80

Audion #2

Date	Edison Meter	I Milliamps	Grid Volts	~~V~~$^{1/3}$ $I^{1/3}$
2600°	1.48	K=1.07 1.584	+14.75	135
1.05A	1.31	1.603	+11.55	126
10 Volts	1.09	1.167	+9.00	110
on plate	.81	.866	+6.	91
O	.42	.449	+3.	59
	15.9	K=.0158 .251	+1.5	40
[illegible]	5.0	.079	0 Grid to –	16
	.9	.01423	–1.00	6
	.0	0	–2.00	0
	.25	.00395	–1.5	~~10.0~~
	1.91	K=1.09 2.045	+22.5	165
	1.71	1.83	+18.1	150
2.35V	2.32	K=1.07 2.48	0	187
	14.00	15.08	+22.5	615
	11.8	12.63	+19.5	550
	10.1	10.8	+16.5	495
	8.45	9.04	+13.05	440
	7.1	7.6	+10.15	390
	5.6	6.0	+7.3	335
	4.2	4.49	+4.35	275
	3.0	3.21	+1.45	220
	1.93	2.065	–1.0	164
	1.53	1.64	–2.0	140
	1.15	1.23	–3.0	115
	.56	.60	–5.0	~~57~~ 71
	11.7	K=.0115 .135	–7.0	32
	2.45	.0387	–9.0	11.4
	.15	.00237	–11.8	
	.0	.000	–13.25	

L.G.F.

Audion #2 R.S.W81

Date	E – C Meter	E – C Mil A (Ke. No 7)	Grid I Meter	Grid I Mil A. (Ke. No 58)	Total Circuit Mil A.	+ Grid EMF. Volts
3/20/13	1.39		14.3			23.8
fil. at .85 A	1.31		12.4			19.5
110-120 V. vary	1.29		10.6			15.0
	1.30		9.1			10.5
	1.31		6.6			5.9
NG	1.07		2.9			3.0
115 V not	1.31		7.4			6.9
giving Sat	.81		.9			1.4
	.53		0			.0

Used 220 fil
.75 Amp

RSW 98

5/22/13

.0158

Audion	Ep	Eg	Im	Ir
9-8	32	-3.5	12.5	.1975
at .685A		4.	9.6	.152
		4.5	7.0	.1105
		5.	4.9	.0774
		5.5	3.7	.0585
		6.	2.6	.0411
		6.5	1.95	.0308
		7.	1.45	.0229
		7.5	1.1	.0174
		8.	.9	.0142
		9.	.65	.0103
		10	.4	.0063
		11	.25	.00395
		12	.12	.00189
		15	.000	.000

.0158

5/23/13	40	-3	.3	.00474
		-3.5	.1	.00158
Audion		-5.5	0	0
#2 at		-2.5	.8	.0126
1.013 =		-2	1.9	.03
2430°K		-1.5	3.7	.0584
		-1.	6.3	.0994
		-.8	7.5	.1185
		-.6	8.8	.139
		-.4	10.3	.163
		-.2	12	.189
		-.1	12.8	.202
		0	13.9	.219
	220	-6.5	14.8	.234
		-7	12.65	.200
		7.5	8.6	.136
		8.	7.9	.125
		8.5	6.25	.0985
		9.	4.7	.0741
		9.5	3.3	.0521

Ep	Eg	Im	Ir
220	10	2.35	.0374
	10.5	1.7	.0268
	11.	1.15	.0182
	11.5	.75	.0119
	12.	.5	.0079
	12.5	.3	.00493
	13.	.2	.00316
	14.	.1	.00158
	15.5	0	00
.7 A Mag field			
220	0	9.5	.15
	-.15	9.2	.145
	-.2	9.0	.142
	.4	8.7	.137
	.6	8.4	.133
	.8	7.87	.124
	1.0	7.45	.1176
	1.2	7.0	.1105
	1.4	6.6	.104
	1.6	6.2	.098
	1.8	5.8	.0915
	2.	5.45	.086
	2.2	5.1	.0805
	2.3	5.0	.079
	2.4	4.95	.0781
	2.5	4.9	.0774
	2.6	5.1	.0805
	2.7	5.3	.0836
	2.8	5.25	.0829
	2.9	5.2	.0821
	3.	5.15 48	.0813
	3.15	4.7	.0742
	3.17	7.3	.115
	3.25	7.2	.1137
	3.5	6.8	.1074
	4.	6.25	.0986

Ep	Eg	Im	Ir
220	-4.5	5.45	.086
	5.	4.8	.0758
	5.5	4.	.0631
	6.	3.2	.0505
	6.5	2.9	.0458
	7.5	2.0	.0316
	10.	.7	.01105
	12.5	.2	.00316
	20	.0	0

PLAINTIFF'S EXHIBIT No. 173.

Report on Relaying of High Frequency Currents by Means of Improved Audions.

W. C. WHITE

May 24, 1918. N. B. 452, pp. 61-64.

The two main objects in making these tests were, first, to determine if the improved audions would relay high frequency currents satisfactorily, and second, to get a working demonstration of geometrical tuning for wireless telegraphy as proposed by Mr. Alexanderson.

A standard 2 KVA high frequency alternator was used in connection with two of the improved audions.

A Marconi Wave Meter, consisting of a resonant circuit with variable condenser, was used to show that the high frequency current was correctly and sharply relayed.

Inductive coupling by means of air core coils was used to connect the different circuits.

A diagram of apparatus and connections is attached. Thruout the tests a constant current of 2.6 amps. was kept on coil D by field regulation of the alternator, so that a magnetic field of constant value was maintained about this coil.

The grid circuit of the first audion was tuned to 66,000 cycles, the audion relaying it to the grid circuit of the second audion, which by means of the wave meter was also tuned to 66,000 cycles.

The frequency was varied between 40,000 and 100,000 cycles, and a reading of 0.126 milliamperes maintained on Meter K by varying the distance between coils C and D.

Therefore the axial distance between these coils was a measure of the responsiveness of the tuning system, the relation between this distance and the field strength relative to that at a co-planar position being known.

Then this distance, corrected as above and plotted against frequency, gave resonance curves, giving the relative responsiveness or sensitiveness to different frequencies.

Three sets of tests were made:

1. Determination of resonance curve in first audion system only, meter K being substituted for coil F to give quantitative results.

2. Determination of resonance curve in second system only, coil G being coupled directly to coil D.

3. Combination of the two systems giving geometrical tuning.

The resultant resonance curves are shown on the accompanying prints.

Comparison of the resonance in the wave meter circuit alone to its resonance when it is actuated by another tuned audion circuit shows that its responsive range is widened, while sensitiveness to frequencies outside of this range is greatly cut down.

Theory predicts that the ordinates of the curve of the two tuned circuits should be the product of the ordinates of the curves of the two circuits alone, the peak of each wave being considered as unity.

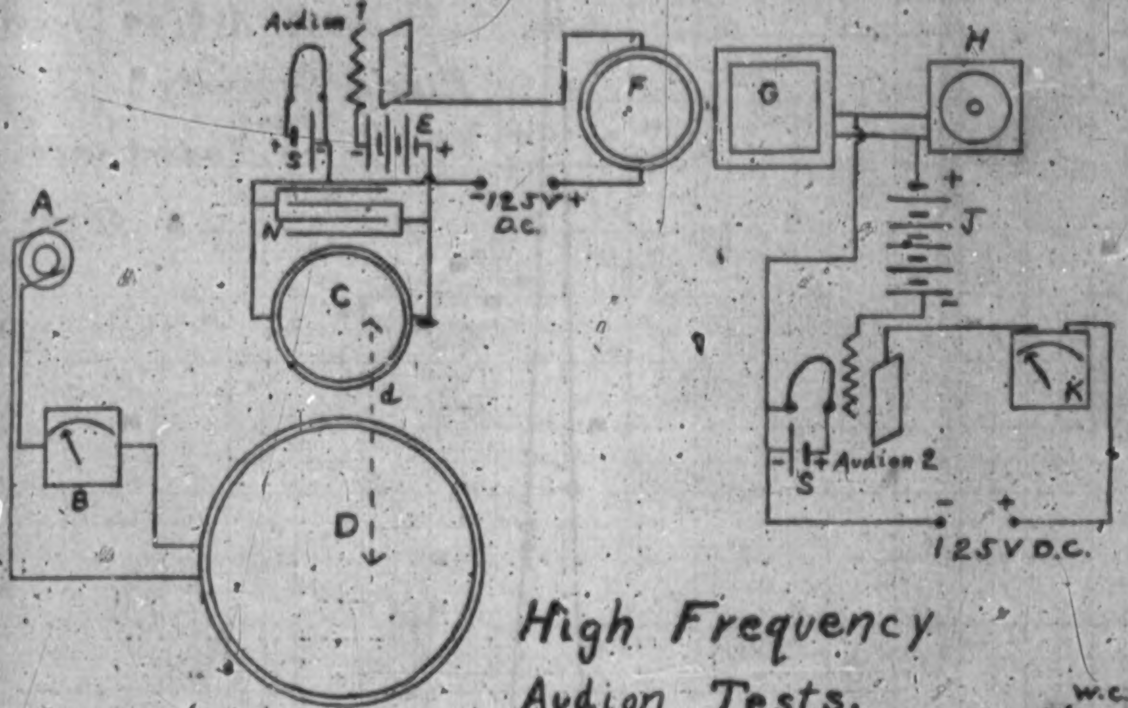
This checks up quite well on the lower portions of the curve, as the dotted line shows, but near resonance the high slope of the curves and the fact that the tuning of the component circuits was probably not closer than 2% prevents close agreement between the predicted resultant curve and the experimental.

The mere fact that sharp and consistent resonance results were obtained in the second circuit is ample proof that the improved audions are not sluggish in action. Tests made show that sharp tuning could be obtained at 105,000.

Witness:

M. E. Christie,
June 3, 1913.

WGW 9/25/13



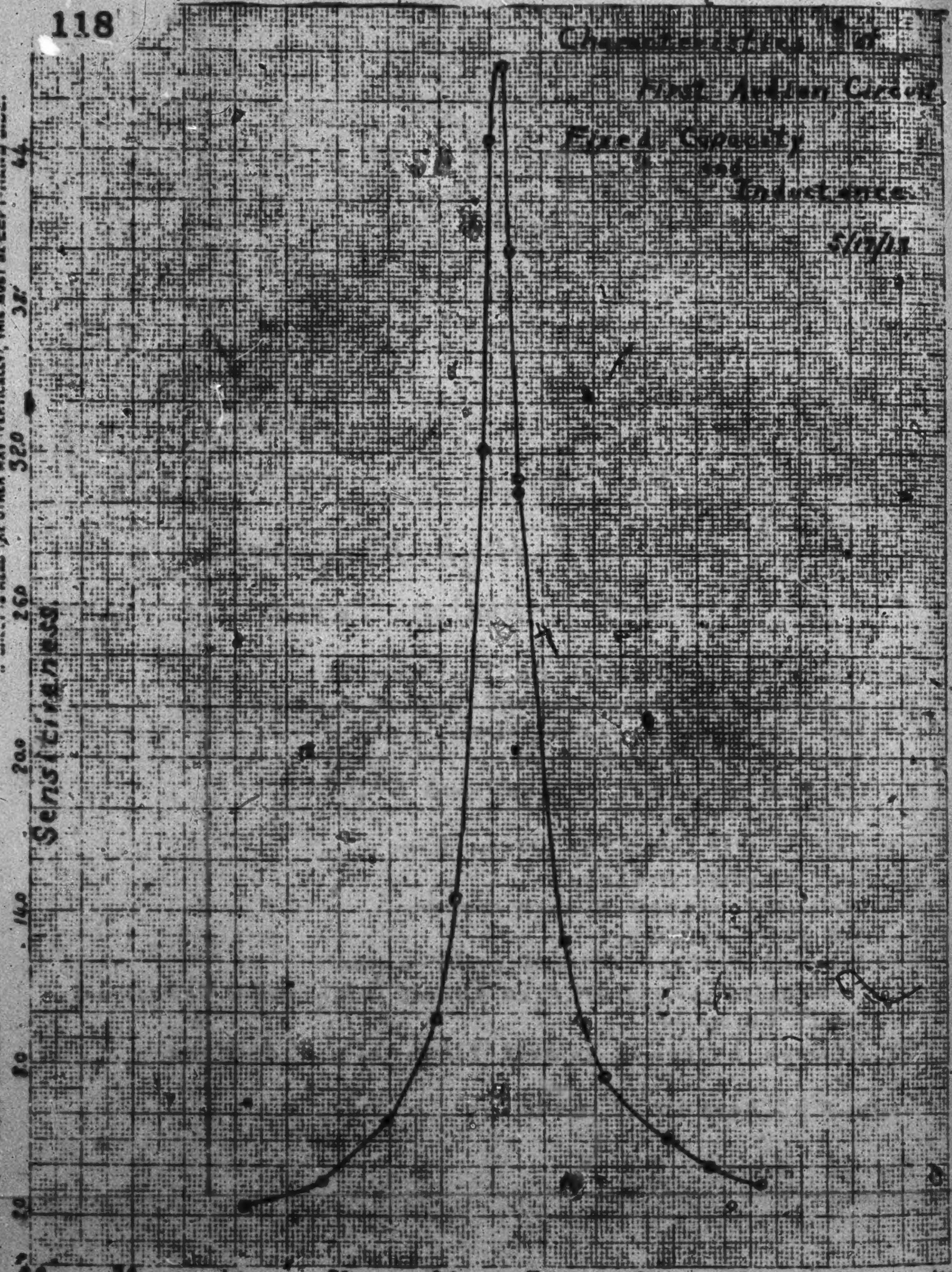
High Frequency Audion Tests.

W.C.W
5/24/13

A – High frequency Alternator 20,000 – 100,000 ~
B – Hot wire ammeter current kept at 2.6 Amps
C – Coil 15 turns #16 15.5cm diam.
D – Coil 8 " #8 40.75cm "
d – Distance along axis between coils C & D.
E – 5 Volt battery
F – Coil 1000 turns #30 15cms diam.
G – Coil of wave meter.
H – Variable condenser of wave meter.
J – 7.5 Volt battery
K – Current meter 0 – 0.25 milli-amps.
N – Condenser, about .09 M.F., in circuit with coil C is resonant at 66,000 ~
S – Storage batteries to heat filaments of Audions.

Coils F & G kept at 7" coupling

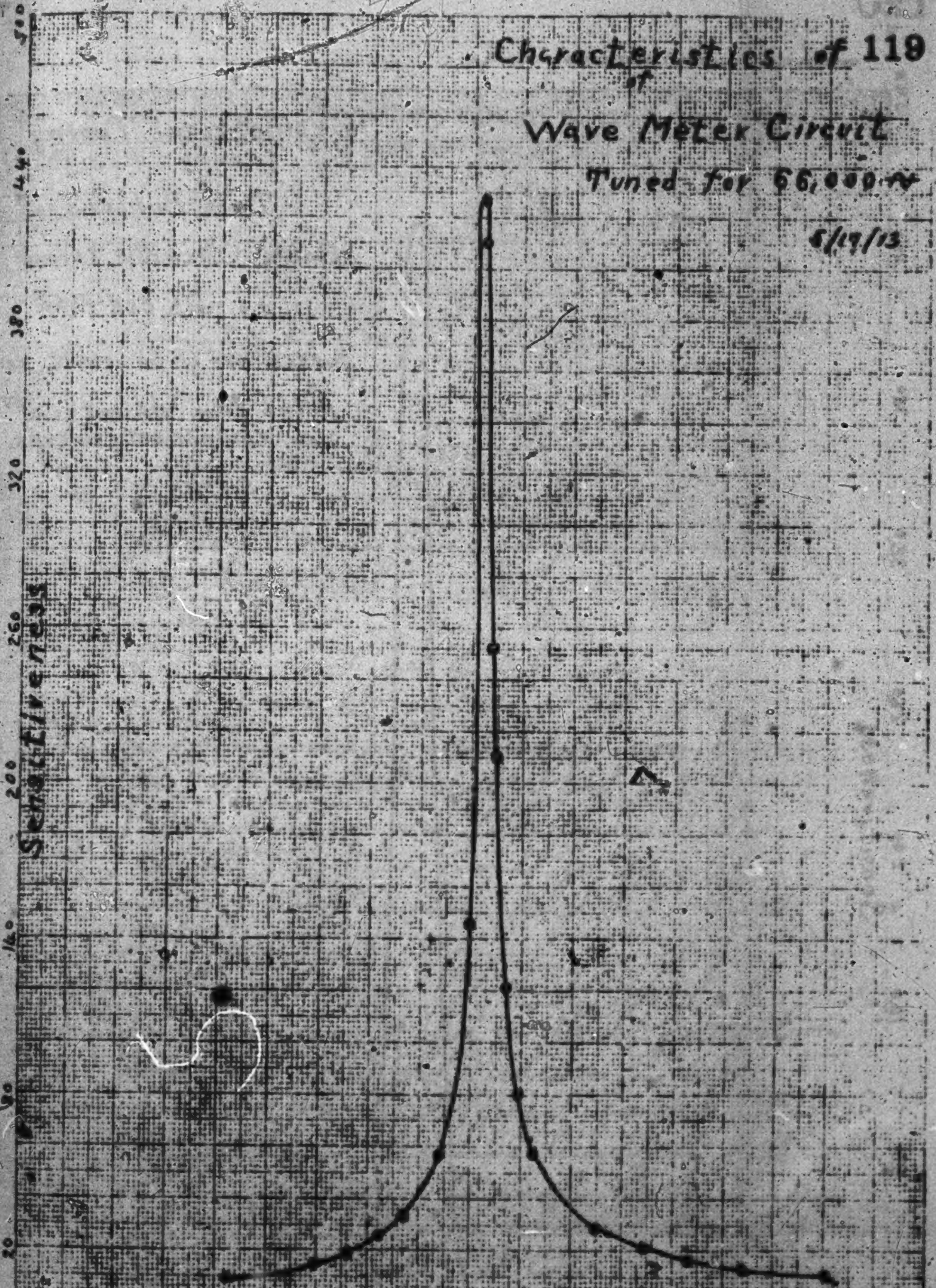
First Audion #8
Second " #2



Characteristics of First Audion Circuit

Fixed Capacity and Inductance.

5/17/13

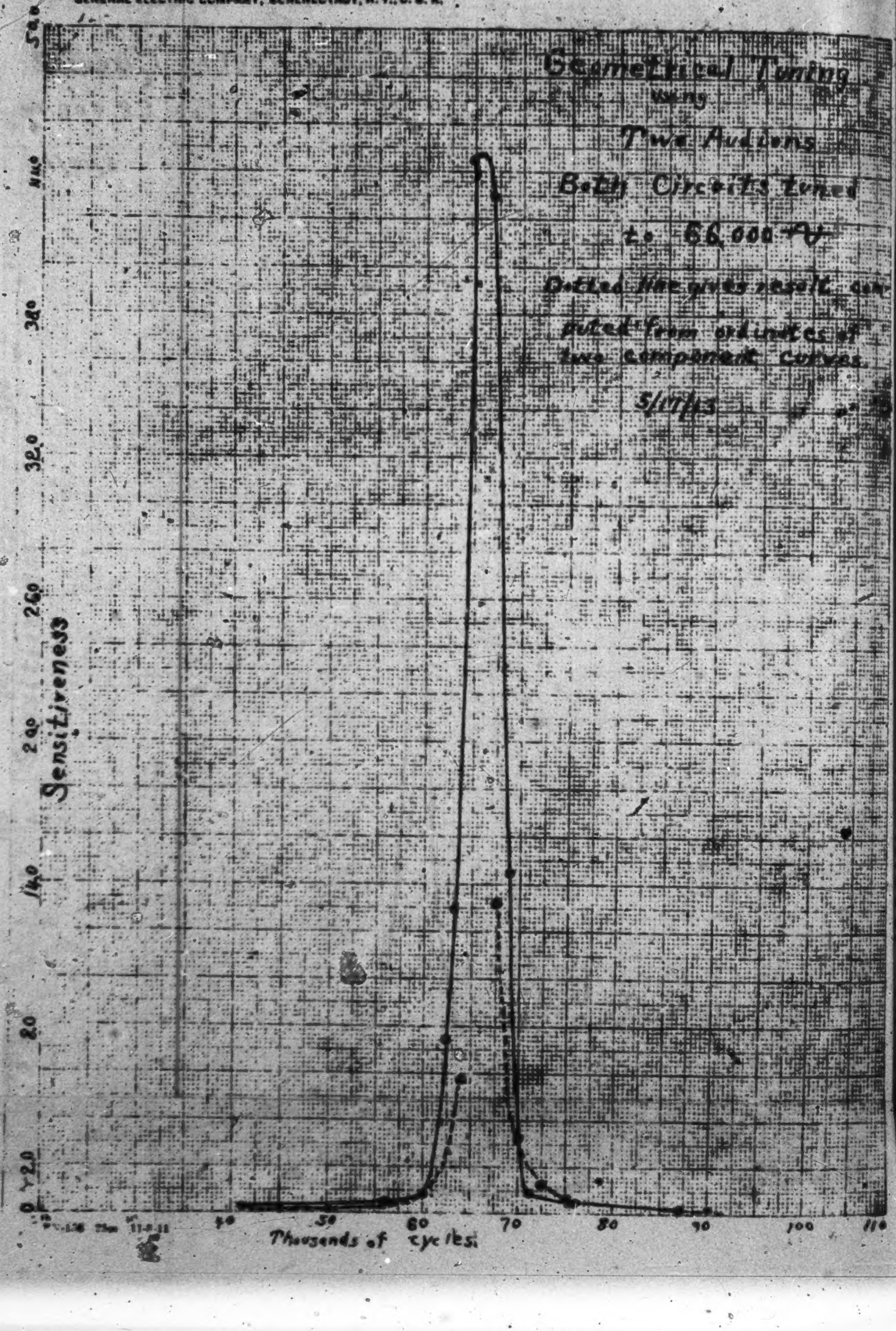


Characteristics of 119 of Wave Meter Circuit

Tuned for 66,000 ~

5/17/13

GENERAL ELECTRIC COMPANY, SCHENECTADY, N.Y., U.S.A.



Geometrical Tuning
using
Two Audions
Both Circuits tuned
to 66,000 ~

Dotted line gives result computed from ordinates of two component curves.

5/17/13

PLAINTIFF'S EXHIBIT No. 174.
Coolidge Note Book No. 327.

May 7, 1912

B. & S. Igniter

Platinum Contacts (Idea)

May 8, 1912.

Received tube *594836 from Wiggin. This is my first tube with a tungsten cathode. It also has a heavy tungsten anode, without any backing. It has the usual regulator, but no auxiliary anode.

Wiggin wrote that the tube was very freaky & would not do at all. My first impressions were that it was by far the "crankiest" tube I had seen. Upon passing *very* little current thro it the vacuum would go from say 3 to 8 inches, and this repeated itself over and over.

The cathode got hot easily, and I finally found that with the cathode ~~[illegible]~~ at bright redness the tube showed entirely different characteristics. The vacuum became beautifully stable and, so far as to-day's expts. show it remains so as long as the cathode is kept at bright red heat.

I have the impression tonight that this tube shows much less excess heating of the glass around the cathode & about the front hemisphere than do the regular tubes. I ran it a long while this afternoon getting intense X-rays. Behind the screen the light in the fluoroscope was very intense.

The perfect steadiness of the tube is remarkable. The glass shows a much deeper purple coloration than I have yet produced in any other tube.

The cathode shows no roughening unless it is at the very center over an area of perhaps $\frac{1}{16}$" diam. The heating at the cathode is clearly strongly localized at the center.

The tube, as it came, showed a black ring ~~around~~ on the glass around the cathode. This darkening has extended all over the bulb to a slight degree. It may be due to ~~the~~ cathode spattering of tungsten or it may be due entirely to the action of the regulator gases on W. I ~~[illegible]~~ used big quantities of the regulator gas before starting

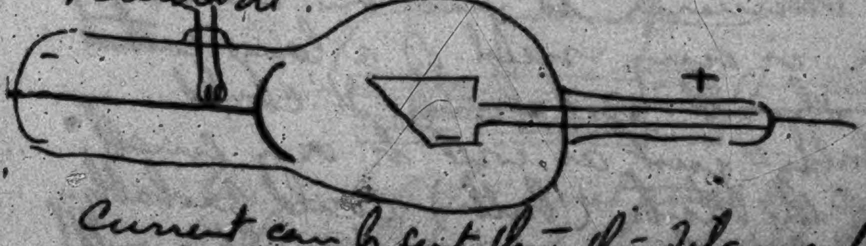
Wit. W. G. Gartner 173
Feb. 13, 1913

to run the cathode hot.

x I believe that the above points the way to the ideal X-ray tube. It looks to me now as though, with the hot tungsten cathode, the degree of vacuum would play an entirely subordinate role, provided of course it is high enough, and that there will no longer be any such thing as a too high vacuum. The tube resistance will apparently be determined by the temperature of the cathode.

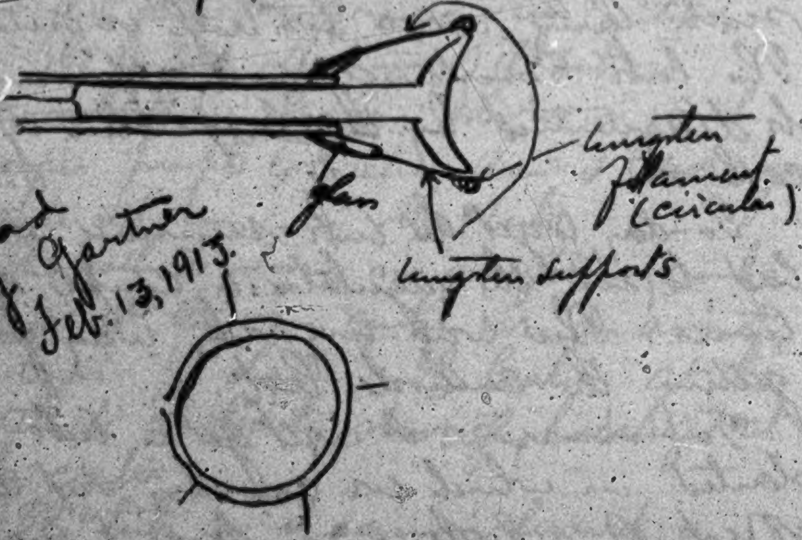
To-day, to get the tube running, I have had to use the regulator a couple of times. This was my only way for getting the cathode hot.

To-morrow I will get a tube started in which we can try out the effect of a little incandescent tungsten filament behind and close to the cathode.



Current can be sent thru the filament from a storage battery, which is insulated from the earth, and the filament can be electrically connected to the cathode.

Or a circular loop of W wire can be put around the cathode, but free from it except at one point & supported from the glass tube surrounding the cathode rod



Read
W. G. Gartner
Feb. 13, 1915.

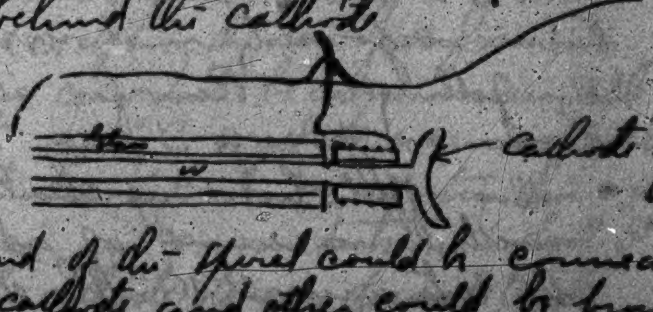
It will be very interesting with a very high vacuum to find out whether there is any need of a large cathode ~~This should not be so~~ It could probably just as well be very small. And the tube (bulb) could probably likewise be very small as it would no longer be necessary to make

it large for stability of vacuum.
A small quartz bulb only 1 or 2 inches in diameter might well be plenty large even for very high power work.

Tube 594036, described above, should, just as it is, readily permit of real moving picture work.

Heating of the cathode might well be made very easy by attaching a hollow stem to it and putting a rod of Chester Moore's sheath wire inside the hollow stem

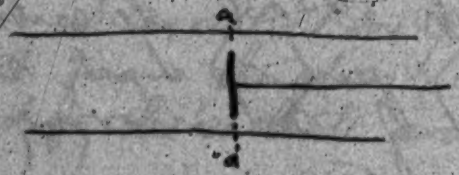
Another very simple stunt might be to wind a tungsten spiral on a thin silica ~~tube~~ or alumina spiral and to slip this ~~tubing~~ on over the cathode supporting rod just behind the cathode



One end of the spiral could be connected to the cathode and other could be brought out through the side of the tube wall

This was repeated over & over

The tube is badly blackened near the target the blackening being



worst at a-a, with none behind here (the line is very sharp) and gradually decreasing towards the cathode.

Sept. 24, 1912

Working with X-ray tube made up by Joe Clayson. W cath. & heavy W anode 7" bulb.

Tube is not in heater. Used Bunsen burner vigorously on it several times H_2 filling. Ran for about an hour on pump.

One effect shows up clearly. Starting with a vacuum of say 20 micron the tube runs O.K. The electrodes both heat up strongly, and there is a as our Cadillac units were ready I would go with him to the Cadillac Co., & to see Kettering, to get them tested out.

Dr. Hubbard from Clark Univ. was here & talked at Colloquium on the spot measurement of the period of oscillation in high frequency circuits.

Dec. 8, 1912.

If disapp. of gas in a tube is due to chem. action, there should be more of it in case of a bulb of fused quartz. Test this out some more.

Dec. 10, 1912.

Dr. Langmuir tells me that, in his study of Edison Effect, the current, in the case of a hot cathode, is greater with a very fine vacuum of 1 or 2 hundredths of a micron than it is at higher gas pressures (excepting the case of Argon). His Edison currents become measurable at about 1600° C & get to a max. value at about 2300° C. I will try this out at once in an X-ray tube in which I can heat the cathode to any desired temp. The above would be in line with my observations on pgs. 171 – 175.

PLAINTIFF'S EXHIBIT No. 175.

Extracts From Coolidge Note Book No. 446.

Feb. 17, 1913.

Worked with Tube 112 this P.M. It has a very small hole in the cathode plate (1" radius of curvature) with the filament point just sticking in to the hole, and the target is placed much closer to the cathode.

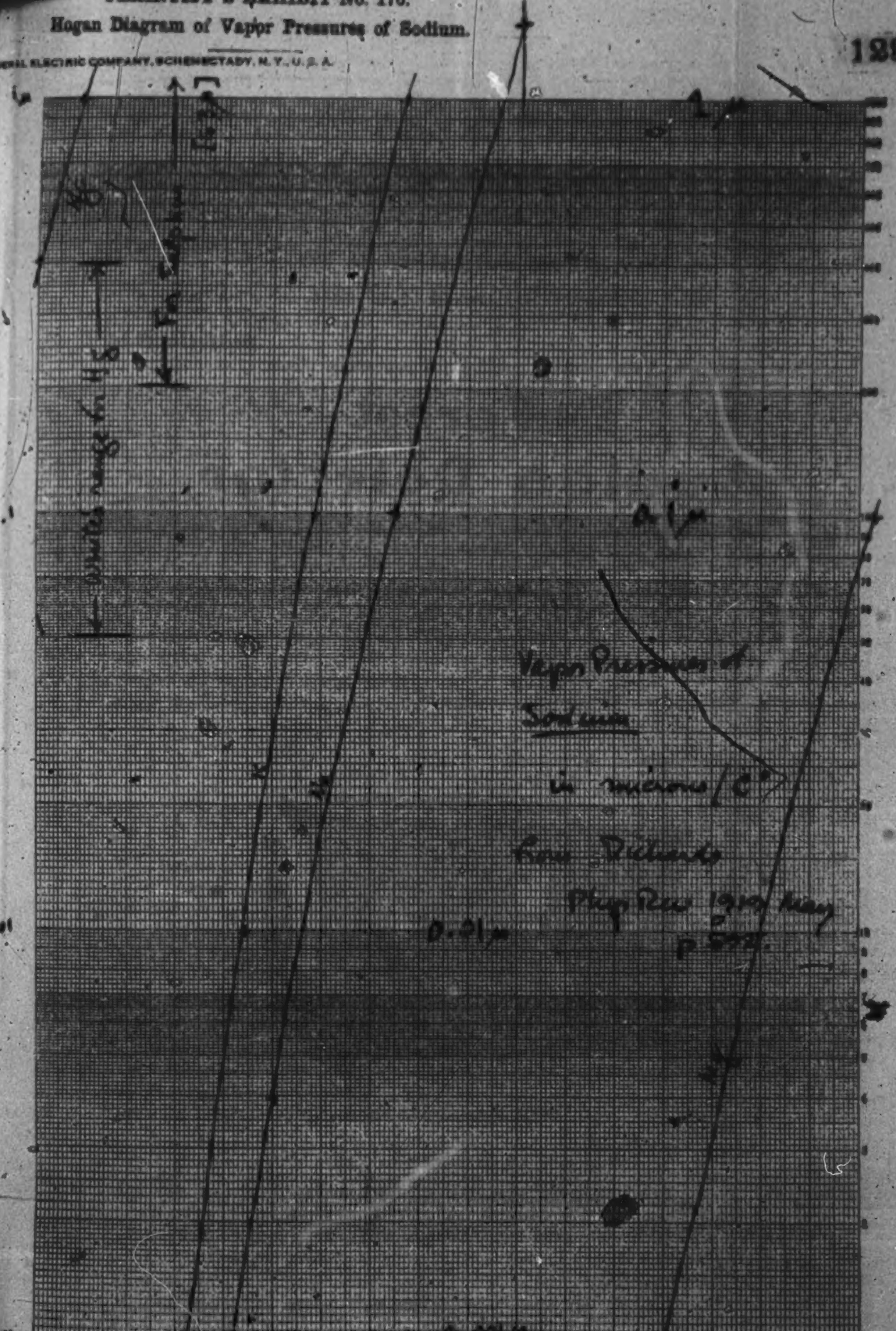
From the very first turning on of the current this tube has focussed sharply. As a result, it has been easy to heat the target so as to get the gas out of it. The tube was therefore in excellent condition after perhaps 1 hour's work ~~with~~ on it after it had come out of the oven. The electrodes were fresh ones, so this expt. demonstrated conclusively that the target has been the troublesome source of gas, and the lack of focussing when running as an ordinary tube, that is before getting a good vacuum has been what has made the tube exhaust so tedious and precarious.

The new 1000~ circuit will be completed by to-morrow morning, but our need for it is certainly lessened by to-day's expt. It will clearly be much better to so design the tubes for permanent work that they shall focus in case the

129

PLAINTIFF'S EXHIBIT No. 176.

Hogan Diagram of Vapor Pressures of Sodium.



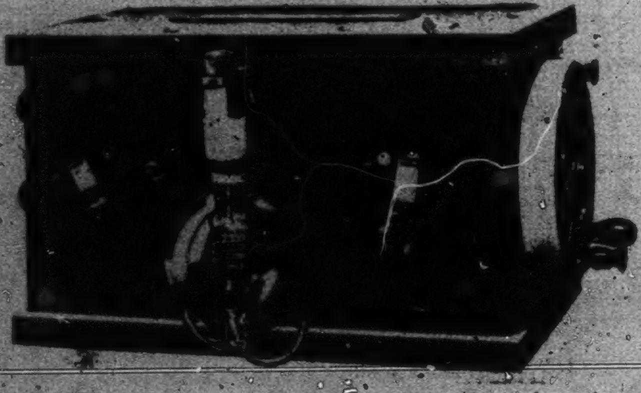
PLAINTIFF'S EXHIBIT No. 177.

DeForest Bulletin B-14 of 1914.

Bulletin B 14

DeForest
Audion Detector

Licensed for private, amateur or experimental use only. The only Audion Detector manufactured for the use of amateurs under the protection of the patents of Dr. Lee deForest.



THE deFOREST AUDION DETECTOR
IMPROVED TYPE RJ4.

Licensed for Private Use Only

THIS instrument represents the highest development of wireless detecting apparatus known to science.

Tests conducted by the United States Bureau of Standards have shown it to be fully 50 per cent. more sensitive than any other form of detector (Bulletin, Bureau of Standards, Vol. 6, No. 4, P. 540).

Its adjustment is instantaneous, and is unaffected by mechanical or electrical disturbances.

This instrument is complete in itself, the only necessary connections being to the secondary terminals of the tuner, to the phones, and to a four volt battery. All these connections are plainly marked on the cabinet.

Throwing on the switch at the right of the Audion bulb to the left or right lights one or the other of the filaments. The battery switch at the left of the lamp and the rheostat lever are then moved to a position where signals are at their best. After these adjustments are once made, the throwing off of the switch instantly places the detector out of service. *Do not keep the Audion bulb lighted when not using the instrument.*

These detectors are thoroughly tested before shipment, and are guaranteed to leave our factory in perfect working order.

Price for the instrument complete as illustrated, $18.00

This detector may be operated by three dry cells. The best results, however, are obtained from the use of a storage battery.

4 volt 30 ampere hour storage battery, $5.00

THE deFOREST AUDION DETECTOR
TYPE RJ5.

Licensed for Private Use Only.

This instrument is complete in itself, the only necessary connections being to the secondary terminals of the tuner, to the phones, and to a four volt battery. All these connections are plainly marked on the cabinet.

Throwing on the two point switch at the right of the Audion bulb lights one of the filaments. The battery switch at the left of the lamp and the rheostat lever are then moved to a position where signals are at their best. After these adjustments are once made, the throwing on or off of the two point switch instantly places the detector in or out of service. After the first filament has been consumed wind the little copper wire tight around the brass base of bulb underneath the rubber band. This connects the second filament.

These detectors are thoroughly tested before shipment, and are guaranteed to leave our factory in perfect working order.

Price for the instrument complete as illustrated, $25.00

AUDION BULBS FOR RENEWALS.

The sensitiveness of Audion bulbs has been still further improved of late. We make two grades, the "S" or standard, and the "X" or extra sensitive. *Audion bulbs are sold only as renewals, or to those who have purchased our Audion Receiving sets,* and then only on the return of the old bulbs.

Renewal bulbs, "S" grade, $3.50 each.
Renewal bulbs, "X" grade, $5.00 each.

INSTRUCTIONS.

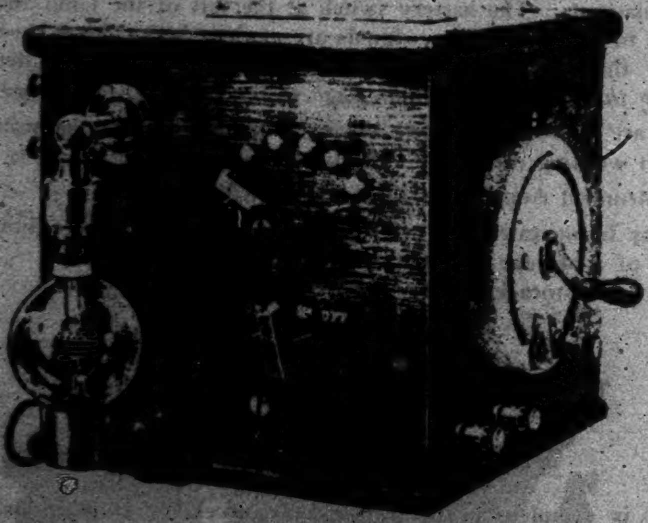
To get the very best results follow instructions explicitly.

Do not connect over six volts storage battery to the external binding posts marked + and —. Before lighting the filament see that the resistance switch is on the "1X" position. Then adjust rheostat until lamp burns at normal brightness. Adjust brightness of filament and the battery B switch to give maximum sensitiveness.

In connecting up the Audion Detector, connect the grid to G and wing to W, as marked below the binding posts. The Grid is the zig-zag wire terminal. The Wing is the plate.

If bulb is capped the green wire leads to the grid, the red leads to the wing.

Connect the little copper wire at base of bulb to the binding post directly beneath the bracket. This connects in the second filament to one point of the battery A, or lighting switch. The other filament is connected through the lamp socket to the other contact point. If one filament is more sensitive than the other reserve this for long distance work.



TYPE RJ6

The Audion has been proven, by scientific and official tests to be from 1.5 to 3 times as sensitive as any crystal detector. With it even in this small and cheap form, telegraphic ranges far greater than those possible with the crystal or electrolytic detectors are easily attained.

It is reliable, requires no adjustment after the proper voltage and heating currents are determined, it cannot be injured by powerful transmitter sparks in the immediate vicinity. If it momentarily loses its sensitiveness by reason of the transmitter spark, it is automatically restored, without the slightest decrease in its sensitiveness.

Receiving ranges with the Audion detector are far greater than with other types.

We have many testimonials from users of the Audion describing surprisingly long distances over which messages are being received, and the extraordinary strength of long distance signals.

If too much "Battery B" voltage be applied a blue glow will appear in the bulb, or may be seen merely around the edges of the "plate" or wing. When this blue glow fills the bulb it is usually not very sensitive. The glow can be removed by simply reducing the B voltage by the 3-point switch on the RJ4 and the 6-point switch on the RJ5. The sensitiveness can be instantly restored by merely switching off and on the lighting current. Only one filament should be burned at one time. This doubles the life of the bulb.

Never burn the filament at excessive brilliancy, as full sensitiveness can be obtained at normal brilliancy.

Always use a storage battery for lighting the lamp, as dry cells run down very quickly when used for that purpose.

Never use more than three cells of storage battery.

Don't let the storage cells run down low and then hook in another fourth cell, because if this is done there is always danger of the run-down cells picking up, or recuperating after a short period of rest and then of burning out the filament when first switched on again.

Connect the secondary of the receiver tuning circuit to the binding post marked "Tuner."

It makes some difference in the results obtained which of these two terminals is connected to one or the other of the two "Tuner" binding posts. The surest way of determining this is to reverse the two connections, and thus observe which gives the louder signals.

(The RJ4 and the RJ5 Audion are for *Amateur* work only and are *not* under any conditions licensed to be used for commercial work.)

We also manufacture other deForest Audion types as follows:—

Audion Detector, P.N. type, licensed for commercial work, each	$ 50.00
Audion Amplifier, one step, each	150.00
Audion Amplifier, two step, each	300.00
Audion Amplifier, three step, each	500.00
Combination Audion Detector and Amplifier, one step, each	200.00
Combination Audion Detector and Amplifier, two step, each	350.00
Combination Audion Detector and Amplifier, three step, each	550.00
Audion Bulbs, double grid and double plate, for renewals only, each	7.50
Variable Condensers, 3 type, each	55.00
Variable Condensers, 3½ type, each	35.00

Full description upon application.

We are also prepared to submit estimates and specifications on Wireless Telegraph and Wireless Telephone apparatus.

PLAINTIFF'S EXHIBIT No. 178.

DeForest Bulletin B-15 of 1915.

Bulletin B 15

DeForest
Audion Detectors, Variometers and the DeForest Audion Time Receiver

Licensed for private, amateur or experimental use only. The only Audion Detector manufactured for the use of amateurs under the protection of the patents of Dr. Lee deForest.

Improved Type RJ4 Audion Detector.

Manufactured by

DeForest Radio Telephone & Telegraph Co.

101 Park Avenue, New York.

Cable Address: Radiotel, N. Y.

REGARDING THE DEFOREST AUDION DETECTOR.

THIS instrument represents the highest development of wireless detecting apparatus. It is the most sensitive and reliable detector in existence. Tests conducted by the United States Bureau of Standards have shown it to be fully 50 per cent more sensitive than any other form of detector (Bulletin, Bureau of Standards, Vol. 6, No. 4 P.540).

One of its greatest advantages over other detectors is its reliability. When once the proper voltage and heating currents are determined, no further adjustment is required. If powerful electrical impulses in the immediate vicinity should momentarily decrease its sensitiveness by their very strength, the Audion will generally restore itself at once automatically, but otherwise, turning the high voltage switch back one point and bringing it to its original position, will bring back full sensitiveness positively and at once.

The Audion Detector is not affected by any ordinary mechanical vibration and is not appreciably affected by the spark of the transmitting apparatus. It will stay in adjustment indefinitely and can be depended upon at all times. Its use enables the operator to receive over the greatest distances possible with any form of detector.

Each DeForest Audion Detector is supplied complete at the prices listed, with the necessary switches, rheostat, fixed condenser and the battery "B", *but without* the battery "A", which is composed of a six volt storage battery or three or four dry cells, preferably the former. *Never use more than six volts* for this battery, which is connected to binding posts on the outside of the case marked AA. All Audion bulbs have 3½ volt filaments.

The battery "B" is located inside the case and is composed of a number (from 10 to 12) of three cell flashlight dry batteries.

The proper methods of using the various styles of DeForest Audion Detectors, are described in this bulletin, and these instructions given for operating the detectors should be followed carefully if the highest efficiency is desired for the station.

All our Audion Detectors are regularly furnished with Standard "S" grade Audion bulbs. The "X" grade will be supplied at the additional prices as given in the PRICE LIST in this bulletin.

THE DEFOREST AUDION DETECTOR

IMPROVED TYPE RJ4.

Licensed for Private Use Only.

This type of Audion Detector is now employed very generally in amateur stations. Like all our Audion Detectors, it is complete in itself with the exception of the Battery "A" which consists of a six or four volt storage battery, or three or four dry cells, preferably the six volt storage battery. Batteries may be purchased from any electrical supply house.

The Type RJ4 Detector is made in a mahogany case and now has a five point Battery "B" control switch instead of three points as shown in the illustration. This gives very close regulation and has greatly improved the efficiency of the detector.

This detector is recommended to those who desire to increase the receiving range of their stations, and who wish the greatest possible reliability of operation. Customers who have purchased Audion Detectors write us that they have discarded all other forms of detectors and use the Audion exclusively.

DIRECTIONS FOR TYPE RJ4 AUDION DETECTOR.

The proper method of connecting the Type RJ4 Audion Detector is described below. It may be used with any wireless receiving set, but best results are obtained with it in connection with a good receiving transformer, and a variable condenser. Simply connect the secondary terminals of the receiving transformer to binding posts on the Audion Detector marked "Tuner". Connect the telephone receivers to the binding posts marked "Telephone". The receivers for all types of Audion Detector should have a resistance of 1000 ohms or more each.

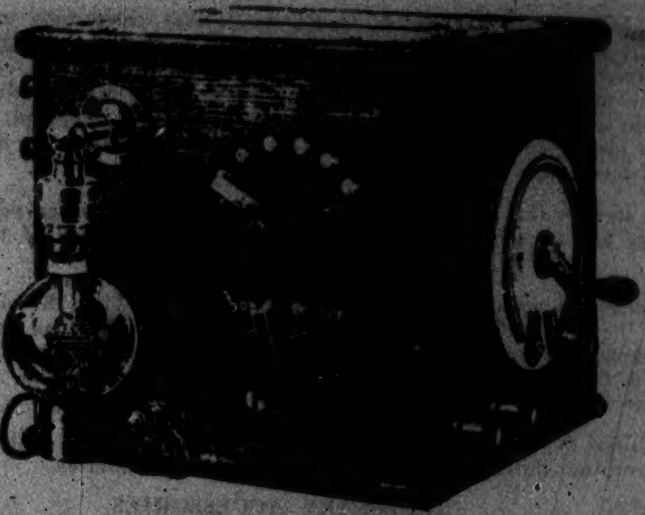
Turn the lever of the porcelain base rheostat (on the right hand end of the case) around to the left as far as it will go, so that it points downward and toward the front of the case. Screw the Audion bulb in the socket and connect the red wire (or wire leading out from the wing or plate of the bulb) to binding post marked R. Connect the green wire (or wire leading out from the grid or zig zag of the bulb) to binding post marked G.

The two point switch at the right of the bulb lights or extinguishes the filament. Light the filament and adjust the five point switch at the left, which controls high voltage battery "B" located inside the case until a slight hissing sound is heard in the receivers, when the filament is bright up to normal incandescence by means of the rheostat. Be careful not to burn the filament too brightly as this would shorten its life and will not materially increase its sensitiveness.

Each detector bulb has two filaments, one of which is connected in circuit when the bulb is screwed in the socket. When this filament burns out, the second is connected by simply twisting the wire projecting from the base, around the screw base and securing it under the rubber band.

Do not fasten any of our instruments by using screws long enough to penetrate the case. This might short circuit the internal condenser or batteries.

THE DEFOREST AUDION DETECTOR
TYPE RJ5.
Licensed for Private Use only.



Type RJ5 Audion Detector.

The Type RJ5 Audion Detector is a larger instrument than the Type RJ4 and is of higher grade construction throughout. The case is of oak with a dark waxed finish and all metal parts are heavily nickel plated. The switches are of four ply laminated construction, insuring positive contact, and the switch knobs are of genuine hard rubber. The battery "B" control switch has six points, permitting very close adjustment.

Instructions for operating and connecting this instrument are the same as for the type RJ4 Detector.

All our detectors are tested thoroughly before shipment and are guaranteed to leave our factory in perfect working order.

If too much battery "B" voltage is applied in any Audion Detector, a blue glow will appear in the bulb, or may be seen around the edges of the plate or wing, and a roaring sound will generally be heard in the telephone receivers. When this blue glow fills the bulb it is usually not very sensitive, and if this discharge is allowed to persist for a time, the bulb will become "hard", and will require a higher battery "B" voltage.

The discharge can be stopped by simply reducing the battery "B" voltage by the 5 point switch on the Type RJ4 or the 6 point switch on the Type RJ5 Detector. The sensitiveness can be restored instantly by switching off and on the lighting current.

A "hard" bulb can be "softened" by heating very carefully and evenly over a flame for a few minutes.

Audion Bulbs are sold for renewal purposes *for our instruments only* and then *only on return of an old bulb or the wing and grid system of an old bulb.*

Connect "Battery A", a 6 volt storage battery, or four dry cells, to binding posts AA, and try reversing these connections as this will make a difference. If dry cells are used, be careful to bring the rheostat lever back after using the detector, because the dry cells will recuperate on standing and their voltage will increase, which might burn out the bulb when turned on again.

Never use a higher voltage than 6 for this purpose.

Don't let the storage cells run down low and then hook in another fourth cell, because if this is done there is always danger of the run-down cells picking up, or recuperating after a short period of rest and then of burning out the filament when first switched on again.

It makes some difference in the results obtained which of these two terminals is connected to one or the other of the two "Tuner" binding posts. The surest way of determining this is to reverse the two connections, and thus observe which gives the louder signals.

THE PURPOSE OF THE DEFOREST AUDION TIME RECEIVER.

Time signals are sent out by radio (wireless) telegraphy every day by the U. S. Government station at Arlington, a suburb of Washington, D. C., at 12 o'clock noon and 10 P. M., Eastern Time. These signals are simply a succession of dots, starting five minutes before the hours mentioned above and terminating in a dash, which begins exactly on the hour. No knowledge of the telegraph code is therefore required to obtain correct time, and this is a great advantage to anyone not skilled in wireless telegraphy.

These signals travel at the rate of more than 16,000 miles per second, so that an accuracy can be obtained which is greater even than that of the ordinary telegraph.

No license is required for operating our Audion Time Receiver and there is charge by the Government for the time service. Practically no knowledge of electrical apparatus is required to obtain excellent results with the Audion Time Receiver, and full directions are given in this bulletin to enable anyone to install and operate it.

The initial expense is practically the only expense, as the set should cost not more than three or four dollars a year to maintain, for new batteries.

NECESSARY ACCESSORIES.

The only accessories needed to form a complete time receiving station, in addition to our Audion Time Receiver, are a first class double head set wound to 2000 ohms or more, a quantity of aerial wire, a few aerial insulators, four dry cells or a six volt storage battery and a switch for connecting the aerial to ground when not in use, which is all that is required by the Fire Underwriters.

THE AERIAL AND GROUND.

Several types of aerial or antenna may be employed for receiving the time signals depending on local conditions. The higher the aerial wires are placed, and the longer, up to a limit of a 300 foot stretch, the better for the purpose and the louder the signals will be. Satisfactory results cannot be obtained generally with stretches of less than 100 feet.

Wherever possible, the flat top or the inverted L type should be used but the other forms may be employed if the former cannot be conveniently installed. Several good types are shown in the drawings. The aerial wires should be of stranded copper or some strong bronze, but iron or aluminum should not be employed for the purpose.

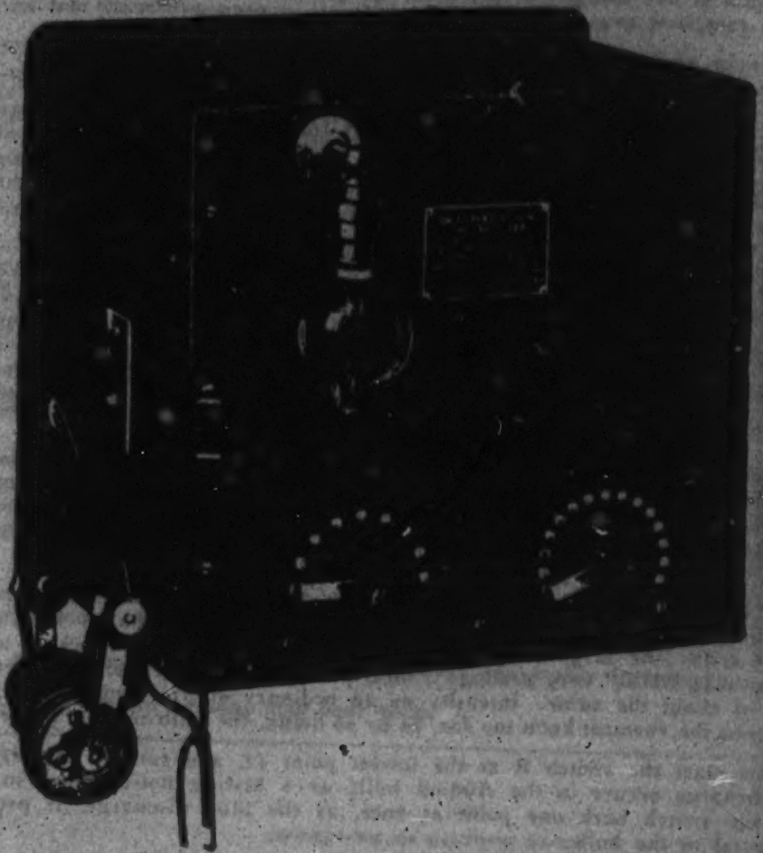
All aerial wires *must* be prevented from touching any objects except insulators, and the diagrams show the proper manner of supporting the aerial system.

A ground connection is best made by connecting to a city gas or water main by means of a ground clamp. When gas or water pipes are not available, a ground connection may be obtained by driving a one inch (not painted) iron pipe at least four feet into the earth in a moist place, and connecting to the pipe by means of a ground clamp. The wire leading to the ground connection need not be insulated.

The *Lighting Switch* has a special waterproof base. It is placed outside the building at the point where the continuation of the aerial wires enter, and is connected separately to the ground in a straight line, by means of No. 4 weatherproof wire. This is a different ground connection than the one for receiving purposes, and is made to an iron pipe driven into the earth at least four feet. The diagram shows the arrangement of the switch and its connections. It will be noted that when the blade is in one position, the apparatus is disconnected from the aerial which is connected to the earth, and in the other position the apparatus is connected to the aerial.

The switch should be left in the former position at all times when the apparatus is not in actual use, simply as a precaution.

THE DEFOREST AUDION TIME RECEIVER



The deForest Audion Time Receiver has been placed on the market to meet a strong demand for the highest grade, most serviceable set for receiving the Government time signals. It is designed primarily for this particular purpose, and will therefore, show a much higher efficiency for this work than any outfit made for general purposes of receiving messages.

This receiver uses as a detector, the famous deForest Audion Detector, which is the *most sensitive* and *reliable* device of its kind in existence (bulletin U. S. Bureau of Standards, Vol. 6, No. 4, p. 540). The deForest Audion Detector is the only highly sensitive detector which when once adjusted, will remain in perfect adjustment indefinitely, irrespective of mechanical vibration or the presence of powerful transmitting apparatus in the immediate vicinity. With its use the owner is assured of *reliable* service every day in the year, and at the greatest possible distance from the origin of the signals.

In addition to employing this peerless detector, we have combined, in a single case of waxed piano finish oak, the necessary tuning apparatus, so arranged that anyone can receive time signals positively and accurately without electrical knowledge or experience.

When once the set is adjusted, it will remain so from one end of the year to the other. When through using the set, simply hang the head receivers on the hook at the left so that it falls, which automatically shuts off all circuits, and when at any subsequent time it is desired to receive the time signals, lift the receivers off the hook at five minutes before noon or 10 P. M., Eastern Time, and place them over the ears, and you will hear the signals *every time positively* and *without fail.*

It is in reality a professional instrument, licensed only for private use. It measures 13 inches long, 11 inches wide and 11 inches high.

The case is of oak with a high waxed piano finish, all metal parts are heavily nickel plated, and all switch and control knobs and binding posts are of genuine hard rubber. The front panel is of black composition in great contrast to the nickel trimmings. The instrument is of such a high grade appearance as to harmonize with the very best of surroundings. From the standpoint of operating efficiency, it leaves nothing to be desired and the illustration shows its extreme simplicity.

DIRECTIONS FOR THE DEFOREST AUDION TIME RECEIVER.

Connect the wires running to the aerial through the lighting switch to the binding post on the set marked A. Connect the ground wire to binding post E. Turn the hard rubber knob under the lamp socket so that the pointer indicates "IN." Connect a six volt storage battery or four dry cells, preferably the former, to the binding posts marked AA. Connect the tips of the head set to the binding posts marked TEL.

Screw the Audion bulb into the lamp socket, and connect the wire leading out from the grid in the bulb to binding post G, and the wire leading out from the wing in the bulb to binding post R. (The grid is the zigzag of wire, and the wing is the metal rectangle.) If the wires leading from these parts are colored red and green connect the green wire to G and the red wire to R.

At five minutes before the hours on which the time signals are sent, Eastern Time, lift the head set off the hook and the bulb will immediately light. Turn the rheostat knob (the larger of the two directly under the lamp socket) away from "IN" toward "OUT," very gradually, until the filament of the bulb becomes normally bright, of about the same intensity as an ordinary electric lamp. Use great care not to turn the rheostat knob too far, as by so doing, the bulb will be burned out.

Now start the switch B at the lowest point 12, and turn to the right until a blue discharge occurs in the Audion bulb, or a hissing noise occurs in receivers. Bring the switch back one point at once, as the blue discharge, if prolonged, is detrimental to the bulb.

Move the switch knob PC from the lowest, left hand contact point, around the arc, in the meantime moving the knob LC slowly, until the high pitched time signals come in loudest. When this occurs, the set is in "tune" with the Arlington station.

If other signals should interfere with the time signals, simply turn the knob LC or VC to the left to reduce the interfering signals, and adjust slightly the switch knob PC for the best results.

No further adjustment will be needed. When finished, simply hang the head set on the hook, so that the light in the Audion bulb is extinguished, and the next time the correct time is desired, simply remove the head set from the hook and the signals will be heard without any adjustments whatever.

Do not leave the bulb lighted when it is not in use for this would reduce the life of the bulb.

If dry cells are used to illuminate the filament it should be remembered that in this service, their voltage drops off rapidly, and after standing, they will recuperate. Therefore, after using the set, the rheostat knob should be turned toward "IN" so that when the set is used again, the increase of voltage of these batteries will not burn out the bulb.

For other directions see those for types RJ4 and RJ5 Audion Detectors.

COST OF THE OPERATION.

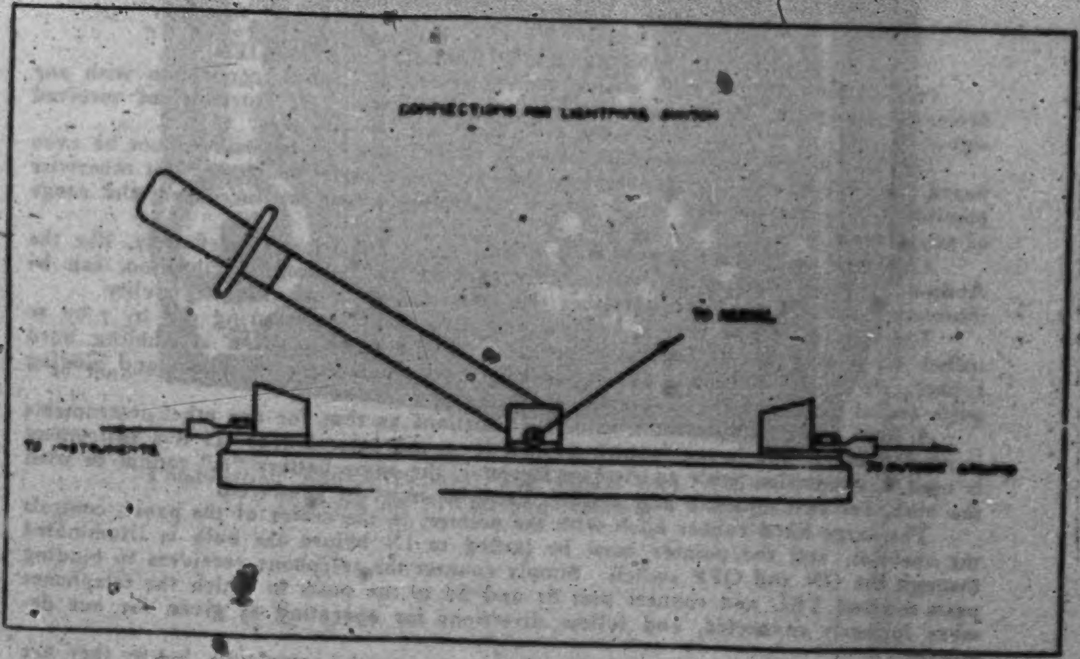
After a period of from eight months to a year, the small flash light batteries contained inside the case will become exhausted, whether the set is used or not. A new set of the common batteries can be obtained from any electrical house, and these may be readily connected in circuit. They must be connected in identically the same way as those now in the case.

The Audion bulb should last for a year or longer, if it is used for time signal reception only, and is not burned at excessive brilliancy. It will be noticed that each Audion bulb has two filaments. When the original filament burns out, the second is connected in circuit by merely twisting the fine copper wire around the brass base of the bulb under the rubber washer so as to make contact with the base.

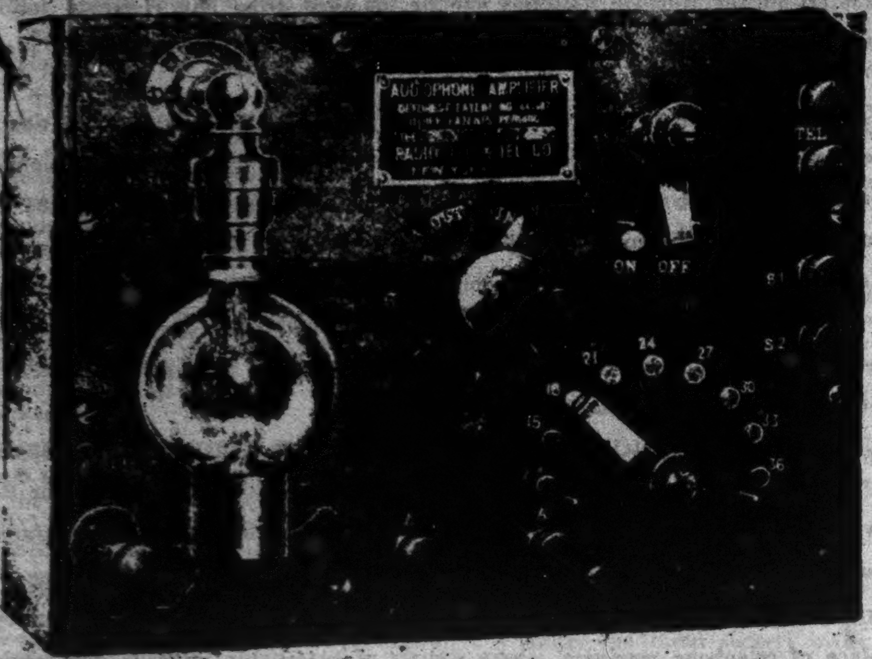
The batteries used determine their cost, but four good dry cells should give at least 30 useful actual operating hours, and a 30 ampere hour storage battery should provide 60 operating hours on a single charge.

USE OF THE AUDION AMPLIFIER WITH THE AUDION TIME RECEIVER.

The use of our Audion Amplifiers in connection with the Audion Time Receiver will permit reception of time signals where no other outfit can give satisfactory results. Wherever received signals are very weak, the amplifier will bring them in strongly, and if desired a loud speaking, high resistance horn may be employed in place of telephone receivers, where signals of reasonable intensity are received, so that any number of persons may hear them.



THE SINGLE STEP AUDION AMPLIFIER
Licensed for Private or Amateur Use Only



TYPE PJ1 SINGLE STEP AUDION AMPLIFIER.

The Audion Amplifier is an instrument which is used in connection with any detector, preferably an Audion Detector, for increasing the intensity of received signals from 5 to 10 times. It is not a detector itself in any way.

Through its use, messages can be read clearly which otherwise cannot be even heard. Its use enables the operator to receive over ranges which are not otherwise possible. it is the greatest improvement of modern times for increasing the range of any station.

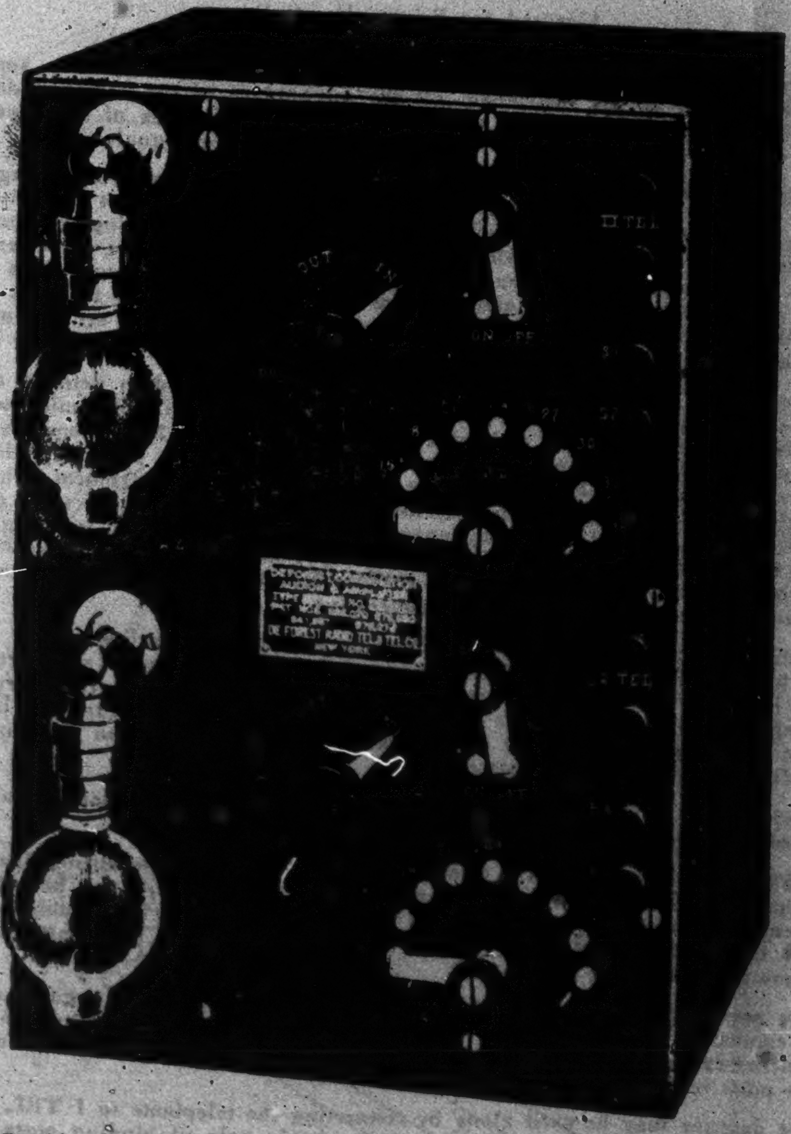
This type of Audion Amplifier will remain in adjustment indefinitely, like the Audion Detector, and is not appreciably affected by mechanical vibration, can be thoroughly relied upon, and amplifies the weak signals with absolute fidelity.

The case is of oak with a high waxed piano finish, measuring 9¼ by 7 by 10 inches deep over all. The front panel is of black composition resembling hard rubber. All metal parts are heavily nickel plated and the switch knobs and binding posts are of genuine hard rubber.

A local battery "A" of the same specifications as that for our other instruments is needed for it but is not furnished with it at the price listed. If this instrument is used in connection with an Audion Detector, the same battery "A" cannot be used for both, but two separate and distinct batteries must be employed.

The large hard rubber knob with the pointer, in the center of the panel, controls the rheostat, and the pointer must be turned to IN before the bulb is illuminated through the ON and OFF switch. Simply connect the telephone receivers to binding posts marked TEL and connect post S1 and S2 to the posts to which the telephones were formerly connected, and follow directions for operating as given for our detectors.

Both filaments of the Amplifier Bulb are used at the same time, but as they are burned at a lower temperature than those of an Audion Detector, they have a very long life.


OUT IN
ON OFF
DE FOREST COMBINATION
AUDION & AMPLIFIER
DE FOREST RADIO TEL & TEL CO.
NEW YORK

Combination Audion Detector and Single Step Audion Amplifier
Licensed for Private and Amateur Use Only.

COMBINATION AUDION DETECTOR AND SINGLE STEP AUDION AMPLIFIER.

Licensed for Private Use Only.

In this instrument are combined an audion detector and single step amplifier, giving the operator in one instrument all the advantages of the ordinary deForest Audion Detector (in itself from 1.5 to 3 times the sensitiveness of the crystal or electrolytic detectors) plus a five-fold amplification of these signals.

Equipped with this combination set an operator has an immense advantage over all those who use other types of detectors. We find this instrument is particularly attractive to all the higher class of operators, as in addition to enabling them to easily read stations many hundreds of miles further than can their neighbors, it tremendously simplifies the labor, and heightens the pleasure of wireless receiving. This on account of its utter dependability, and freedom from all delicate and frequent adjustments. When once the battery switch and rheostat are correctly set the operator *knows* that if he is once tuned to the distant station he will hear it *every time* it calls.

Moreover, on account of the extreme efficiency of the Audion detector and the negligible damping which it adds to the secondary receiving circuit, tuning with the Audion is much sharper than with other forms of detectors. Much looser coupling may be used, with corresponding freedom from interferences. Especially does this last feature hold for the combination detector and amplifier instrument, wherewith it is easily possible to couple so loosely that all signals, and static as well, are first rendered entirely inaudible with any unamplified detector, and then to bring up the signals (especially if slowly damped wave-trains be used) to a full audible intensity. By this means it is possible to read long-distance messages through static disturbances which render other forms of receivers inoperative.

In this connection we recommend increasing the damping qualities of the antenna system, by inserting therein a variable non-inductive resistance (as practised by Dr. Austin of the U. S. Bureau of Standards) to render same as nearly a periodic to static impulses as possible. It is then found that the Amplifier can still bring up the strength of signals over that of the static more than enough to compensate for their reduction by this added resistance.

Combinations of the Audion Detector with the two-step Amplifier and also with the three-step Amplifier are made.

The case of this instrument is of oak, with a high waxed piano finish. It measures approximately 9½ by 18 by 15 inches over all. All metal parts are heavily nickel plated and all switch knobs and binding posts are of genuine hard rubber.

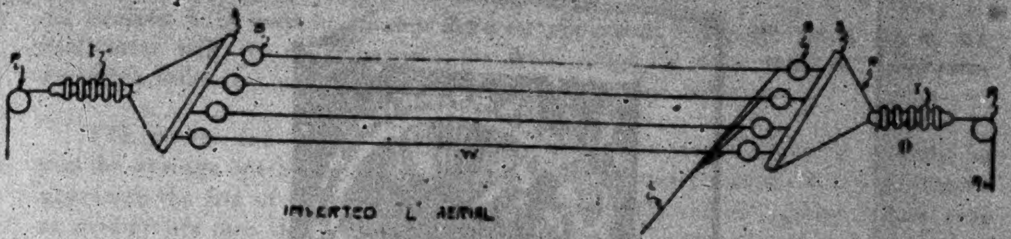
The lower bulb is that of the detector, and the upper one is the amplifier bulb, which has two grids and two plates.

The secondary terminals of the receiving transformer of the regular receiving set are connected to binding posts RA and RE. Reversal of these connections sometimes increases the efficiency of the set. A large variable condenser also connected to these posts is of great value in tuning.

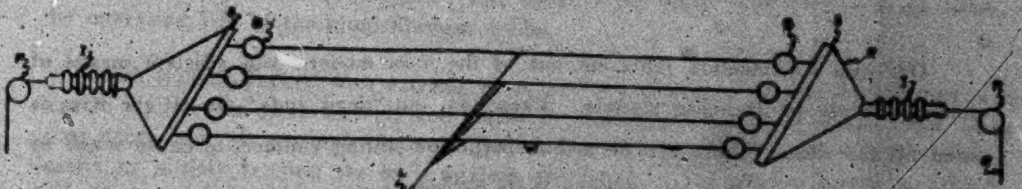
The detector may be used alone by connecting the telephone to I TEL. If both detector and amplifier are to be used, connect this pair of binding posts to posts S1 and S2, and connect the telephone to posts II TEL. Each bulb has its individual control switches. B1 and B2 control each battery "B," and each bulb has its own rheostat lettered OUT and IN.

All other directions for operating are the same as given herein for the Types RJ4 and RJ5 Audion Detectors.

Try reversing connections of both "A" batteries for best efficiency. Two separate "A" batteries are required for this instrument.



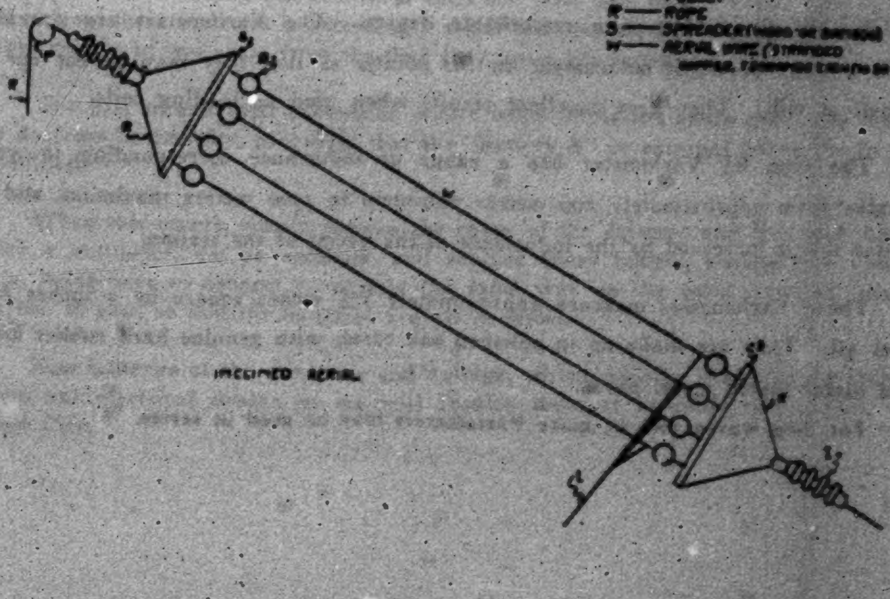
INVERTED 'L' AERIAL



'T' AERIAL

KEY

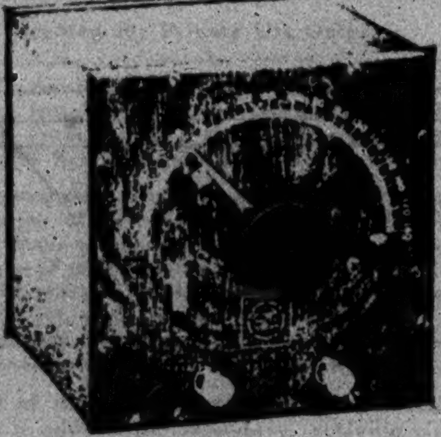
B —— BALL INSULATOR
I —— 10 INCH INSULATOR
L —— "LEADING IN" WIRES
P —— PULLEY
R —— ROPE
S —— SPREADER (WOOD OR BAMBOO)
W —— AERIAL WIRE (STRANDED COPPER, 7 STRANDS EACH [illegible])



INCLINED AERIAL

DEFOREST VARIOMETERS

TYPE RJ



DeForest Variometers represent one of the most modern and efficient means of tuning sharply to incoming signals. They have no "dead ends," as all the wire is used all the time. There are no switch points or sliding contacts to cause waste of the minute received currents through their resistance.

These Variometers are extremely sharp in tuning. They give excellent results through interference, and are recommended to every operator. They may be placed in a vertical position or horizontally as they are balanced so that they remain in any position where set. All adjustments are made with a single hard rubber knob, which simplifies tuning to a remarkable degree. The Variometers are provided with a short circuiting attachment on the pointer so that they may be cut out of circuit at will. They give excellent results when used as loading coils.

The type RJ Variometer has a range of inductance corresponding to wave lengths from approximately 200 meters minimum to 1500 meters maximum, and of course this is increased by the inductance of the aerial of the station.

These Variometers measure approximately 7¼ inches square by 9 inches high over all. They are made up in polished oak cases, with genuine hard rubber knobs and nickel plated metal parts.

For long waves, two or more Variometers may be used in series.

RENEWAL AUDION BULBS

Audion Bulbs are sold *for renewal purposes, for our instruments only, and then only on return of an old bulb or the wing and grid system of an old bulb.* They are not licensed to be used in any but deForest apparatus, and under positively no circumstances will we be responsible for their action in other than our apparatus. Amplifier Bulbs are not renewable in place of detector bulbs.

The quality and life of Audion Bulbs have been much improved recently, so that the average operating life is about 800 hours if properly used. While we cannot guarantee the life of a bulb, actual tests of bulbs selected at random showed even as greater life than this. So much depends upon the proper use of bulbs, however, that no guarantee of life can be given.

Audion Bulbs are furnished in two styles—those of standard degree of sensitiveness (style "S") and those of especial sensitiveness (style "X"). Every bulb is given two tests before leaving our factory, against a standard.

Amplifier bulbs are supplied only in "X" grade, in tantalum filament and Hudson or tungsten filament types. The latter types have from two to three times the operating life of tantalum filament bulbs.

Each bulb is packed with extreme care, and we cannot be responsible for breakage in transit. In general, very few bulbs are damaged in this way, and when this does occur, the plate simply becomes jarred out of line. It can be brought back easily by simply tapping the bulb against the hand in the proper direction, taking care that the plate and grid do not strike the filament.

RENEWAL BATTERIES FOR "BATTERY B" IN ALL DETECTORS AND AMPLIFIERS.

In each Audion Detector and Amplifier a number of flashlight batteries are contained. Each battery contains three cells and tests four to five volts. The current taken from these batteries is exceedingly small and they therefore generally last from eight months to two years from the time they leave our factory.

The first sign of their exhaustion occurs when received signals gradually weaken or decrease in intensity, providing that the "Battery A" or external battery is in good condition.

When this occurs, simply remove the cover of the detector and test each battery with a voltmeter, *not an ammeter,* and replace every battery testing four volts or less, being sure to connect in exactly the same way as the cells removed, that is, carbon to zinc, so that the batteries are all in series.

New batteries of the same size and voltage, which *must* be used, can be obtained from any electrical dealer, or we will furnish them at 25 cents each F.O.B. New York City.

PRICE LIST F.O.B. NEW YORK, N. Y.

Type RJ4 Improved Audion Detector	$ 18.00
Type RJ9 Audion Detector	25.00
Type PJ Single Step Audion Amplifier	65.00
Combination Audion and single step Audion Amplifier	110.00
DeForest Audion Time Receiver, less Telephones and Accessories	75.00
Special High Resistance Loud Speaker Telephone with Horn	50.00
Type RJ DeForest Variometer	20.00

Renewal Audion Bulbs*

Type S, Standard Grade Audion Bulb	3.50
Type X, Extra Sensitive Audion Bulb	5.00
Renewal Amplifier Bulb (Tantalum Filament)	6.00
Renewal Amplifier Bulb (Hudson Filament)	7.50

Above prices subject to change without notice.

We are in a position to furnish all accessories needed for the deForest Time Receiver, and will submit prices on request.

*AUDION BULBS WILL NOT BE SOLD OR LICENSED TO BE USED EXCEPT WITH OUR APPARATUS. Renewal bulbs supplied only on return of the wing and grid system of our burned-out bulbs.

All forms of Audion, Amplifier and Ultraudion protected by the following U. S Patents granted to Lee de Forest.

824,637	836,070	837,901	841,387	867,877	879,532	943,969
824,638	836,071	841,386	867,876	867,878	979,275	995,126

Other Patents Pending.

Most wireless dealers handle our Audion Detectors and Amplifiers. Write us for name of nearest dealer.

If your dealer does not carry a stock of our instruments, he will order them for you, or otherwise we shall be glad to receive your order direct.

The price of Hudson and Tungsten filament Audion detector bulbs has been reduced to the old prices of tantalum filament detector bulbs.

PLAINTIFF'S EXHIBIT No. 179.
DeForest Bulletin C-16 of 1916.

Bulletin C 16

De Forest
Type T Tubular Audion Bulb

"There is only one Audion - The De Forest"

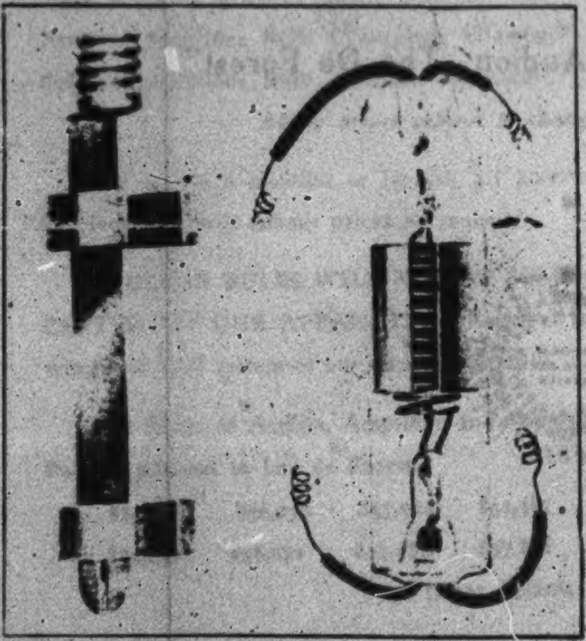
Manufactured by
DeForest Radio Telephone & Telegraph Co.
Sales Office 101 Park Avenue,
New York.

Cable Address: Radiotel, N. Y.

"THERE IS ONLY ONE AUDION—THE DE FOREST."

The Audion Detector is the most sensitive detector in existence. The Bulletin of the U. S. Bureau of Standards, Vol. 6, No. 4, Page 540, states that it is fully 50 per cent. more sensitive than any other known form of detector. It is the only reliable sensitive detector.

For the benefit of those amateurs who desire to experiment, and who do not wish to buy complete Audion Detectors with the necessary accessories, and for those whose limited means will not permit the complete instruments to be purchased, we have brought out the Type T Tubular Audion Bulb.



Commencing March 15th, 1916, this type of Audion will be sold separately, without the other parts necessary for a complete Audion Detector. It is licensed for amateur use only and is NOT interchangeable with the regular round Audion Bulbs.

This type of Audion Bulb gives very loud response to signals. Every bulb passes two tests by our experts and is thoroughly up to our standard of sensitive qualities. It is finished in only one grade—the best.

The life of the Type T Tubular Bulb is exceptionally long on account of the fact that the single straightline filament has no loops, and as there is no second filament, the Edison discharge to same is completely eliminated.

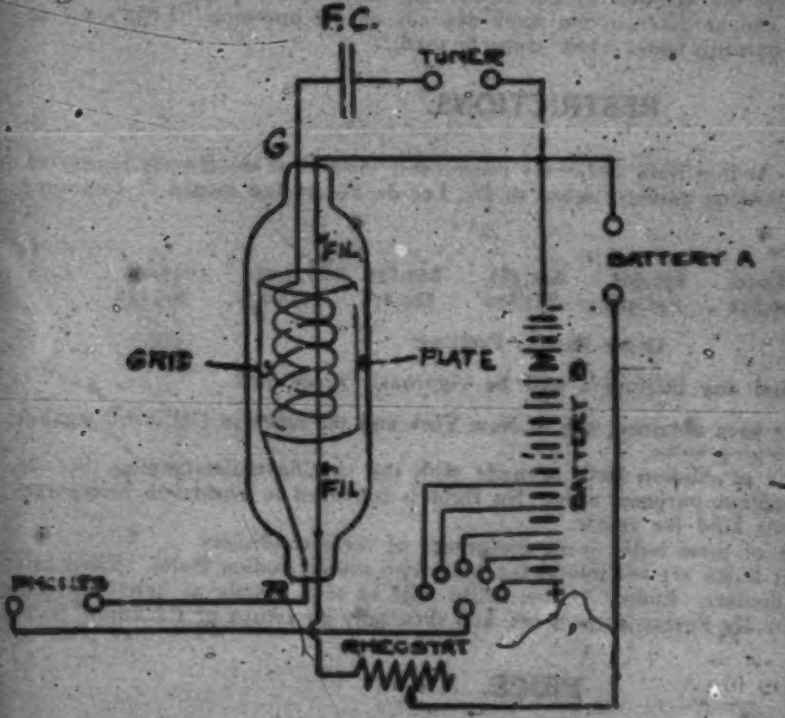
The plate or wing is in contact with the glass, preventing overheating. The filament is surrounded by a spiral grid.

This type of bulb is an excellent oscillator for the reception of continuous waves, being different in this respect than round Audion Detector Bulbs.

The grid is the spiral inside the tube and is connected to the green covered wire. The plate is connected to the red covered wire. The filament terminals are the white covered wires.

DIRECTIONS FOR USING
THE TYPE T TUBULAR AUDION BULB.

1. The diagram below illustrates the various accessories needed with the bulb. The rheostat is an ordinary battery rheostat, furnished by electrical supply houses. Battery B consists of 10 three cell flashlight batteries, each showing at least 3½ volts on a *voltmeter*. They are connected in series, with zinc of one to carbon of the next, and so on throughout the series. It is very important that each shows at least 3½ volts to 4½ volts and that they are properly connected together, otherwise the results will be very poor. The negative or zinc end of this battery *must* lead to the filament.



A switch is to be arranged as shown to cut in 6, 7, 8, 9 or 10 batteries at will.

The fixed condenser F.C. consists of two sheets of tin foil 2 inches square, separated by a *mica* sheet. This *must* be of first-class construction and of small capacity. A *small* variable condenser may be substituted.

Battery A should be a 6 volt storage battery of at least 40 Ampere hours capacity. Two sets of dry cells, each having 4 cells may be arranged in parallel instead, but the storage battery is recommended.

CAUTION

Do not permit either of the filament wires to come in contact with any circuit or any metal part carrying current. This might connect it to the Battery B and burn out the filament. *No credit* can be offered for a bulb burned out from *any* cause.

2. The bulb *must* be operated in a vertical position to give best service.

3. Always turn in all resistance on the rheostat before lighting the filament. Batteries recuperate on standing idle and the increase of voltage might burn out the filament.

4. Adjust rheostat to give normal filament brilliancy and adjust Battery B switch to best point. Then try reversing current from the lighting battery to find out which direction is better.

5. The bulb is most sensitive at a point just below that at which the hissing sound is heard in the telephones.

6. The receivers should be each of at least 1000 ohms resistance.

7. FOLLOW THESE DIRECTIONS TO THE LETTER. They are important.

GUARANTEE.

We guarantee the Type T Tubular Audion Bulb to have been tested by our expert and to have passed our standard which is fully 50 per cent more sensitive than any crystal or electrolytic detector, when leaving our factory.

We guarantee these bulbs to arrive in good condition. If a tubular Audion Bulb is broken in transit when shipped by us, and is returned *at once*, it will be replaced.

We will *not* replace any bulb for any other reason, whether due to breakage on account of negligence on the part of the operator or due to burning out of the filament.

No guarantee of life can be given as too much depends on the operator. Tests show an average life of over 800 burning hours when properly used.

RESTRICTIONS.

This and every other Audion Bulb and every conceivable method of using same is covered by one or more of the following patents, issued to Dr. Lee de Forest and owned or controlled by this company.

824,637	836,070	837,901	841,387	867,877	879,532	943,696
824,638	836,071	841,386	867,876	867,878	979,275	995,126

Other Patents Pending.

All and any infringers will be vigorously prosecuted.

Two injunctions have been obtained, one in New York and the other in California against makers and users of infringing bulbs.

The sale of this type of Audion Bulb is made with the specific understanding that the bulb is to be used for amateur purposes only. No right is conveyed to anyone to incorporate this bulb in any set of any kind for resale.

The purchase of one of these bulbs is an acceptance of these conditions.

The Type T Tubular Bulbs are not interchangeable with round Audion Bulbs. Their sale is entirely separate and distinct. Round Audion Bulbs will be sold exactly as heretofore, for renewal purposes only for De Forest instruments, and then only on return of De Forest Bulbs of similar type.

PRICE.

The price of the Type T Tubular Audion Bulb only is $5.50. The adapter to fit it to a screw socket will be furnished at 40 cents extra. It is not necessary to return the burned out bulb for renewal.

This Bulb and our other receiving equipment is furnished by 45 distributors conveniently located throughout the country. Name of nearest distributor furnished on request.

Write for Bulletins on Audion Detectors, Amplifiers and Receiving Sets if interested.

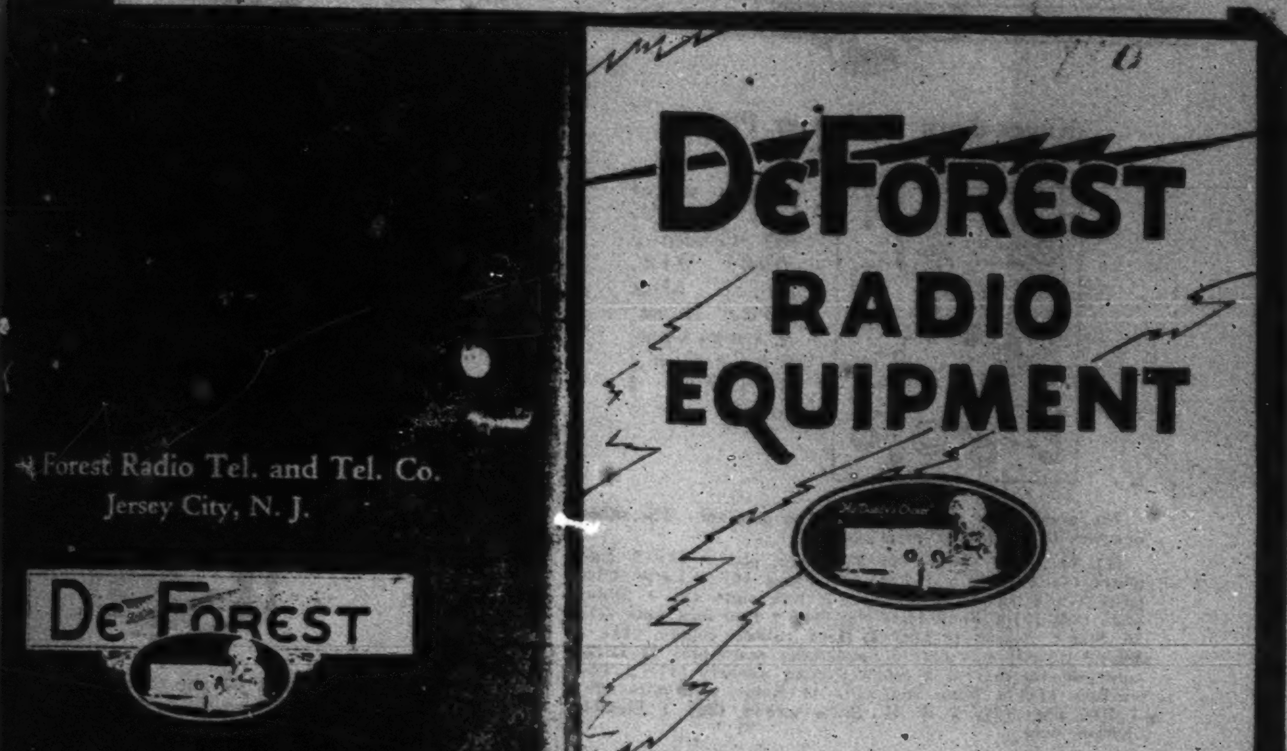
DE FOREST RADIO TELEPHONE & TELEGRAPH CO.

Sales office

101 Park Avenue New York, N. Y.

PLAINTIFF'S EXHIBIT No. 180.

DeForest Catalogue L.



Forest Radio Tel. and Tel. Co.
Jersey City, N. J.

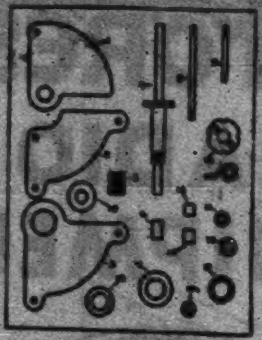
[illegible] [illegible] & HINDLE, INC., NEW YORK

DEFOREST
RADIO
EQUIPMENT

DE FOREST RADIO TELEPHONE
AND TELEGRAPH COMPANY
Inventors and Manufacturers
of High Grade Radio Apparatus
JERSEY CITY · NEW JERSEY

CATALOGUE L

Knock-down Condenser Parts



Complete sets of parts for CV-500 Condenser .0005 Mfd. Price, $3.00 *Code Word:* LAMBESER. *Shipping Weight:* 1 pound.

The numbers in parenthesis refer to diagram. The other numbers to number of parts required:

(1) 12 Rotor plates (2) 13 Stator plates (3) 2 End plates (4) 1 Shaft (5) 2 End bearings (6) 3 Large filler posts (7) 4 Insulating collars for lock nuts (8) 3 Stator plate rods (9) 1 Rotor plate rod (10) 4 End lock nuts (11) 38 Stator separators (12) 2 Hard rubber collars (13) 3 Round tie rod nuts (14) 3 Small filler posts (15) 12 Large rotor separators (16) 2 Small friction washers (17) 2 Flat washers (18) 1 Rotor nut (19) 11 Rotor separators (20) 5 Hex nuts (21) 2 R. H. Brass screws (22) 1 Flexible charade wire.

Radio Frequency Transformers for Reflex Sets

The Transformers illustrated are sold singly or in sets for use in the Reflex circuit. These are laboratory precision parts, made with the care characteristic of all De Forest equipment. They are numbered to indicate the position in the circuit. Price, $2.50 each.

2
De Forest
REFLEX
FREQUENCY TRANSFORMER

De Forest Combination Detector Amplifier Audions— Type DV-6 Vacuum Tubes

This new tube is of the metallic vapor operates without injury from 2½ to 6 volts dry batteries or storage batteries. It may with any standard circuit and in any type of ing apparatus without any change in wiring tube is as near a universal one as it is pos obtain. It functions with equal efficiency tector or an amplifier of audio frequency. It possible to use this tube successfully in ra quency circuits. It has small elements, there capacity, which is a very desirable feature fo frequency work.

These tubes are so called "hard" or gas because of this they are stable in their op They are excellent oscillators and have suffic put so that they may be used as radio frequen erators for measuring purposes. The filame sumption is small being approximately 2.8 wa depending on the use to which the bulb is put operated as a detector, the filament current than when operating as an amplifier. It is recommended that 40 volts be used on the plate when this tube is used as a detector and 40 to 60 volts when used as an amplifier. When working with a fully charged storage battery, never turn the rheostat on full. This tube should never be operated with more than five volts on the filament:

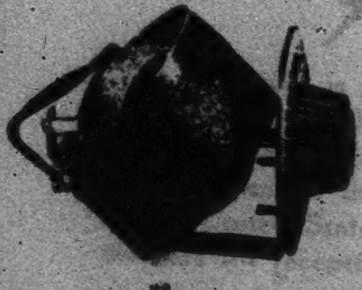
Filament 5 Volts; 5/10 of an ampere.

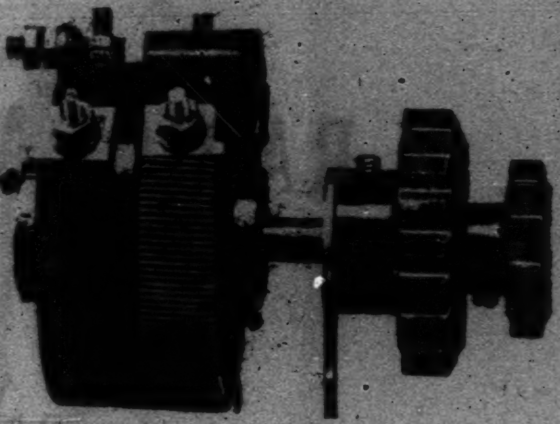
Plate Voltage, 40 to 60 Volts. Price $6.00.

Code Word: **Anda** *Shipping Weight:* **8 ozs.**

De Forest VL 180° Variocoupler Unit

This variocoupler is similar to that which has given such universal satisfaction in the De Forest D-7-A Reflex Receiver. It has twice the tuning efficiency of a 90 degree coupler, and quantity production has made it possible to sell this high quality laboratory tested product at a lower price than this type usually commands. Its wavelength range is 150 to 700 meters; it takes up only the amount of panel space necessary for its three inch dial; all metal parts are of brass, heavily nickel plated; solid Bakelite Dilecto XX grade tubing and silk covered wire are used throughout. Supplied with bracket and screws for either panel or table mounting; flexible leads provided for connecting to switch points. Advantageously used in connection with De Forest Type S-600 Variable B Battery switch. Price complete with Bakelite knob and dial, $3.75.





Combination Rheostat and Potentiometer Type RP-500

Unusual conservation of panel space and ease of control is afforded by this combination, on one moulded base with double knob control, of our F-500 standard rheostat and our P-1 potentiometer. Made also as RP-600, combining our F-600 power rheostat with the P-1 potentiometer, on common Bakelite mounted base, with concentric two-knob control. Price of either combination instrument, $2.00.

Made with the precision characteristic of all De Forest parts.

PLAINTIFF'S EXHIBIT No. 181.
DeForest Catalogue B of 1919.

DE FOREST

181
Plaintiff's

POST-WAR MODELS
of
RADIO APPARATUS

RADIO TELEPHONE AND TELEGRAPH APPARATUS
DeFOREST WIRELESS SYSTEM

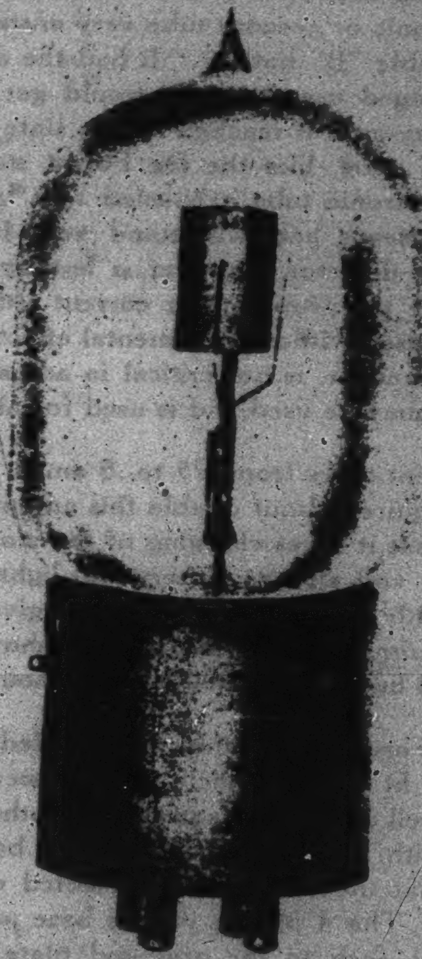
CATALOG B

Manufactured by
De Forest Radio Telephone & Telegraph Co.
1415 Sedgwick Avenue, New York

Cable Address: Radiotel, N. Y.

SEPTEMBER 1919

THE NEW DE FOREST "VT" AUDION



This tube is identical with the latest forms of tubes manufactured by the De Forest Radio Tel. & Tel. Co. for war work and is similar in shape to the VT-21 tube of which the De Forest Company made thousands for the Signal Corps during the war. In the United States its sale is restricted to amateurs and experimenters for reception only.

The tube consists of a highly evacuated vessel cylindrical, rather than bulbular, in shape enclosing the three elements, grid, plate and filament in the form of the old type T tubular De Forest tube with which amateurs are familiar. The plate is of nickle, cylindrical in shape and surrounds a helical grid also of nickle. The filament is a crimped tungsten wire passing through the center of the grid exactly as it did in the old style T type De Forest tube.

The chief difference between this tube and the type T tube of similar mechanical construction is in its evacuation. The old style type T was an ionic or gaseous tube very unstable in operation and requiring a variable "B" battery. It had the decided disadvantage that after continued use the tube would get "hard" and require more "B" battery until it reached such a state as to be inoperative. The new "VT" tube, like the De Forest standard tubes to-day, is purely an electronic tube exhausted to a very high vacuum, so that it is nongaseous and will stand very high plate potentials. When used as a detector, however, a battery of 20 to 40 volts is sufficient to give the proper plate current although voltages of 80 to 100 may be used without detrimental effect upon the tube. The "B" battery moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work.

The filament takes from .75 to .8 amps. only, whereas the old type T tube required about double this amount. This is a decided advantage in that it saves charging of the storage batteries at short intervals. A 4 volt storage battery will light the filament, but a 6 volt battery with a control rheostat will give better results. The filament is of crimped tungsten and tests show that the majority of these tubes will burn from 1000 to 2000 hours.

The De Forest "VT" tube is provided with the standard 4-prong base to fit the receptacle on all recent types of De Forest apparatus as well as apparatus put out by other concerns. The base is provided with a pin which fits into a bayonet lock in the receptacle, so that the tube may be inserted or removed by merely a slight twist. The 4 prongs on the base are connected, 2 to the filament and 1 each to the grid and plate. These prongs mesh with springs in the bottom of the receptacle and in this way perfect connection is made to the receiving apparatus without the use of awkward flexible leads, binding posts, etc.

Amateurs are warned that the only tube available on the market at present is the De Forest "VT" tube above described. All other tubes advertising an outside plate or outside grid are humbugs sold to get around the De Forest patents and are absolutely worthless from an operative point of view.

De Forest "VT" Audion **Price $7.00 each**

INSTRUCTIONS FOR USING THE DE FOREST AUDION

These instructions apply to the new type high vacuum tube such as was used by the U. S. Army and Navy and is at present being manufactured by the Moorehead Company exclusively for the De Forest Company under the latter's patents. The Marconi Company are sole distributors for us. The old type gaseous tube with the candelabra base can be used similarly, except that a variable "B" battery of from 20 to 50 volts is required. The gaseous type tubes are, however, no longer being manufactured.

The audion tube should not be inserted into its socket until the operator is definitely sure that the control rheostat is set at the point marked "Off" or with its full resistance in circuit.

A 6 volt storage battery should be connected to the binding posts on the audion panel marked "A Bat" making sure that the polarity is as indicated.

After the tube has been placed in the socket turn the rheostat up slowly until the filament burns with the brilliancy of a tungsten lamp. Connect a fixed battery of from 20 to 60 volts into the plate circuit and in series with the telephone receivers. If then the grid circuit is connected in the usual way (by means of the binding posts "RA"—"RE" found on all De Forest apparatus) to the tuner, the audion should be operative and signals should be received as the circuits are tuned to the proper wave lengths.

PLAINTIFF'S EXHIBIT No. 182.
DeForest Type-T Audion Tube.

De Forest "VT" Audion **Price $7.00 each**

PLAINTIFF'S EXHIBIT No. 183.

Circular of Sterling Reactivator.

183

Sterling
RADIO
EQUIPMENT

Vacuum Tube Reactivators

Home and Professional
Vacuum Tube Testers

"A" and "B" Battery Chargers

Full Range Audio Transformers
Radio Frequency Transformers

Pocket Ammeters, Voltmeters
and Voltammeters

Panel Ammeters, Voltmeters
and Milliammeters

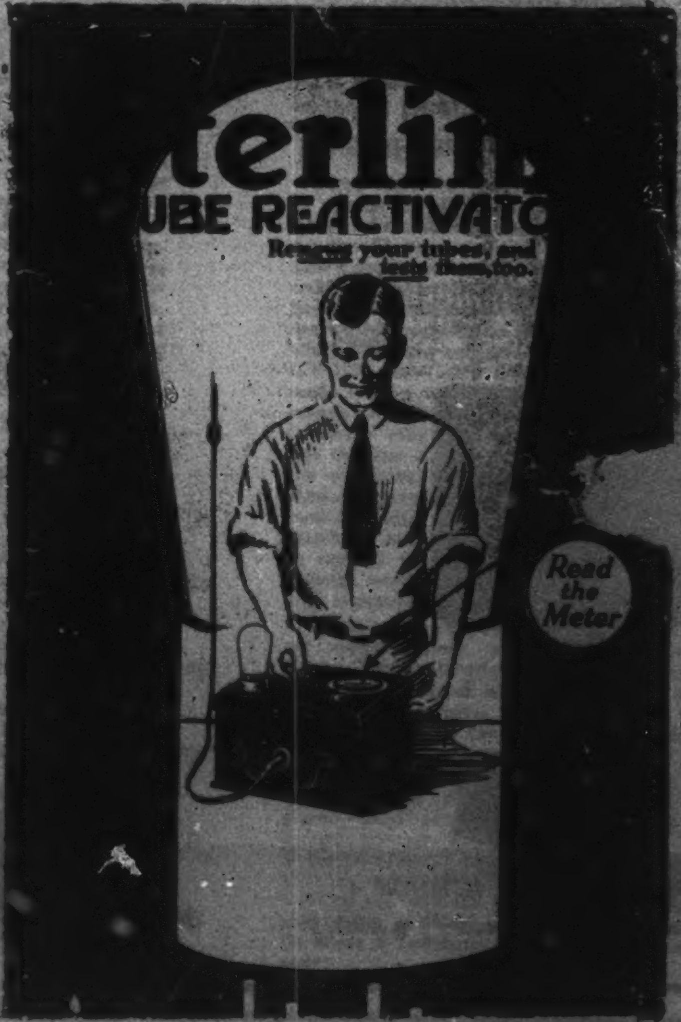
Soft Tread Rheostats
Potentiometers

Wide Range Microcondensers

Manufactured by
THE STERLING MANUFACTURING CO.
2831-53 Prospect Avenue
Cleveland, Ohio, U. S. A.

Electrical Manufacturers since 1906

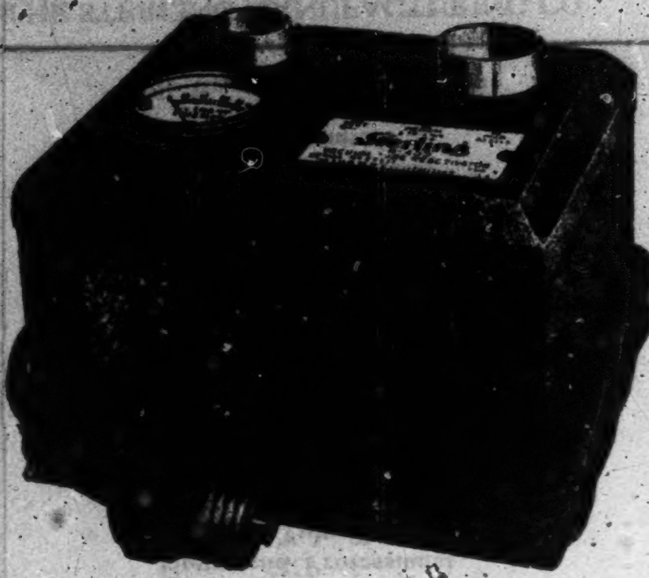
Form No. 60


terlin
UBE REACTIVATO
[illegible] your tubes, and tests them, too.
Read the Meter

The Sterling No. R-403 Vacuum Tube Reactivator

Every User and Seller of Vacuum Tubes Needs This—

For
UV-201-A
C-301-A
and
UV-199
C-299
Types of
Vacuum
Tubes



Size—6"x7½"x5" high.
Weight—4¼ lbs. net.
Portable, handle on back.
Black frostine finish.
Silver etched meter dial.
Rubber feet.
Nickel sockets for large and small tubes.
5' lamp cord with plug.
Meter Equipped.

Sterling

Sterling Meter Equipped
Portable

TUBE REACTIVATOR

A Promoter of Good Reception
An Economizer of Tube Expense
A Tube Saver for the Set Owner
A Profit Maker for the Radio Dealer
A Time and Money Maker
for the Service Man

THE EMISSION METER

shows—

Whether a Tube Actually Needs Reactivation
Just How Much Its Amplification Has Been Improved By The Process.

LIST PRICES

For 110 Volt (A.C.) Current 50 or 60 cycle frequency— $12.50
For 110 Volt (A.C.) Current 25 or 40 cycle frequency— $14.00
West of the Rockies—Slightly Higher.

Manufactured by
The Sterling Manufacturing Company
2831-53 Prospect Ave., Cleveland, O., U. S. A.—Electrical Mfgr's. since 1906

How to Get the Most Out of Your Radio Tubes—Most Economically

USERS of Radio sets are of two general classes—

> *—those who derive their pleasure from listening to continuously good radio, preferring not to concern themselves with the how and why of it.*
>
> *—and those who delve into the technicalities of radio construction and find pleasure or profit in the results of their own handiwork.*

Sooner or later, however, *all* who enjoy radio, whether layman or expert, will realize the importance of the results which can be obtained by renewing the life of vacuum tubes. And this is true because not only does the quality of radio reception depend upon the condition of tubes, but one of the heaviest items of a set's maintenance expense results from tube replacements.

The radio expert is already familiar with the simple process which renews the life of what is known as the thoriated filament types of vacuum tubes. This process is called Tube Reactivation. Filament reactivation of vacuum tubes is not a mystery beyond the layman's understanding, nor is it beyond his interest, because by tube reactivation he can be assured of getting the utmost in quality of reception and in length of service from his vacuum tubes, and at the same time save a large portion of his tube expense. These two advantages, therefore, should be well worth the few moments spent in learning how tubes can be quickly and thoroughly reactivated, and why the process can be repeated time after time.

What Are the Symptoms of Weakened Tubes?

The conditions which definitely indicate to the set owner that the tubes should be checked up immediately are those with which most set owners are already familiar, although they seldom understand the cause. Some of the most common difficulties are weak signals on distant stations, loss of volume on local stations, or general poor quality reception from all stations. Another indication of an impaired tube, or tubes, is found in the necessity of turning the filament current higher and higher in an effort to force the tubes to function as they originally did. This is an injurious practice, because it not only draws excessively on the A battery and pulls down the volume of the good tubes in the set, but the excessive filament voltage damages the tubes and speeds the hour when they become wholly inoperative.

It should be remembered that no radio set is better than its weakest tube. And no set will long continue to operate efficiently nor economically unless all of its tubes are given frequent tests, and reactivated when the evidences of deterioration appear. The process of reactivation or renewing the life of a vacuum tube filament is more simple than charging an A battery. Less time is required to do it. The result is more lasting, the cost much less.

Reactivate Tubes of the Thoriated Filament Types

The tubes found in most sets are of two types known as UV-201A and C-301A (large tubes) and UV-199 and C-299 (peanut tubes). In these tubes are three elements—the plate, the grid and the filament. Each of these elements has a very definite work to do, but most important is that of the filament. It is upon the *condition* of the filament that the functioning of the other elements depend. And what is more important, this condition largely controls the quality of reception that can be had from a receiving set.

Every time a tube is used the filament performs its work less efficiently than the time before. Indeed, from the very moment of its first use, the filament goes through a continuous process of change and deterioration until finally the tube becomes lifeless and fails to amplify. This falling off in tube efficiency may be abrupt under certain conditions, but usually it is so gradual that the user either wastes much time in looking elsewhere for his difficulties or discards his tubes altogether. *Nine out of ten of these discarded tubes could have been made to give many more months of good service by the process of reactivation.*

So, by a better understanding of the importance of the filament, just how it functions, and a knowledge of the method now offered to renew its life, home operators of sets may have good reception continuously and at a fraction of a tube cost heretofore necessary.

What Actually Happens to the Filament?

First, let it be understood that for a vacuum tube to operate at all its filament must give off electrons. This is technically known as "filament emission". As the filament emission becomes less and less the tube's ability to amplify diminishes and the quality of reception falls off in proportion. New tubes should possess high filament emission, but this constantly decreases according to the amount of use or abuse to which they are subjected. In the UV-201A, C-301A, UV-199 and C-299 types of tubes, the filament is made from a special tungsten wire in which a metal known as thorium has been combined. The filament is active only when there is a layer or coating of this thorium on the surface, and, as previously stated, the condition of this coating governs the amount of filament emission. Operating a set at too high filament voltage will destroy the coating quickly and result in rapid deterioration of the tubes; and even at normal voltage the filament usually deteriorates through continuous use. In either case, poor reception will eventually result.

When poor reception becomes apparent, too many set owners—those who are unfamiliar with the process of reactivating the thorium coating—discard one or more tubes because they have been long in use. Other owners, not equipped to properly test tubes, replace the tubes believing the discarded ones must be worthless. *Nothing could be farther from the truth.*

A thoriated filament tube should not be declared "dead" simply because it fails to give the required amount of amplification. So long as the thoriated filament tube will burn, reactivation seldom fails to restore it. By the Sterling method of controlling the process of reactivation, the renewal of such tubes to their original amplification values may be made a certainty, and may be repeated over and over.

How It Is Possible to Make Tubes Come Back to Life

The thoriated filament tube becomes weak or lifeless as the thorium disappears from the surface of its filament. It is obvious that if the coating of thorium could be restored to the surface of the filament the tube would again be capable of amplification. This seemingly impossible result can be easily accomplished with the proper equipment. Inside the filament there remains a considerable supply of thorium and this is what makes recuperation possible, not only once, but repeatedly.

By the use of a simple and inexpensive electrical device, the STERLING REACTIVATOR, it is found that by burning the filament for a very short time at a high temperature followed by a lower temperature for a longer period, the thorium molecules are brought to the surface of the filament where a new thorium layer is formed. Thus, the amplifying ability of a seemingly exhausted tube is restored to its original strength. Some tubes have been successfully treated as many as seventy-five times with the Sterling Reactivator.

The Sterling Metered Instrument Takes the Guesswork Out of Tube Reactivation

Unless some means is provided for first actually testing a tube's emission, also for retesting to determine its increase in emission during and after a treatment, then tube reactivation becomes an uncertain process.

(1) When does a tube need reactivation?
(2) Is emission improving during treatment?
(3) What is its filament emission afterward?

Because of the importance of these three questions, the Sterling is provided with a FILAMENT EMISSION METER which removes all doubt as to what the reactivator accomplishes. For example, if, when a UV-201A tube is inserted in the Sterling instrument, the emission meter shows a reading lower than 20, reactivation is necessary. This test can be made instantly simply by moving a lever. Very often tubes will be found in which the filaments are slow to respond to reactivation, yet are capable of much higher emission than will be shown after one short treatment. For example, if the meter indicates only 30 to 40 after the tube has been in the instrument for the prescribed time, the "Low" or "Test" voltage generally results in increasing the emission. Without the meter in the instrument for checking the emission, the need of a second treatment would many times not be apparent, and even if it were tried the user would not be *certain* that he had increased the tube's amplification ability in the least.

Moreover, without an emission meter it is impossible to match tubes—to group them of approximately equal filament emission. In fact, without a meter the determination of the relative filament emission of tubes, to obtain the best reception from a set, is no more than a matter of guess-work. With the Sterling metered instrument results are *observed*, *controlled* and known to be *definite*.

Reactivate Tubes Only When a Filament Emission Test Shows They Need It

Reactivating tubes at regular periods without first testing them to determine the amount of filament emission present, is *not* recommended. Unless the filament needs reactivation, the process has the tendency to shorten the useful life of the tube. It is good practice, however, to check emission frequently to insure good amplification, also to be certain that one or more tubes are not being operated at too low efficiency, and that tubes are not being blamed for other possible defects in the receiving set.

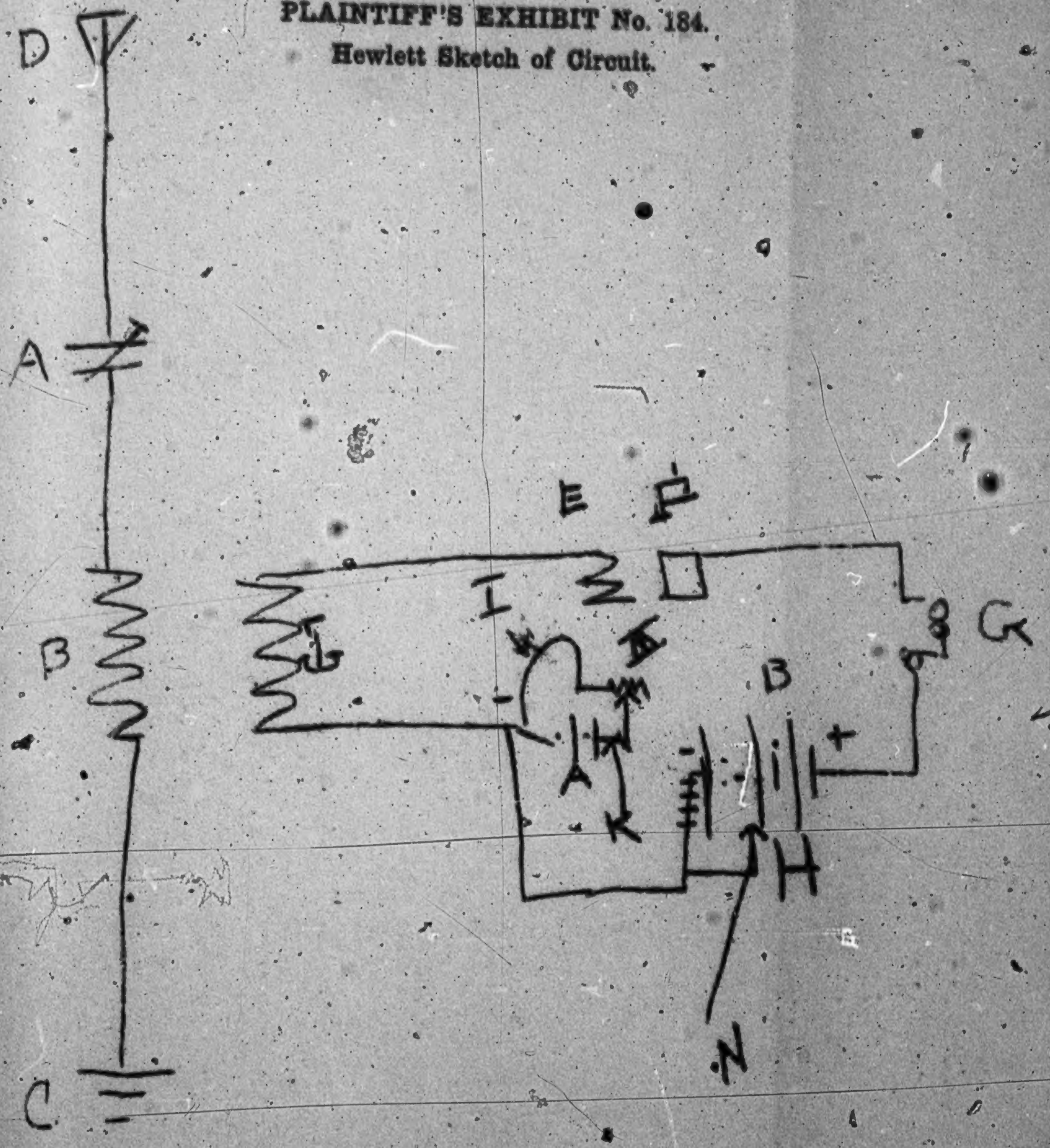
The filament emission meter used in the Sterling instrument is a unique feature, essential to intelligent treatment of tubes and to accurate results. By its use, treatment of most thoriated filament tubes may be repeated many times with the result that the tubes will give their original amplification after being reactivated. Complete Instructions for operating are attached to the bottom of each instrument.

Sterling R-403 Tube Reactivator is just as essential to the proper care and use of vacuum tubes as is the battery charger to the battery. It is built with the same care that has for more than fifteen years made every Sterling electrical product worthy of its name.

In case your Dealer can't supply a "Sterling" write the factory direct.

PLAINTIFF'S EXHIBIT No. 184.

Hewlett Sketch of Circuit.


D
A
B
C
E
P
I
G
B
A
K
H
N
-
+
-

PLAINTIFF'S EXHIBIT No. 185.

Letter and Data Sheets Furnished by Witness Kelly.

October 28, 1926

Dear Mr. Hogan:

In the preparation of this data two slight errors were detected. The pressure for Exhibit 32 should be about one-half that previously given. The actual slope of the lower line for 9.111 should be a little steeper.

These matters will be alluded to (so I understand) in my further examination this morning.

M. J. KELLY.

8 sheets of data herewith.

Type 7510 with N_2

	Pr. .002 microns	.02 microns	.64 microns	1.2 microns
E_B	I_B	I_B	I_B	I_B
20	.30	.30	.30	.30
30	.90	.90	1.10	1.20
40	1.95	1.94	2.30	2.60
50	3.15	3.15	3.90	4.40
60	4.80	4.81	5.80	6.50
70	6.50	6.48	8.10	9.40
80	8.60	8.60	10.60	12.70
90	10.60	10.60	13.30	15.80
100	12.80	12.82	16.30	20.10
110	15.25	15.22	19.20	24.0
120	17.65	17.67	22.30	28.4

All I_B in milliamperes.

Audion 64-91

Ex. 30

$E_C = 0$

E_B	I_B microamps.
20	7.5
30	15.0
40	25.0
50	43.
60	65
70	95
80	135
90	185
100	225
110	265
120	315.

Plaintiff's Exhibit No. 185

Tube No. 9399

Arnold 105 approx.

$E_C = 0$

E_B	I_B in microamperes.
20	1.8
30	12.4
40	36.0
50	74.8
60	128.4
70	196.4
80	277.
90	377.
100	487
110	616
120	756
130	904

102-D

$E_C = 0$

E_B	I_B
10	.001
20	.010
30	.034
40	.076
50	.146
60	.250
70	.370
80	.500
90	.664
100	.848
110	1.040
120	1.260
130	1.490

Milliamperes.

Ex. 32 Tube 105

E_B	I_B
20	—
30	0.5
40	5.5
50	16.0
60	32.0
70	57.0
80	92.5
90	137.
100	191
110	256
120	332
130	406.

Microamperes.

Arnold Ex. 30

$E_B - 10$, $E_C + 100$ volts from negative end of fil.

10^{-7}amps.

	I_A	I_C	I_{B_1}	I_{B_2} Leak.	$I_{B_1} - I_{B_2}$	
	1.10 A.	.65 ma.	3.12 × 10^{-7}amp.	2.61	.51	Pr
	1.13	1.10	3.54	2.48	1.06	micron
	1.17	1.60	4.13	2.69	1.44	.0144
2 min.	1.18	1.60	4.17	2.69	1.48	.0148
4 min.	1.20	1.60	4.19	2.78	1.41	.0141
8 min.	1.17	1.60	4.16	2.70	1.46	.0146

Load Test Plate Pos. Grid Neg.

I_A 1.15 amps. × 10^{-7}amps.

I_B	E_B	E_C	I_{C_1}	I_{C_2}	$I_C = I_{C_1} - I$
.3 na.	150	−0.67	5.20	3.65	Gas. 1.55
thruout.	160	2.2	6.10	4.15	1.95
	180	4.4	6.85	4.70	2.15
2 min.			7.00	4.80	2.20
4 min			7.05	4.90	2.15
6 min			7.10	5.00	2.10

Arnold Ex. 32

Pr in microns $= K_3 \times I_B$ (in microamps).

Ionizat— Meas. Grid Pora, Plate Neg.

See separate page.

$E_C = + 100 \quad E_B = - 10 \times 10^{-7}$ amps.

	I_A	I_C	I_{B_1}	I_{B_2} Leak	$I_{B_1} - I_{B_2}$	Pr Micas u
	1.26	.92	.48	.19	.29	—
	1.34	2.27	.92	.19	.73	.0051
2 min.	1.34	2.30	.98	.23	.75	— .0053
5 min.	1.36	2.3	1.06	.27	.79	— .0055
10 min.	1.36	2.31	1.04	.28	.76	— .0053

I_A—Approx const.

Load Test — $\times 10^{-7}$ amp.

I_B	E_B	E_C	I_{C_1}	I_{C_2} Leak	I_C Gas.
.4 m.a.	130	— .37	1.17	.18	.99
.4 m.a.	140	— .74	1.32	.21	1.11
	150	—1.10	1.42	.25	1.17
same thruout	160	—1.47	1.54	.26	1.28
	170	—1.80	1.65	.33	1.32
	180	—2.20	1.72	.36	1.36
2 min.	180	—2.25	1.80	.40	1.40
6 min.	180	—2.20	1.89	.46	1.43
0 min.	180	—2.10	1.77	.39	1.38
4 min.	180	—2.20	1.80	.33	1.47

$P = K\ I_{Gas.}$

Thruout P in microns

K_G in microamperes.

K_1 for std manometer for 20 milamp. at E_C 100 E_B — 10 is .005.

K_2 for × — 9450 — × 9452 for 20 milap at E_C 100 E_B — 10 is .010 by comparison with standard for range of pressures.

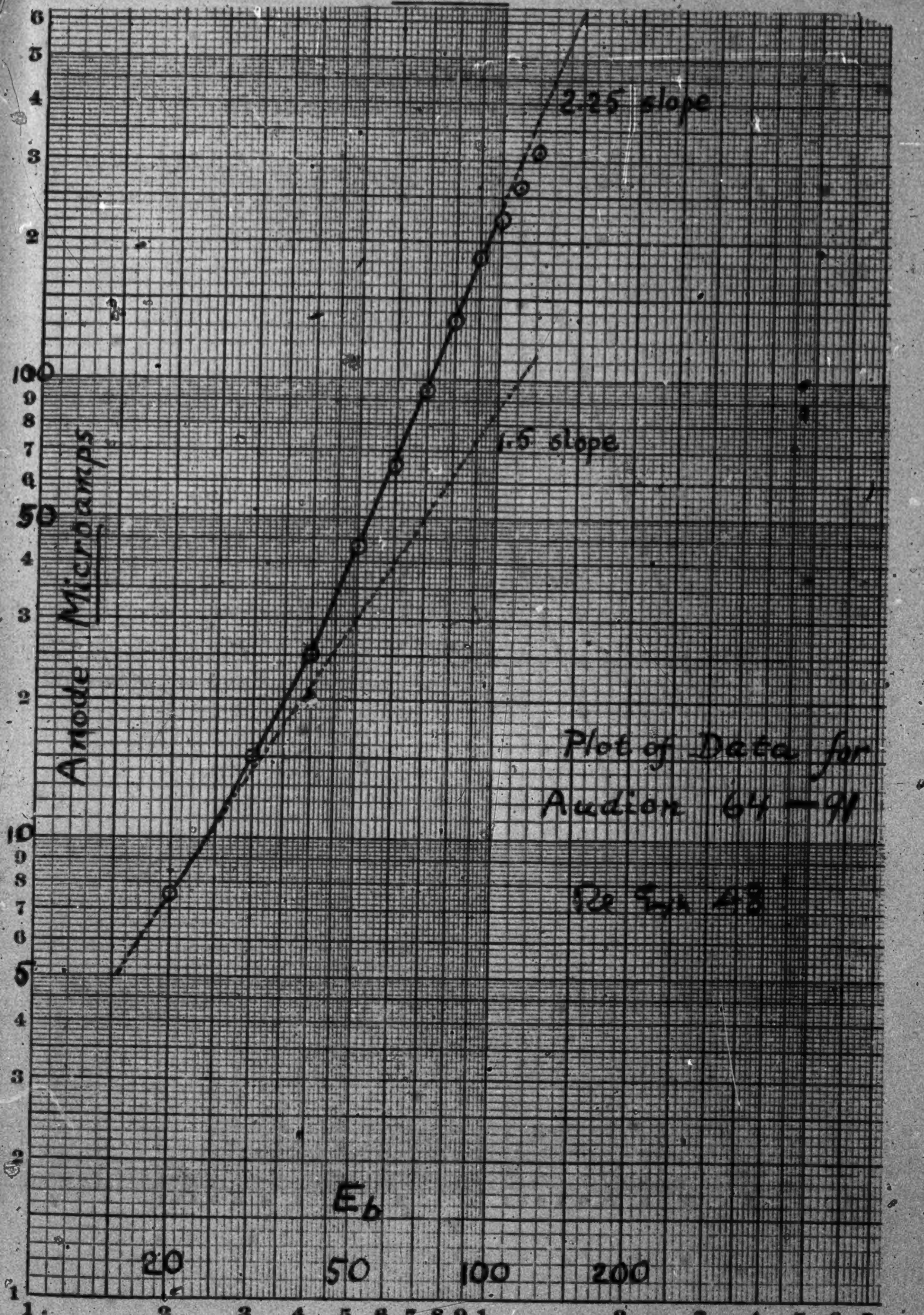
K_3 for $I_B = 2.3$ milamperes $= 0.07$.

K_4 " $I_B = 1.6$ " " $= 0.10$

K_3 and K_4 determined by keeping for fixed and varying electric current to grid over range of values including 1.6, 2.3 and 20 m.a.

PLAINTIFF'S EXHIBIT No. 186.

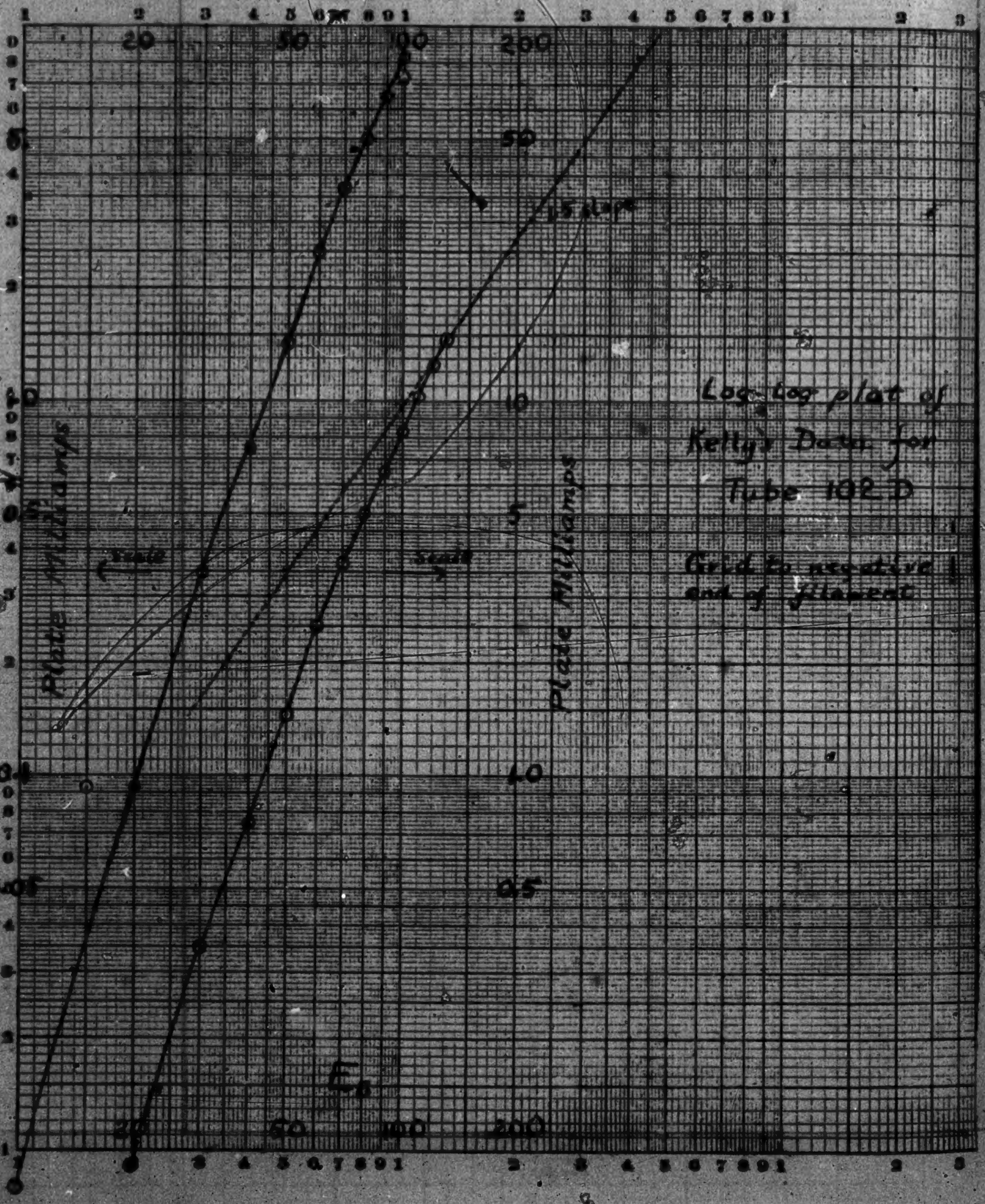
Hogan Logarithmic Plot of Audion 64-91.



187

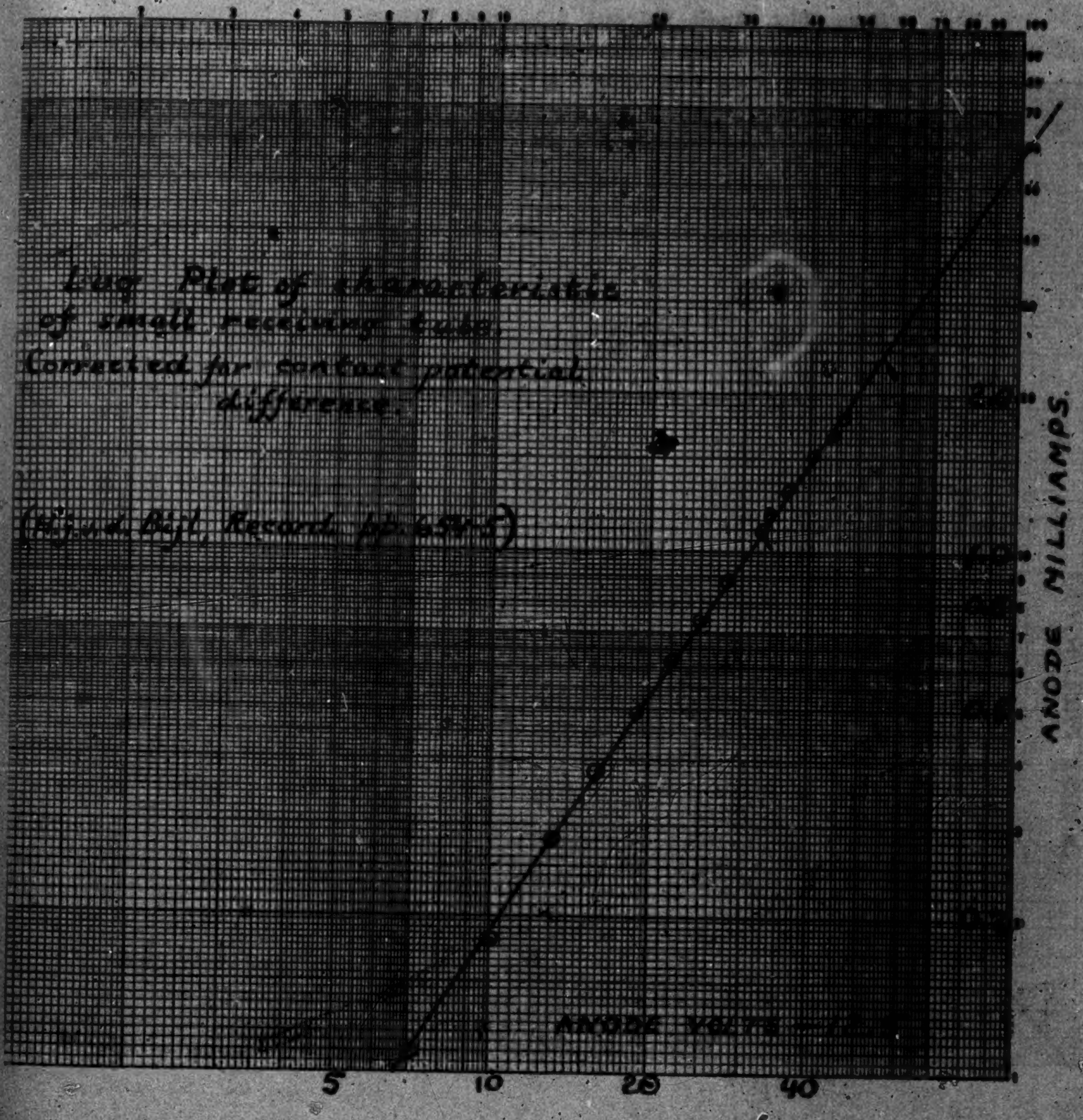
PLAINTIFF'S EXHIBIT No. 187.

Hogan Logarithmic Plot of Kelly Data for Tube 102-D.



PLAINTIFF'S EXHIBIT No. 188.

Hogan Logarithmic Plot of Characteristics of Small Receiving Tube Corrected for Contact Differential.

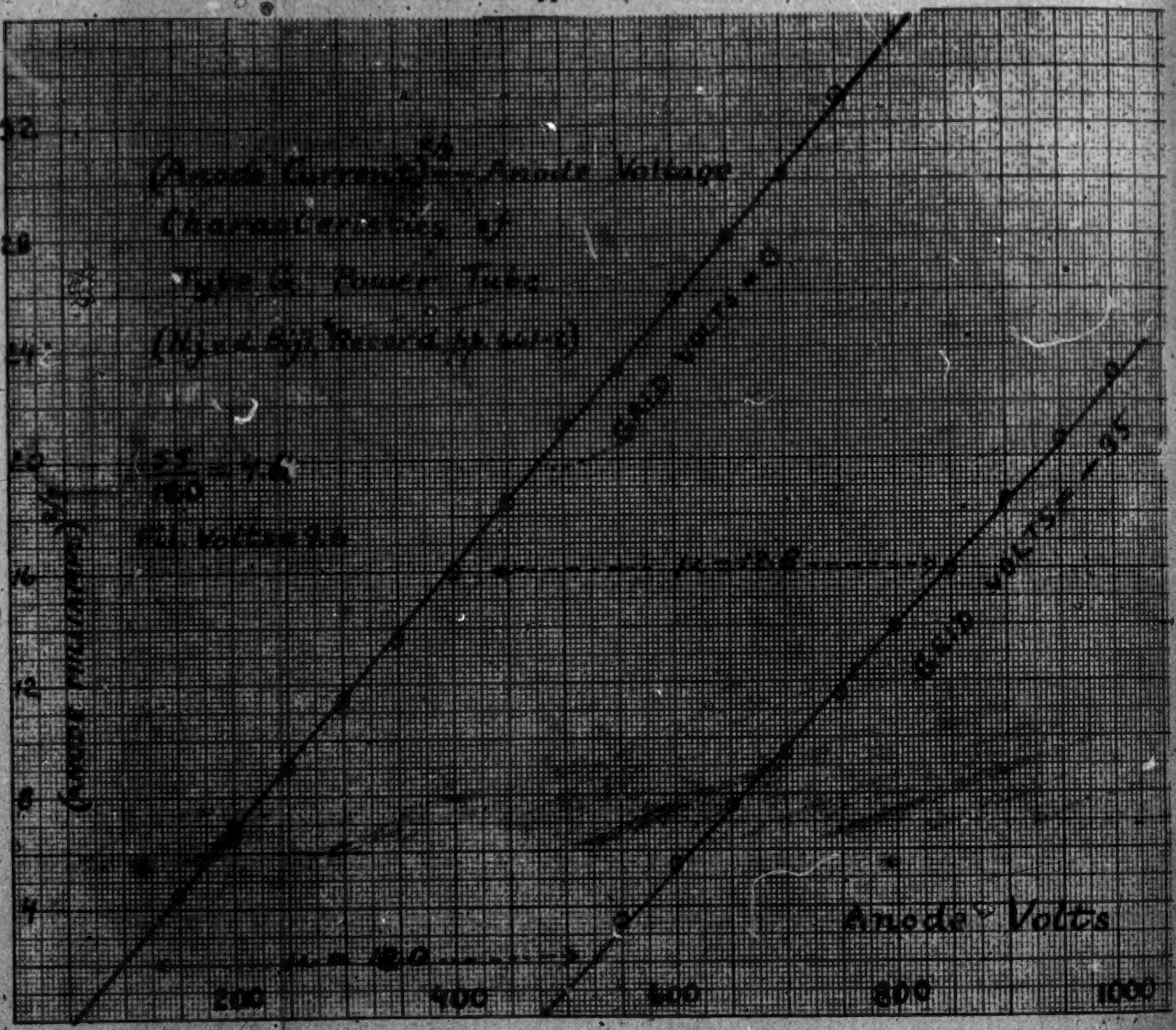


Log Plot of characteristic
of small receiving tube.
Corrected for contact potential
difference.

(H. J. v. d. Bijl, Record, pp. 658-5)

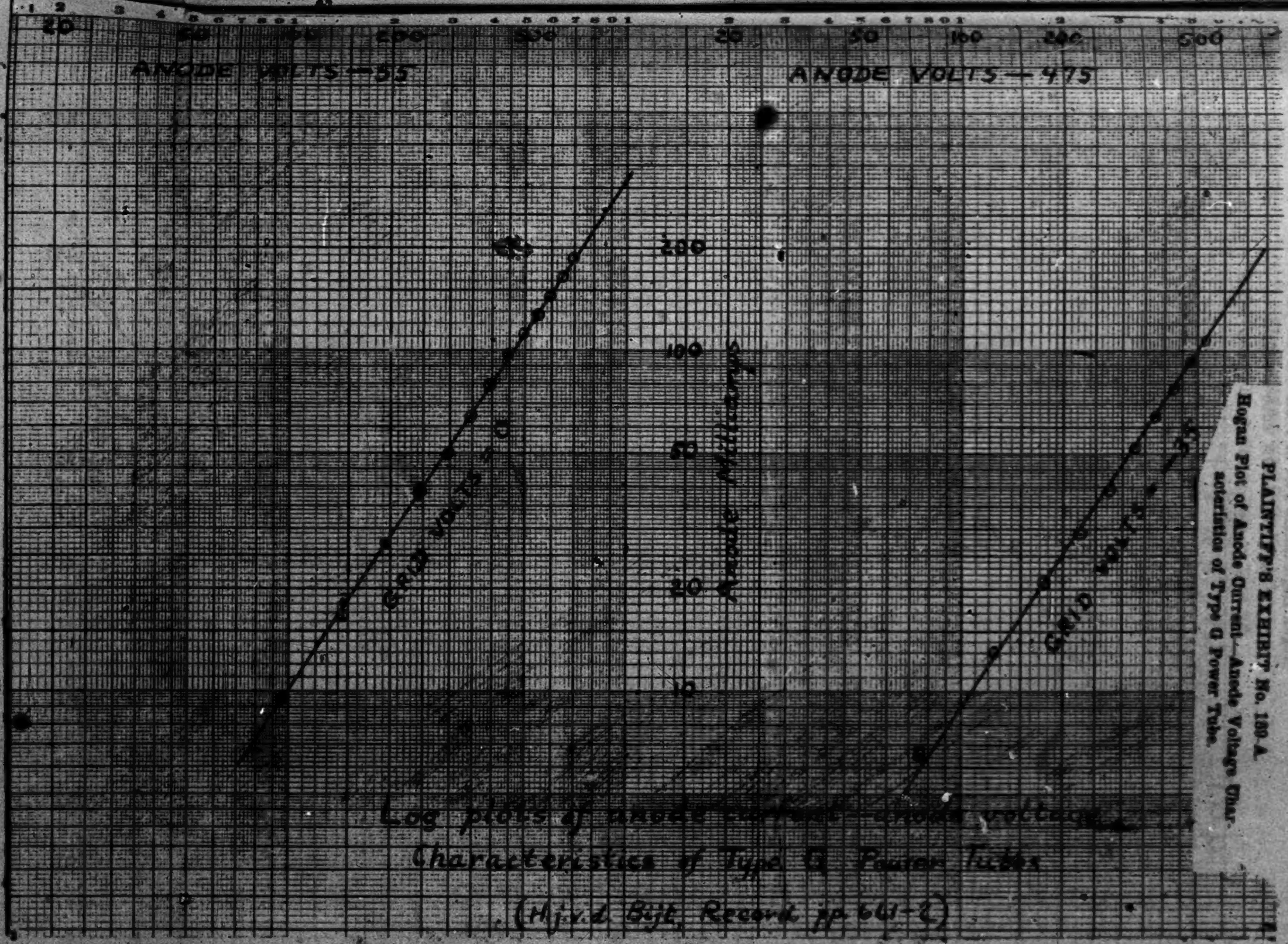
PLAINTIFF'S EXHIBIT No. 189.

Hogan Plot (Anode Current) 2/3—Anode Voltage Characteristics of Type G Power Tube.



PLAINTIFF'S EXHIBIT No. 189-A.

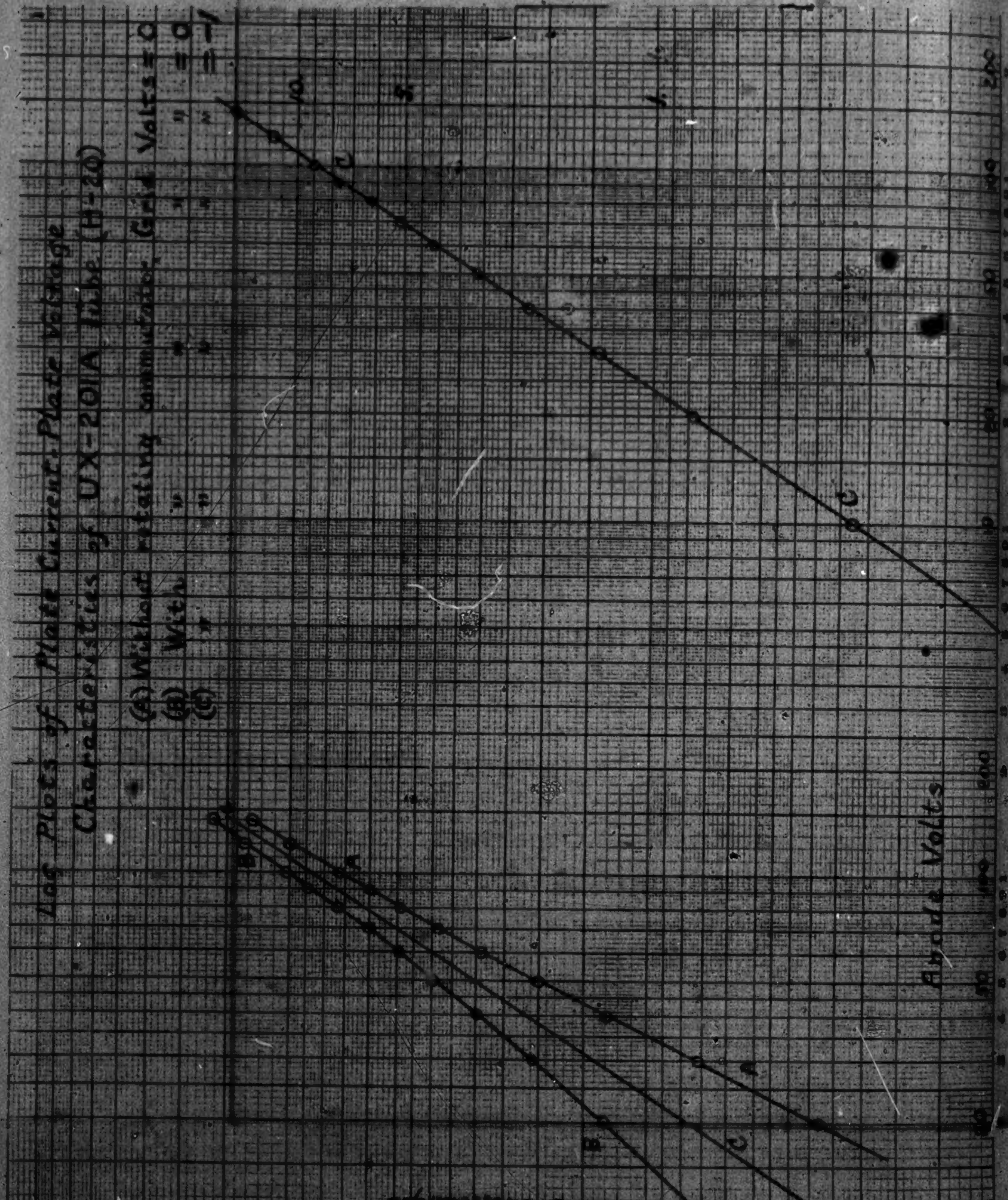
Hogan Plot of Anode Current—Anode Voltage Characteristics of Type G Power Tube.



Log plots of anode current—anode voltage
Characteristics of Type G Power Tubes
(Hj.v.d. Bijl, Record pp 641-2)

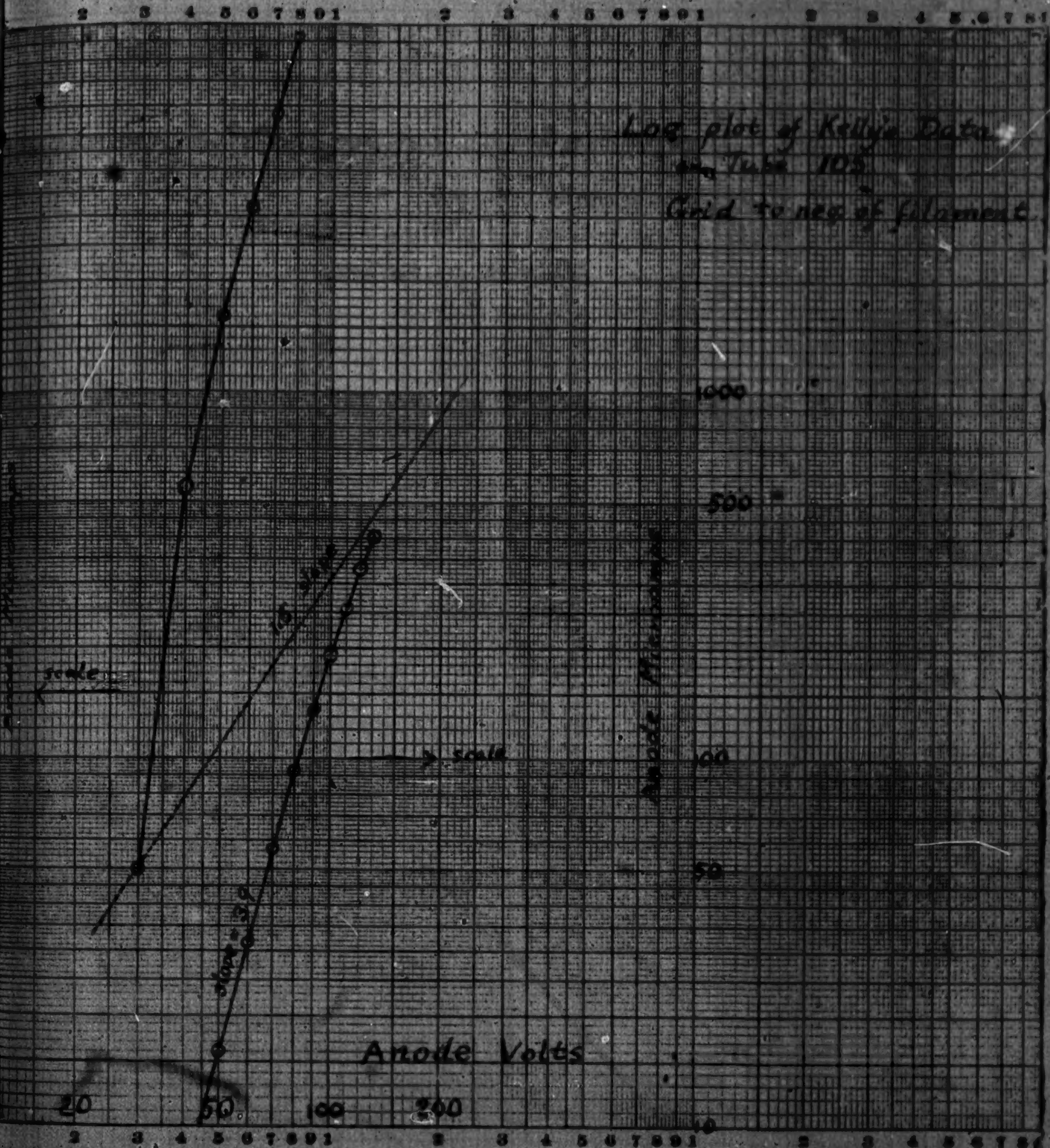
PLAINTIFF'S EXHIBIT No. 190.

Hogan Logarithmic Plot of Plate Current-plate Voltage of UX-201A Tube (H-20).



PLAINTIFF'S EXHIBIT No. 191.

Logarithmic Plot of Kelly's Data on Tube 105.

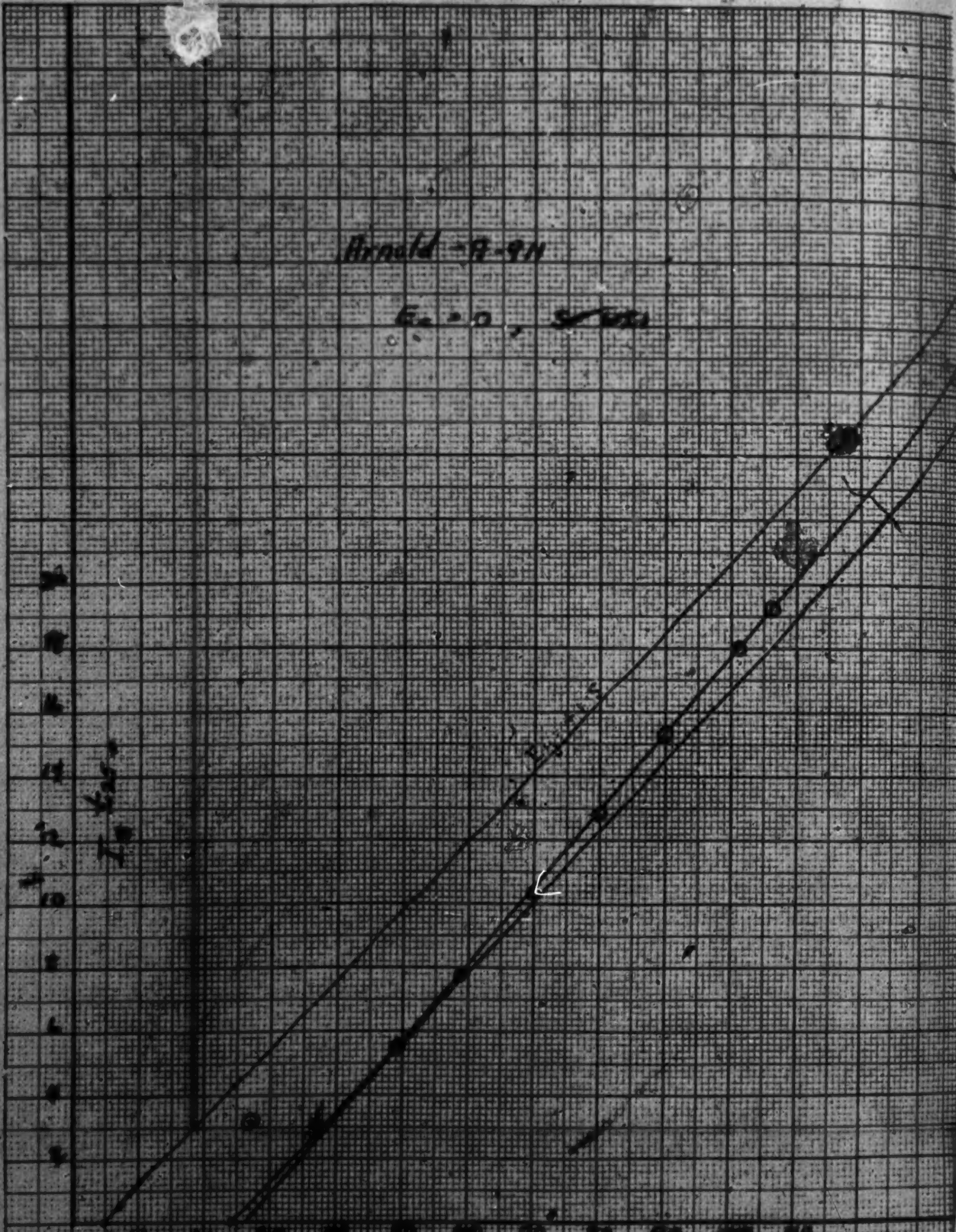


PLAINTIFF'S EXHIBIT No. 192.

Hogan Copy of Defendant's Exhibit 54-A, with Additional Lines Thereon.

BELL TELEPHONE LABORATORIES

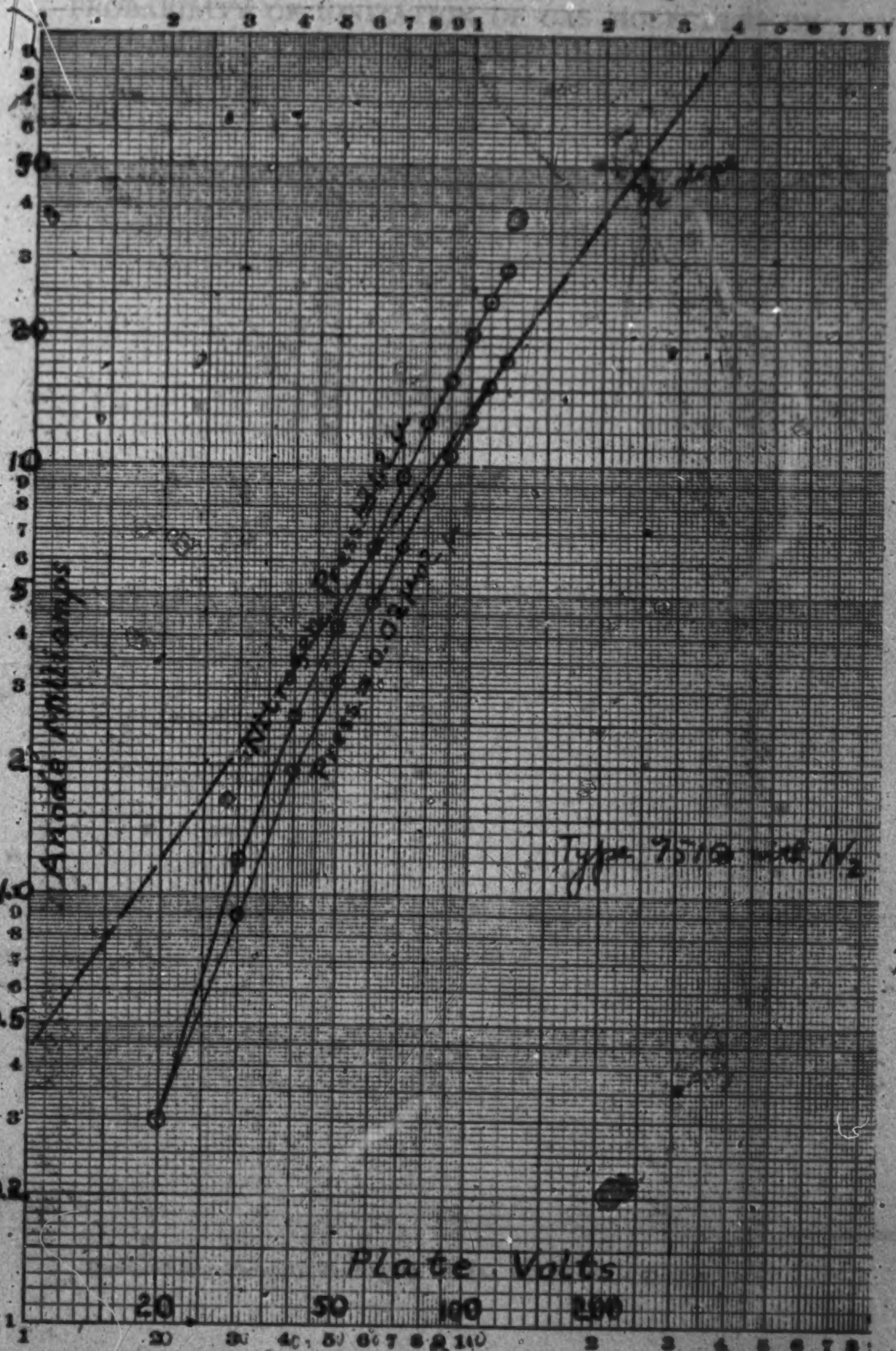
Sketch No. ES



183

PLAINTIFF'S EXHIBIT No. 183.

Hogan Logarithmic Plot of Type 7510 with Nitrogen.



PLAINTIFF'S EXHIBIT No. 194.

PROBABILITY OF IONIZATION OF GAS MOLECULES BY ELECTRON IMPACTS

BY

K. T. COMPTON AND C. C. VAN VOORHIS

Reprinted from PHYSICAL REVIEW, pp. 436-453, Vol. 26, No. 4, October, 1925

PROBABILITY OF IONIZATION OF GAS MOLECULES BY ELECTRON IMPACTS

By K. T. Compton and C. C. Van Voorhis

Abstract

Ionization in various gases by electrons of energy 0-325 volts.—Electrons from a hot filament were projected through an ionization chamber B containing gas at low pressure (.001 to .005 mm) and into a trap. Positive ions produced in B were collected on fine wires arranged in the form of a squirrel cage C and maintained at a potential lower than B by an amount V_r. Corrections were made for the facts (1) that the wires C lowered the potential at the center of B and hence retarded the electrons passing through B by a maximum amount of $0.4\times V_r$, and (2) that if V_r was numerically less in value than the accelerating potential V_a, some primary electrons reached C. The pressures were measured with a McLeod gauge to 1 percent and were corrected for the heating effect of the filament, which was determined by using the apparatus as an ionization manometer to be about 26°. The resulting curves for N, the number of ions per cm path produced by an electron moving through a gas at 1 mm pressure, are believed correct within a few percent. In agreement with previous results of Hughes and Klein and others, the curves each rise to a maximum. The maximum values found and the corresponding voltages are as follows:

	H_2	He	Ne	A	N_2	Hg	HCl
N(max):	3.55	1.65	3.2	10.33	9.96	19.44	17.3
V(max):	145	210	340	140	178	135	130
P(max):	0.29	.209	.254	.466	.423	.239	.558

The values for P(max), the corresponding probability that a collision will result in ionization of the hit molecule, were computed from N(max) assuming the kinetic theory values for electronic mean free paths. These results are compared with previous experimental values. Ionization was found to begin at the ionizing potential in each case, except that with N_2 weak ionization was observed at 10 volts. This may possibly be associated with the presence of traces of active nitrogen.

TOWNSEND'S original theory of ionization by collision[1] assumed that ionization of a gas molecule occurs whenever it is struck by an electron whose speed exceeds the minimum ionizing speed, but this theory led to values of the minimum ionizing speed which were considerably in error. Bergen Davis[2] and one of the writers[3] modified Townsend's theory by assuming that the relation between the energy V of an electron at impact and the probability P that ionization of the molecule results from the impact is given by $P=(V-V_i)/V$ when $V>V_i$ and $P=0$ when

---

[1] Townsend, "The Ionization of Gases by Collision."

[2] Bergen Davis, Phys. Rev. 24, 93 (1907).

[3] K. T. Compton, Phys. Rev. 7, pp. 489, 501, 509 (1916); Compton and Benade, ibid. 11, 234 (1918).

$V<V_i$. This assumption led to calculated values of the minimum ionizing energy V_i which agreed better with the true values than did Townsend's original theory, but which were still incorrect. The recent advances in the study of various types of electrical discharge through gases, and especially the development of Langmuir's[4] new method for determining the distribution of velocities of the electrons in an ionized gas, have emphasized the importance of accurate knowledge of the values of the probability P of ionization by electron impacts at various speeds and in various gases.

The first experimental observations of this sort were made by Lenard[5] and were extended under his guidance by Kossel[6] and Mayer.[7] These investigators found that the probability of ionization is zero for impact energies up to the minimum ionizing potential, then increases to a maximum of less than 0.5 at impact energies of about 150 volts, followed by a decrease as the energy is further increased up to 1000 volts.

The present investigation was designed to introduce a number of refinements in technique, so as to permit the maximum possible accuracy of the observations. Shortly after we had begun, Hughes and Klein[8] published results of a research on the same problem, in which a considerable number of gases was tested over a large range of electron impact energies. In general features and in order of magnitude our present results agree with the findings of these and of the earlier investigators. We believe, however, that the present method permits greater accuracy of observation and reliability of interpretation than the methods previously used, so that we felt justified in continuing the work to its present conclusion.

The general procedure in such work is to accelerate electrons from a photo-electric or thermionic source and project them into a region in which the products of ionization are collected by a subsidiary system of electrodes. Besides obvious precautions of accuracy, calibration, gas purity, etc., there are several inherent difficulties encountered in endeavoring to measure the ionization per electron per unit path through the gas. The first of these is due to the fact that the electrode system which collects the products of ionization is subject also to charge arising from photo-electric action on the electrodes by radiation excited by electron impacts in the gas. The second difficulty is due to the necessity of applying a field in the region between the collecting electrodes in order to draw to them the products of ionization and to prevent any of the primary ionizing electrons from reaching these electrodes. Because of this field, the primary electrons do not pass through the gas with a constant speed, but with speeds which vary from that with which they are projected into the ionizing region down to much smaller values (down to zero in the experiments of Hughes and Klein). It is, therefore, impossible to say to just what energy of impact the observed ionization should be ascribed, and it is necessary to compute the desired result by setting up an integral equation to represent the observations and to solve it by differentiating the experimental curve. To the above difficulties might be added a third source of error which arises from any ionization of a cumulative type or from more than one impact by the same primary electron.

---

[4] Langmuir, General Electric Review, 26, 731 (1924); Langmuir and Mott-Smith ibid. 27, pp. 444, 538 (1924).

[5] Lenard, Ann. der Phys. 12, 474 (1903); 15, 485 (1904).

[6] Kossel, Ann. der Phys. 37, 393 (1912).

[7] Mayer, Ann. der Phys. 45, 1 (1914).

[8] Hughes and Klein, Phys. Rev. 23, pp. 111, 450 (1924).

In the present work we have eliminated the first and third of these difficulties and reduced the second so that the value for the ionization per electron per centimeter path is set experimentally within rather narrow limits and may be computed within these limits with but a small probable error.

APPARATUS AND ITS USE

The apparatus employed is shown in Fig. 1. The filament F consisted of a few turns of 10 mil (.25 mm) molybdenum wire, in front of which was placed a focusing ring connected to the negative terminal. The narrow tube T through the bottom of the shielding box served to direct a narrow beam of electrons into the middle region of the chamber B. The positive ions formed in B were attracted to the collector C, which consisted of five 20 mil wires supported at each end by a ring of the same sized wire. The use of small wires for collecting the positive ions had the triple advantage of reducing to an inappreciable value the photo-electric current from this electrode, of reducing the chance that primary electrons which might be scattered in the gas would reach this electrode, and of reducing the effect on the velocity of the primary electrons due to the collecting field V_r. The ion trap S served to catch the electrons after passing through B, and also any positive ions produced after passing through the gauze at the bottom of B. The chamber B was 2.8 cm long and about 3 cm in diameter. All metal parts were made of nickel except the filament, and were freed from gas by heating in vacuo to a red heat by high frequency induction currents.

The electrical connections used in making the measurements are shown in Fig. 2. The variable accelerating voltage was measured by a voltmeter V_a, while G_- and G_+ measured, respectively, the electron current I_- into the chamber B and the positive ion current I_+ resulting from ionization by the electrons passing through the gas in this chamber. We thought, when beginning the investigation, that a magnetic field produced by a current through a coil wound around the glass jacket and

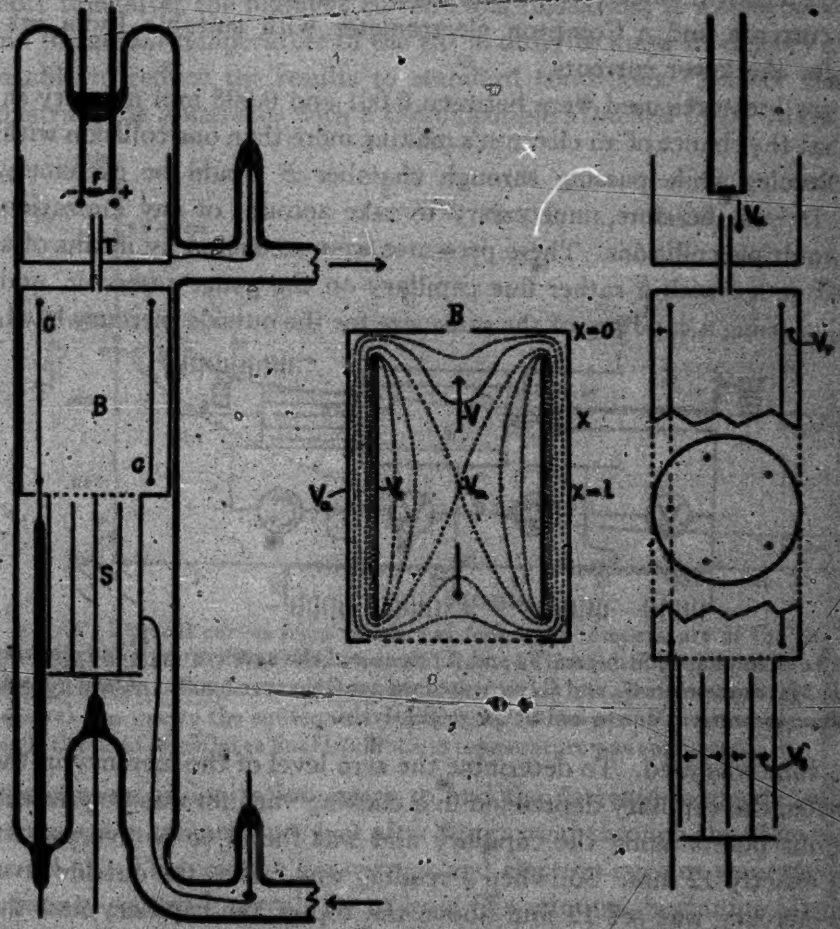


Fig. 1. Electrons from the filament F were projected through the tube T into the ionization chamber B in which the products of ionization were collected by a "squirrel cage" arrangement of wires C. The non-colliding electrons passed into the ion trap S. The dotted curves represent equipotential surfaces, with an axial point of minimum potential V_m, when the potentials of B and C are V_a and V_c, respectively, with respect to the filament.

coaxial with the chamber B would prevent electrons from reaching the collector C and thus permit us to use so small a collecting field as not appreciably to affect the speed of the primary electrons passing through the chamber. When this plan was tried, however, it was found that the ratio of I_+ to I_- for any given pressure was very irregular, being subject to small variations in the magnetic field, and that these irregularities could be shifted from lower to higher voltages by increasing the magnetic field. Not succeeding in explaining or eliminating this effect of the magnetic field, we abandoned its use and applied a retarding voltage V_r to the collector C to prevent electrons from reaching it. A galvanometer with a sensitivity of about 300 megohms was used as G_-, while for G_+ were employed a galvanometer of about 11000 megohms sensitivity for the higher currents and a Compton electrometer with suitable India ink shunts for the lower currents.

The gas pressures used were between 0.001 and 0.005 mm mercury in order that the chance of an electron's making more than one collision with gas molecules while passing through chamber B would be extremely small. It was, therefore, unnecessary to take account of any ionization due to multiple collisions. These pressures were measured by means of a McLeod gauge with a rather fine capillary on the gauge reservoir, and instead of using a capillary of the same size for the outside mercury level, a 1 cm tube was used. To determine the zero level of the mercury in the 1 cm tube, the capillary depression in a clicking vacuum was determined at various points along the capillary and was found to be everywhere almost exactly 12 mm. So, when a reading was taken, the outside level of the mercury was set 12 mm above the top of the capillary and the pressure read off the calibration curve as usual. The capillary tube was always tapped with a pencil while the mercury was coming to equilibrium in the tubes, to avoid any error due to the adhesion of the mercury to the walls. Also, parallax was avoided by observing the level of the mercury in the capillary through a lens mounted at the end of one edge of a small square. With these refinements the readings of the pressures varied less than 1 percent for different settings on the same pressure. A further check on the accuracy of the pressure readings was made occasionally by finding the product of the length of the gas-filled capillary times the difference in level of the mercury columns (the 12 mm capillary depression being de-

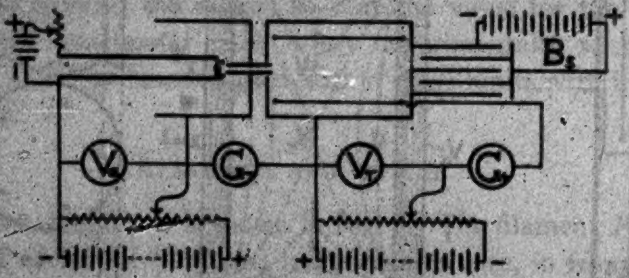


Fig. 2. Circuits. Voltmeters V_a and V_r measured the accelerating and collecting fields, and galvanometers G_- and G_+ measured the total electron current entering B and the positive ion current due to ionization, respectively.

ducted of course) for different levels of the mercury in the capillary. This check was used whenever there seemed to be any pronounced sticking of the mercury in the capillary near the level used in the regular method of reading.

Determination of gas temperature. Since the chamber *B* became warm a short time after the filament current was turned on, it was necessary to find the actual temperature of the gas in order to know its density and to be able to reduce the results to standard conditions. Rather than reconstruct the apparatus with a thermocouple attached to *B*, we used the apparatus as an ionization gauge to find the decrease in gas density due to increase in temperature just after the current through the filament was turned on. The positive ion current and electron current were measured at twenty second intervals for at least five minutes, beginning about one minute after the filament current had been turned on, and then at less frequent intervals until stable conditions were reached. Fig. 3 shows the results of two typical runs in mercury vapor, one with $V_a = 160$ volts and the other with $V_a = 320$ volts. The ordinates are numbers of positive ions produced per electron in traversing the length of *B*, per 0.001 mm pressure of the vapor.[9] The values of this number at time 0, i.e., at room temperature, are obtained by a short extrapolation of the curves back-

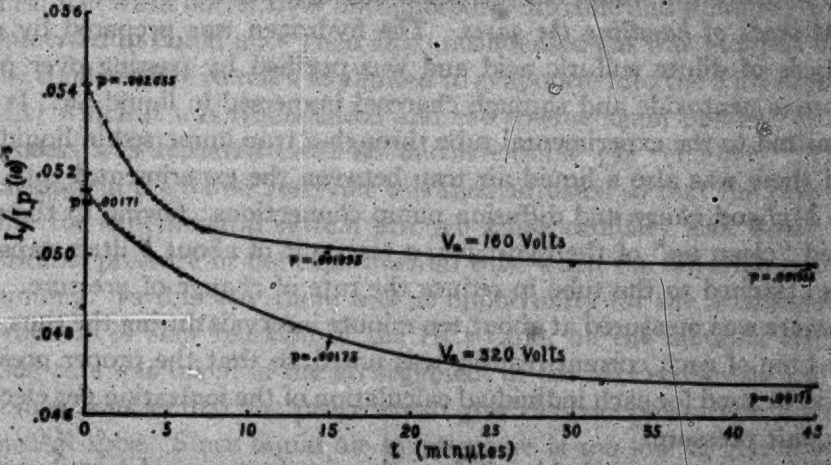


Fig. 3. Typical curves from which was found the temperature of the gas in the ionization chamber *B*. Time was measured from the instant of turning on the filament heating current. The decrease in ordinate (ionization per electron per 0.001 mm gas pressure) was due to the subsequent warming up of the gas. By use as an ionization gauge, the ratio of initial to final equilibrium temperature was computed.

---

[9] The difference in the shape of these curves is due, for the most part, to the differences in initial pressures and in changes of pressure during the runs. That is the reason for giving the pressures in the figure.

ward. Thus with $V_a=160$ volts the final ordinate is 91.9 percent of the initial one, and corresponds to a temperature rise of 26° above the room temperature of 25°; and with $V_a=320$ volts the final ordinate is 90.7 percent of the initial one and corresponds to a temperature rise of 30° above the room temperature of 23°. From the consideration of nine such runs, it was decided that 51°C best represents the temperature of the gas in chamber *B* throughout the various observations. The possible variations from this temperature would not introduce any appreciable error.

Methods of handling the gases. The hydrogen was prepared by electrolysis of dilute sulfuric acid and was purified by passing over phosphorous pentoxide and through charcoal immersed in liquid air. It was admitted to the experimental tube through a trap immersed in liquid air, and there was also a liquid air trap between the experimental tube and the McLeod gauge and diffusion pump connections. Owing to the very rapid "clean up" of the hydrogen, a reservoir of about 5 liters capacity was attached to the tube to reduce the rate of change of pressure. The pressure was measured at about ten minute intervals during the runs, and the time of each current reading was noted, so that the proper pressure could be used for each individual calculation of the ionization per electron per unit pressure.

The argon was purified by prolonged arcing between calcium electrodes and was admitted to the experimental tube through a liquid air trap. To insure the purity of the neon and the helium in the tube, a charcoal trap, a tube containing copper and copper oxide, and a high pressure diffusion pump were added to the system in such a way that the gas could be circulated by the pump through the glowing copper and copper oxide and the charcoal, which was immersed in liquid air. This circulation was not continued while observations were being made, since the action of the circulating pump caused somewhat erratic variations in the gas pressure within the experimental tube. The helium and neon were each spectroscopically free from each other before being admitted to the system.

The nitrogen first used was generated by the reaction of sodium nitrite and ammonium chloride, stored in contact with phosphorous pentoxide and admitted through a tube immersed in liquid air. After finding that some ionization set in at about 10 volts (see Fig. 5) it was thought that possibly there might be some nitrogen oxides present, so that other runs were made using nitrogen generated by the action of bromine on ammonia and stored over phosphorous pentoxide—a method which is supposed to yield very pure nitrogen.[10] However, the experimental results with the gas prepared by the two methods were almost identical.

---

[10] Waran, Phil. Mag. 42, 246 (1921).

While making the observations on mercury vapor, the liquid air was removed and the pressure varied for different runs by varying the room temperature. The slight temperature changes during a run were taken account of by noting at ten minute intervals the temperature of a thermometer placed in the vicinity of the system, and the time of each current measurement was noted, as in the case of hydrogen.

For the observations on hydrogen chloride, the gas was generated by the action of sulfuric acid on hydrochloric acid, passed through a sulfuric acid wash bottle, over phosphorous pentoxide and solidified in a tube immersed in liquid air. Then any uncondensed gas was pumped off, and the condensed material was allowed to evaporate into the 5 liter reservoir, after which it was recondensed and the residue again pumped off. This process was repeated until no uncondensable gas remained. The gas pressure in the 5 liter reservoir was then adjusted so that the rate of flow into the experimental system through a fine capillary leak would give a suitable pressure in the experimental tube when the diffusion pump was running. In this way there was no opportunity for the accumulation of products of slow reaction of the HCl vapor on the metallic electrodes. Due care was taken in the arrangement of the McLeod gauge and pump connections so that the gauge would give the true pressure in the experimental tube. Since liquid air temperature is too low to give a suitable vapor pressure of hydrogen chloride, a temperature between 10° and 25° higher than liquid-air temperature was maintained in the traps for keeping out mercury vapor, by surrounding the traps with cylinders of brass closed at the bottom, these in turn being surrounded by large glass test tubes immersed in liquid air. By allowing about an inch of the brass cylinder to extend above the top of the liquid air flask, the pressure of the hydrogen chloride could be made as high as about 0.015 mm. Since there was usually a slight pressure change during a run, the same method of obtaining the correct pressure for each observation was used as in the cases of hydrogen and mercury vapor.

Potential at the center of chamber B. In order to prevent any appreciable number of electrons from striking the positive ion collector, V_p had to be made slightly larger than V_a. Thus the space through which the electrons passed within the chamber B was not field free, but had a potential distribution, probably such as shown in the central part of Fig. 1. The potential with respect to the filament would be a minimum at the center of B. Thus an electron, entering B with the speed corresponding to V_a, would be retarded until it reached the center, and then would be accelerated so that it would pass out of B with the same speed as that with which it entered, provided it suffered no inelastic collision on the way. Two methods were used in determining the potential at the center of B. The first consisted in measuring the total electron current I_- while V_a was kept constant and V_r varied, for a series of values of V_a both in a vacuum and in hydrogen. When I_- was plotted against V_r, a marked change in slope was found in every curve at a value of V_r about 2.5 times that of V_a. This critical value of V_r was interpreted as being the one above which electrons were turned back before reaching the center of B, some striking the tube T or the under side of the shield containing it. Therefore V_m, the potential at the center of B, may be taken as $V_a - 0.4|V_r|$, where $|V_r|$ represents the numerical value of the retarding potential applied between B and C.

The second method of determining V_m was to place a sensitive galvanometer in series with the 22.5 volt battery B (Fig. 2), connecting the two sets of vanes of the ion trap, and noting at what value of V_a, for a given V_r, electrons began getting through B into the ion trap. It was found that they began to get through when V_a was from 0.40 to 0.45 times $|V_r|$, thus confirming the conclusion that $V_m = V_a - 0.4|V_r|$, to a close approximation.

Methods of measurement and calculation. Series of measurements were made on all the gases investigated by noting G_- and G_+ as V_a was varied from below the minimum ionizing potential to about 320 volts (410 volts in the case of neon to make sure that the voltage for maximum I_+ had been passed) with $|V_r|$ always about 1.5 volts greater than V_a. Readings were taken at intervals of one volt to above twice the ionizing potential; then of two volts to about 100 volts; of five volts to about 180, and then of ten volts over the rest of the range. Preliminary tests showed that the ratio I_+/I_- was independent of the filament temperature, i.e., of I_-, over a wide range. For convenience, about the same filament current was used all through the investigation and the galvanometers were calibrated at the beginning and end of each individual run. Several runs were made at somewhat different pressures with each gas. The only limitations in the pressures and currents which could be used were (1) that these must be large enough to give sufficient ionization for accurate measurement, and (2) that they must not be so large as to allow appreciable ionization by cumulative action or by more than one impact by an electron.

From the readings of G_- and G_+, the galvanometer and electrometer calibrations and the gas pressures, the ratio $I_+/(I_-p)$, where p is the pressure of the gas in mm of mercury, was calculated. Then from the results of three or more such runs which agreed within 2 percent with one another over most of the range for each gas, the mean values of this ratio were found for each voltage V_m. When these mean values were plotted against the values of V_a they gave such curves as curve *a* in Figs. 4 and 5. The ordinates of this curve should give the average number of ionizing collisions made per electron while moving a distance equal to the length of B (2.8 cm) through the gas at 1 mm pressure with velocity corresponding to V_a, if it were not for the fact that the space within B is not field free and consequently the electrons do not all have the velocity V_a when they strike the gas molecules. Two methods were used to take into account this uncertainty, (1) by calculation based on the distribution of potential within B, and (2) a direct method whereby the desired quantity can be set by experiment between narrow limits.

First method. Of several assumptions made regarding the variation of potential along the path of the electrons in B, the one which gave the most reasonable results was the assumption that the potential varies at a uniform rate from the end to the center. Then the value of the potential V (with respect to the filament) at any point x in B is given by

$$V=V_a-\int_x^l Edx=V_a-E(l-x)\ ,$$

where l is the distance from the center to the end of B, x is the distance of the point x from the center of B and E is the electric intensity (supposed constant). At the center, $x=0$, hence

$$V_m=V_a-El=V_a-0.4(V_a-V_c)$$

where $V_c=V_a-|V_r|$ is the potential of the collecting electrode. Thus $E=0.4\ (V_a-V_c)/l$. Substituting this above, and remembering that V_c in our experiments was only 1.5 volts, we have approximately

$$V=V_a(0.6+0.4x/l)\ . \tag{1}$$

Let $M=I_+/(I_-p)$ stand for the observed ionization per electron per unit pressure in the chamber B. Let $f(V)$ be the average number of ionizing collisions made by an electron if it passed through B with uniform velocity of V volts, at unit pressure. Then we should have

$$M=\int_{V_m}^{V_a} f(V)d(x/l)\ .$$

Since $V_m=0.6V_a$, and differentiation of Eq. (1) gives $d(x/l)=(2.5/V_a)dV$, we have

$$M=(2.5/V_a)\int_{0.6V_a}^{V_a} f(V)dV\ .$$

By differentiation,

$$0.4\,d(MV_a)/dV_a=f(V_a)-f(0.6\,V_a)\ . \tag{2}$$

In applying this equation to determine $f(V_a)$ from the experimental values of V_a and M, we have two cases to consider:

If $V_a < 1.67$ times the minimum ionizing potential V_i, then $f(0.6\ V_a) = 0$, and we have

$$f(V_a) = 0.4\, d(MV_a)/dV_a\,. \qquad (3)$$

If $V_a > 1.67\ V_i$, then

$$f(V_a) = 0.4\, d(MV_a)/dV_a + f(0.6\ V_a) \qquad (4)$$

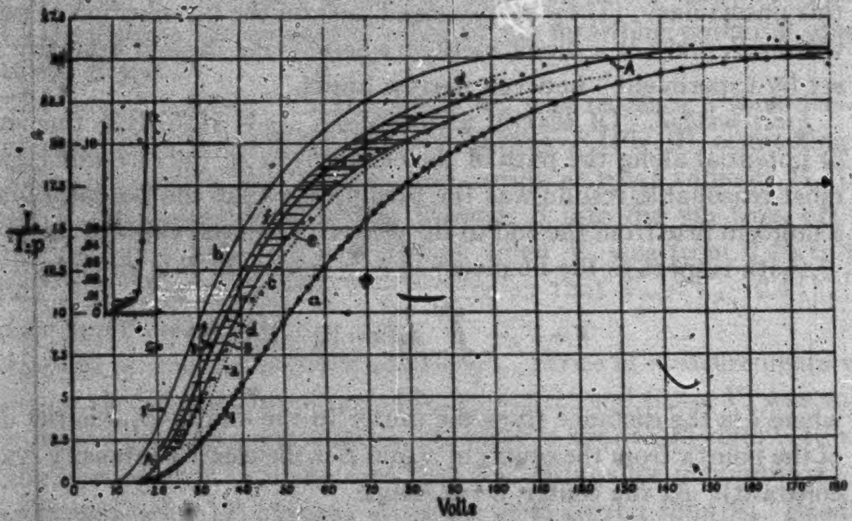


Fig. 4. Curves for nitrogen; positive ions formed per electron per mm pressure per 2.8 cm path as a function of energy of electrons, in volts. Curve *a* gives experimental results when $V_r = V_a + 1.5$ volts, thus with primary electrons prevented from reaching *C*. Curve *b* gives the same values plotted against the minimum energy V_m instead of the maximum energy V_a. The true curve lies between these. Curve *c* gives experimental values when V_r was adjusted for maximum ionization, and curve *d* gives the same for minimum voltage V_m. Curves *e* and *f* were obtained by correcting *c* and *d* for stray electron current. The true curve lies between *e* and *f* and is taken as curve *A*. Crosses are points which were computed from curve *a* by method (1).

The values of $f(V_a)$ were calculated for the different voltages used, by means of Eq. (3) and (4) and plotted at the mid-points $V_a - \frac{1}{2}\, dV_a$, giving results such as are shown by the crosses in Figs. 4 and 5. A rather marked change in slope was noted in all of the M curves at a value of V_a approximately twice the ionizing potential, and this break was still more pronounced in the $f(V_a)$ curves. It was at first suspected that these breaks might be due to ionization of highly excited molecules, or by the double ionization which might occur if a molecule, excited by an energy at least twice the minimum ionizing energy, should make a collision of the second kind with a neutral molecule. Such effects should, however, tend to disappear at very low gas pressures, whereas we found that the curves, including this break, were identical down to extremely low pressures. In the second method, described below, it was found that this break shifted according to the value of V_r, so that we are inclined to attribute it to a peculiarity of the field within B, due to lack of radial symmetry of the collecting electrode system. It probably indicates a second order error in the values of M and $f(V_a)$ in the lower voltage ranges.

The second method for finding the number of ionizing collisions which would be made by an electron moving with a uniform speed V_a through B in gas at unit pressure, can be best explained by referring to Fig. 4. Consider, for instance, the experimental reading marked 1. Here the electrons entered the chamber B with velocity of 36 volts and reached the center of B with velocity of 0.6 of 36, or 24 volts. The ordinate at 1 must therefore be the value of $f(V_a)$ corresponding to some value of V_a between 36 and 24 volts. In other words, the corresponding point on the $f(V_a)$ curve must be somewhere between 1 and 1′. Similarly for every point on curve *a* there is a corresponding point on curve *b* which is shifted to the left by an amount 0.4 of V_a. The true curve for $f(V_a)$ must lie between the curves *a* and *b*.

Now, by decreasing the field V_r to a value considerably less than V_a, keeping V_a constant at 36 volts, it was found that the current I_+ increased to a maximum value when V_r was 11 volts, and then decreased with further decrease in V_r. The reason for this is that decrease in V_r produced two opposing effects: (1) It diminished the retardation of the electrons, thus causing them to traverse B with speeds more nearly equal to V_a, and thus increased the ionization produced by them; (2) it permitted some electrons to reach the collecting electrode, and thus diminished the apparent amount of ionization. The observed value of I_+ corresponds to point 2 in Fig. 4. Owing to the electrons which reached the collecting electrode, the true ionization must have been somewhat greater than this. The amount by which it was greater was determined by making a similar measurement with the gas removed from the tube, so that the stray electron current only was measured, and this was checked by similar measurements in the gas at values of V_a less than V_i. Adding this to the current corresponding to point 2 gives the current which would have been observed with V_r equal to 11 volts, had there been no reverse current due to electrons. This ordinate at point 3 corresponds to electrons which entered B with velocity 36 volts, and whose velocity fell by 0.4 of 11 volts, or by 4.4 volts within B. Thus the ordinate is the value of $f(V_a)$ for some value of V_a between 36 and 31.6 volts. Thus the limits within which the value of $f(V_a)$ must lie have been much narrowed down; it must lie between points 3 and 4. A consideration of all the factors involved led to the choice of point 5 as the most probable point, and it is certain that this value of V_a and $f(V_a)$ cannot be in error by more than a few percent. In this way, the values of $f(V_a)$ were found and plotted as curve A, which lies between the experimentally fixed limits shown by curves e and f.

Of the two methods, the second is the more reliable in that it does not depend on any assumption regarding the distribution of potential within B. The agreement between the two methods is indicated by the way in which the crosses are distributed with respect to the experimental limits

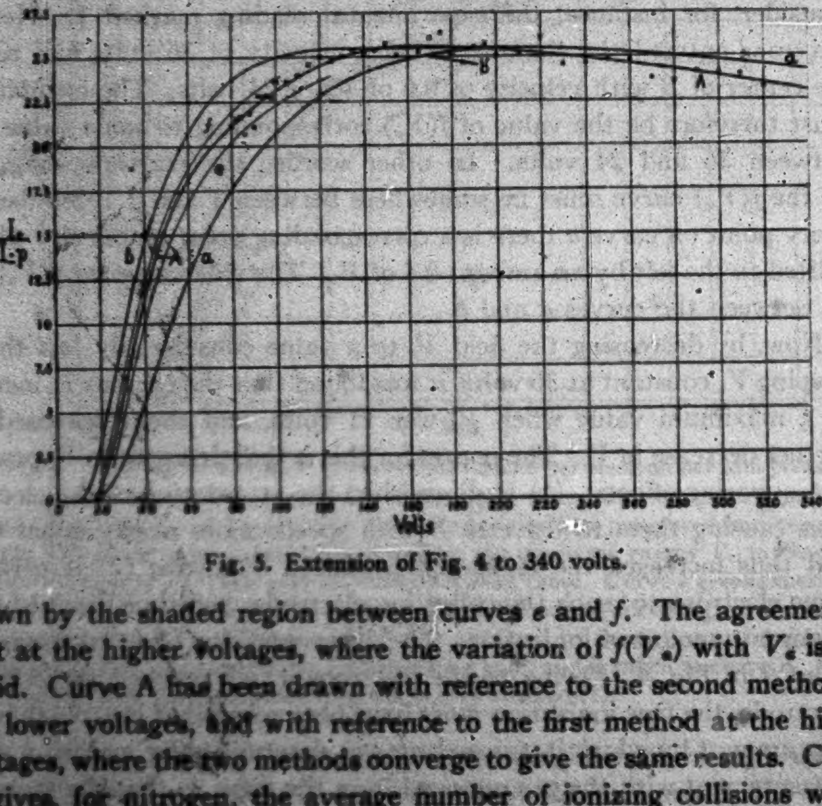


Fig. 5. Extension of Fig. 4 to 340 volts.

shown by the shaded region between curves e and f. The agreement is best at the higher voltages, where the variation of $f(V_a)$ with V_a is less rapid. Curve A has been drawn with reference to the second method at the lower voltages, and with reference to the first method at the higher voltages, where the two methods converge to give the same results. Curve A gives, for nitrogen, the average number of ionizing collisions which would be made by an electron moving with constant speed V_a through chamber B containing the gas at 1 mm pressure. Fig. 5 shows the same results, continued to the higher voltage ranges.

DISCUSSION OF RESULTS

If the values of the ordinates of curve A are divided by the length of the chamber B, they give the average number N of ionizing collisions per electron per cm path per mm gas pressure as a function of the velocity. The assembled results of our experiments are shown in Fig. 6, where N

stands for the quantity defined just above. It is of interest to note that the value of N continues to decrease with still greater electron speeds. For air, according to Kossel[6] N decreases from about 10 at 200 volts to 3.3 at 1000 volts, 0.4 at 30,000 volts and 0.18 for β-rays.

The probability P of ionization at an impact may be found by dividing these values of N by the number of collisions per cm path made by an electron moving through the gas at 1 mm pressure. Although there is some uncertainty regarding the true values of this number, the experiments of Ramsauer[11] and Mayer[12] indicate that the ordinary kinetic theory value of electronic mean free path is at least approximately correct at speeds as large as those in which we are interested, except for argon at the lower speeds. We shall, therefore, assume that the electronic mean free path equals $4\sqrt{2}$ times that of the gas molecules. The values are given

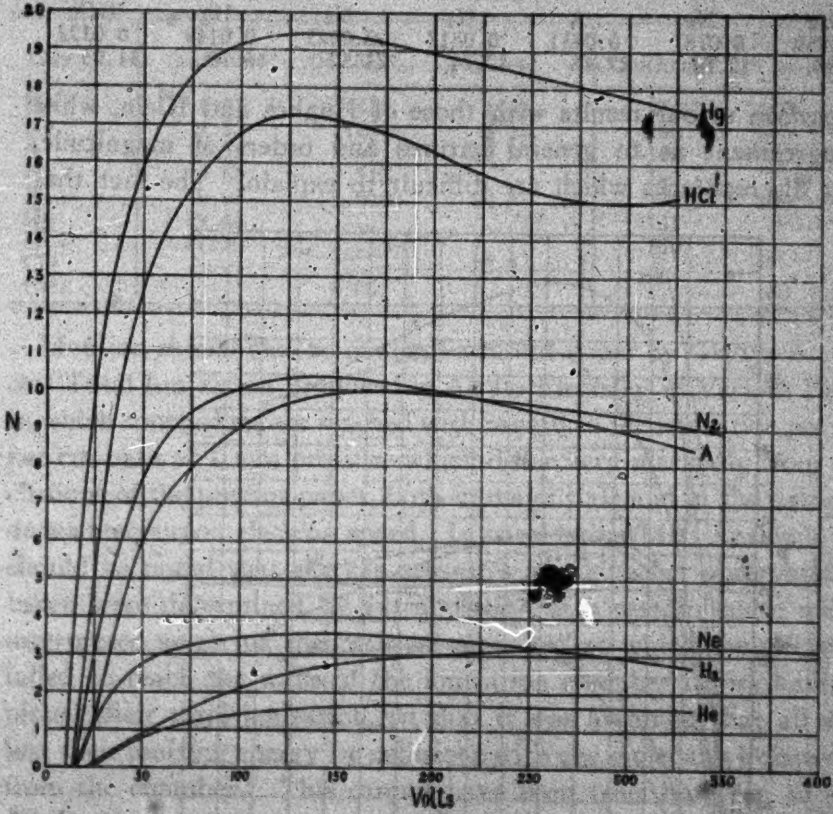


Fig. 6. Number of positive ions formed per electron per cm path through gas at 1 mm pressure, as a function of the electron energy in volts.

Multiply by
0761
to get P:
at 1000 bars
~ 20°C

at 25°C

---

[11] Ramsauer, Ann. der Phys. 64, 513 (1921); 66, 546 (1921).

[12] Mayer, Ann. der Phys. 64, 451 (1921).

in Table I. They are calculated from values given in "High Vacua," by Dushman, except in two cases for which the data were not available there and were obtained from Kaye and Laby's Tables. All are calculated for a temperature of 25°C. The values of the probability *P* are shown in Fig. 7.

TABLE I

Gas:	He	Ne	A	H_2	N_2	Hg	HCl
l :	0.1259	0.0787	0.0451	0.0817	0.0425	0.0149	0.0322
1/*l*:	7.95	12.[illegible]	22.18	12.24	23.52	66.70	31.05

A comparison of our results with those of Hughes and Klein, while showing agreement as to general features and orders of magnitude, brings out discrepancies which are difficult to explain. The fact that their values are consistently smaller than ours may be due to the fact that they appear not to have taken account of the heating of the gas in the apparatus by the filament. We feel that their results are definitely too low, since they fall below the lower limit set by curves, such as curve *s* of Figs. 4 and 5, which are the direct result of measurement and depend on no calculations or assumptions, but only on the calibration of the gal-

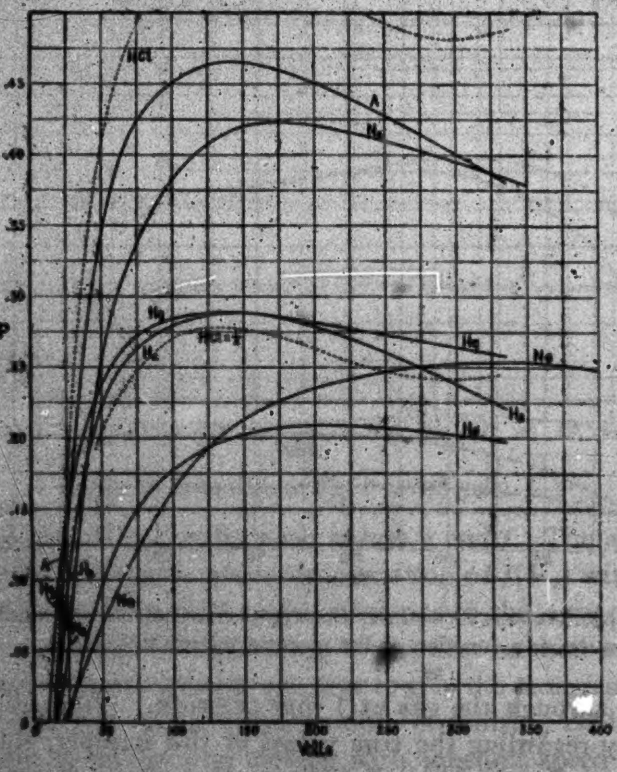


Fig. 7. Probability of ionization at an impact as a function of the electron energy in volts, assuming kinetic theory values of electronic mean free paths.

vanometers and the McLeod gauge. Some aspects of this comparison are shown in Table II. This table also contains values from a recent paper by Jesse.[13] Although he does not claim much accuracy for his absolute values of N, his results agree more closely with ours than do those of Hughes and Klein.

TABLE II

Gas	N(max) (authors)	N(max) (H. & K.)	N(max) (Jesse)	V_e(max) (authors)	V_e(max) (H. & K.)	V_e(max) (Jesse)
He	1.65	0.881	1.61	210	150	140
Ne	3.22	1.828	3.16	340	160	220
A	10.33	7.65	14.5	140	80	100
H_2	3.55	2.518	.....	145	73.5	...
N_2	9.96	7.640	10.3	175	100	100
Hg	19.44	.....	.....	135	.....	...
HCl	17.30	.....	.....	130	.....	...
CO	.....	.....	12.8	...	.....	120
CH_4	.....	8.06	.....	...	80	...

Mention should also be made of a recent paper by Gladys A. Anslow[14] on "Total Ionization Produced in Air by Electrons of Various Energies," in which conclusions are reached with regard to the ionization per electron per cm path at 1 mm pressure which differ very markedly from the conclusions of the present paper, both in magnitude and in the nature of the dependence upon electron speed. In considering Miss Anslow's work, it should be noted that the gas pressures at which her observations were taken were determined by extrapolation of a certain curve which was interpreted as giving the "critical pressure" at which the electrons just failed to reach the walls of the ionization chamber before having completed their total ionization, so that it was assumed that all electrons lost their ionizing energy by collisions with gas molecules before escaping from the chamber. This cannot have been true, however, as a simple calculation based on electron mean free paths shows. For all of her voltages below 1000 volts, an appreciable number of electrons would have traversed the ionization chamber without having collided at all; below 300 volts the majority would have thus escaped collision, while at the maximum of her curve, Fig. 6, not more than one percent of the electrons would have collided. Thus the interpretation of the results at the lower voltages is incorrect and these results cannot be taken as inconsistent with the results of the present paper. Incidentally, we believe that the maximum in Miss Anslow's Fig. 6 is due to the combination of the variation in the number of electrons which collide and the variation of the probabilities of ionization at the different pressures and voltages used.

[13] W. P. Jesse, Phys. Rev. 26, 208 (August, 1925).

[14] Gladys A. Anslow, Phys. Rev. 25, 484 (1925).

On the basis of measurements with the ionization gauge, Dushman[15] suggested that the ionization in different gases is proportional to the total number of electrons in the molecules of the gases. The present results do not support this suggestion as a quantitative relation. It may be, however, that the proposed relation is more accurate at higher voltages than those at which we worked—as might be expected on theoretical grounds and as is indicated by the early work of Kossel,[16] who made the same suggestion on the basis of measurements at 1000 volts.

Finally, the apparent ionization of nitrogen at about 10 volts (see Fig. 4) raises an interesting question of interpretation. As shown in the insert, this is extremely weak as compared with the ionization setting in at the ordinary ionizing potential. Three possibilities present themselves: (1) It may represent a weak and hitherto undiscovered type of ionization of nitrogen; (2) it may be due to photo-electric effect on the collecting electrode C by radiation excited in the gas; (3) it may be due to electron emission from the collecting electrode C produced by contact with "excited" or "active" molecules of nitrogen. In opposition to the second suggestion is the fact that in no other gas was there any detectable current which could be ascribed to photo-electric effect; the scheme for eliminating complications from this cause seemed to be quite successful. In favor of the third suggestion is the fact that this observed critical potential agrees well with the internal energy of at least one type of active nitrogen, which has been placed at 9.52 volts by Saha and Sur,[16] as revised by Foote, Ruark, and Chenault.[17] If this is the correct interpretation, the detection of the active nitrogen by an apparatus relatively insensitive to the photo-electric effects would be due to the greater probability of electron emission at a collision of the second kind between an excited molecule and the metal than by photo-electric action of radiation. If this be true, it must still be remarked that the efficiency of these low voltage impacts in producing active nitrogen must be quite small, else Duffendack would have detected it in his low-voltage arcs.[18] We hope later to be able to give a definite answer to this question.

Note added with proof. Further consideration of the work by Hughes and Klein[8] and by Jesse[11] indicates that in both cases the assumed values of primary electron current must be in error. The former are too large, owing to an incorrectly assumed linear relation between current and field on one side of the grid. The latter are too small on account of neglect of

---

[15] Dushman, "High Vacua"; Dushman and Found, Phys. Rev. 23, 734 (1924).

[16] Saha and Sur, Phil. Mag. 48, 421 (1924).

[17] Foote, Ruark, and Chenault, Phys. Rev. 25, 241 (1925).

[18] Duffendack, Phys. Rev. 20, 665 (1922).

secondary electrons which subtract from the primary electron current. Experiments are being undertaken to see whether these corrections are adequate to account for the discrepancies in the three experiments on this subject. It may be noted that in the present work both the ionization and the primary electron currents were measured directly, and that secondary electrons were avoided by use of the electron trap.

PALMER PHYSICAL LABORATORY,
PRINCETON, NEW JERSEY,
July 15, 1925.

PLAINTIFF'S EXHIBIT No. 195.

COPY

40380 - 4

Statement of Arnold
Filed Sept. 2, 1916
Examined " 8, 19 "
Approved 19 W.

UNITED STATES PATENT OFFICE

ARNOLD
v.
LANGMUIR

Interference No. 40,380

Subject: Thermionic Devices and Method of Constructing and Operating the same.

PRELIMINARY STATEMENT OF HAROLD DeF. ARNOLD

State of New York
County of New York
ss.

ARNOLD

HAROLD DeFOREST ARNOLD, in the County of New York, State of New York, being duly sworn, deposes and says:

I am one of the parties to the interference declared by the Commissioner of Patents on August 8, 1916, between my application for Letters Patent for Thermionic Devices and Method of Constructing and Operating the Same, filed November 2, 1915, and an application of Irving Langmuir.

I conceived the invention set forth in the declaration of interference and disclosed the same to others in the latter part of 1912.

The first written records evidencing invention were made on various dates in the latter part of 1912 and at frequent intervals thereafter, and the first drawing illustrating the invention was made on March 24, 1913.

The invention was reduced to practice on December 26, 1912 and again on March 24th, and April 25th of 1913.

Since the date of reduction to practice, the invention has been used in wire and wireless telephonic communications carried on by the American Telephone and Telegraph Company and the Western Electric Company, Incorporated, both in experimental and commercial work.

(signed) HAROLD DeFOREST ARNOLD.

Sworn to and subscribed before me this 1st day of September, 1916.

(signed) Robert E. Williams,

Notary Public.
New York County No. 297,
New York Register No. 7245.

PIW–DC
PIW

PLAINTIFF'S EXHIBIT No. 196.

COPY

Room No. 261. Paper No. 6.
Address Only
"The Commissioner of Patents,
Washington, D. C."
And not any official by name.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
Washington, D. C.

IAW September 8, 1916.
In Re Interference No. 40380.

ARNOLD
v.
LANGMUIR

Before the Examiner of Interferences.

U. S. PATENT OFFICE
Interference Division
SEP. 8 1916
MAILED

H. D. Arnold, c/o John G. Roberts, New York, N. Y.

Please find below a communication from the Examiner in charge of Interferences in regard to the above-cited case.

Very respectfully,
(signed) THOMAS EWING,
Commissioner of Patents.

In the preliminary statement of Arnold the allegations with respect to conception, disclosure and written description are too indefinite. The exact day and month in 1912 when these acts took place should be set forth.

Arnold is given until September 18, 1916, within which to file an amended statement overcoming these objections. For failure to so amend he will be restricted to December 31, 1912, for conception, disclosure, and first written description.

(signed) LOUIS E. GILES
Acting Ex'r of Intfs.

PLAINTIFF'S EXHIBIT No. 197.

COPY

Room No. 261. Paper No. 9.
Address only
"The Commissioner of Patents,
Washington, D. C."
and not any official by name.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
Washington, D. C.

IAW September 18, 1916.

IN RE Interference No. 40380.

ARNOLD
v.
LANGMUIR
Before the Examiner of Interferences

U. S. PATENT OFFICE
Interference Division
SEP 16 1916
MAILED

Please find below a communication from the Examiner in charge of Interferences in regard to the above-cited case.

Very respectfully,
(signed) THOMAS EWING
Commissioner of Patents.

The telegraphic request filed on behalf of Langmuir is approved and in accordance therewith the time for filing preliminary statements is hereby extended to and including September 25, 1916.

Any further extension should be sought by stipulation or motion.

(signed) H. E. STAUFFER,
Examiner of Interferences.

PLAINTIFF'S EXHIBIT No. 193.

COPY 40380 – 4 & 10

Statement of Arnold
Filed Sept. 18, 1916
Approved " 29, 1916 W.

UNITED STATES PATENT OFFICE

ARNOLD
v.
LANGMUIR

Interference No. 40,380

Subject: Thermionic Devices and Method of Constructing and Operating the Same.

PRELIMINARY STATEMENT OF HAROLD DeF. ARNOLD

State of New York
County of New York } ss.

HAROLD DeFOREST ARNOLD, in the County of New York, State of New York, being duly sworn, deposes and says:

I am one of the parties to the interference declared by the Commissioner of Patents on August 8, 1916, between my application for Letters Patent for Thermionic Devices and Method of Constructing and Operating the Same, filed November 2, 1915, and an application of Irving Langmuir.

I conceived the invention set forth in the declaration of interference and disclosed the same to others on or about November 1, 1912.

The first written records evidencing invention were made on November 16, November 19, November 29 and December 27, all of 1912, and at frequent times thereafter. The first drawings illustrating the invention were made on November 16, November 19, November 29, all of 1912, and March 24 of 1913, and at frequent times thereafter. The invention was reduced to practice on November 29 of 1912, March 24, April 25 and May 12 of 1913.

Since the date of reduction to practice, the invention has been used in wire and wireless telephonic communications carried on by the American Telephone and Telegraph Company and the Western Electric Company, Incorporated, both in experimental and commercial work.

(signed) HAROLD DeFOREST ARNOLD

Sworn to and subscribed before me this 15th day of September, 1916.

(signed) Ella Edler
Notary Public No. 23,
New York County
Commission Expires
March 30, 1917.

PIW–AA

PLAINTIFF'S EXHIBIT No. 199.

COPY 32.

MAIL ROOM
Jan. 15
1917
U. S. PATENT OFFICE

UNITED STATES PATENT OFFICE

ARNOLD
vs.
LANGMUIR } Interference No. 40,380

COMMISSIONER OF PATENTS,
Washington, D. C.

Sir:

Referring to the order of the First Assistant Commissioner, January 11, 1917, the following additional particulars are now given in regard to the citation of articles appearing on page 6 of Arnold's Supplementary Motion to Dissolve:—

The article in Annalen der Physik, Vol. 28, pages 537-552 (1909), comprising sixteen (16) pages, is considered to be of importance and will be relied upon.

The entire articles of Majorani published in Atti Della Reale Accademia dei Lincei, Vol. 21, pages 235-239 inclusive, and in the same publication, pages 274-277 inclusive, are considered to be of importance and will be relied upon. These articles comprise respectively five pages and four pages.

The article by Fleming in the Proceedings of the Royal Society, January 1905, pages 476-487 inclusive comprises twelve (12) pages, three pages of which are given up to tables, and all of this article is considered to be of importance.

The article by McClelland in Proceedings of Cambridge Philosophical Society, Vol. 10, (1900), page 241, is hereby withdrawn from consideration.

The address by Dewar before the Royal Institution of Great Britain, June 7, 1907, published in Engineering, Vol. 83, page 781, June 14, 1907, is all comprised on one page.

The article in the Sitzungsberichte der Physicalisch Medischen Gesellschaft, Vol. 37, pages 312-315 (1905), comprises only four pages, all of which are pertinent and should be considered.

Respectfully,
(signed) D. C. TANNER,
Attorney for Arnold.

468 West Street,
New York, January 13, 1917.

DCT-DG

PLAINTIFF'S EXHIBIT No. 200.

DEPARTMENT OF COMMERCE

UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of Letter to Office, filed February 8, 1918, in the matter of

Interference Number 40, 380,

ARNOLD VS. LANGMUIR,

Subject Matter:—

Electric Discharge Apparatus and the Process of Preparing the Same.

[SEAL] IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this fourteenth day of September in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

THOMAS E. ROBERTSON,
Commissioner of Patents.

ATTEST:
D. E. WILSON,
Chief of Division

IN REPLY ADDRESS
THE SECRETARY OF THE NAVY
AND REFER TO NO.

40380—85

NAVY DEPARTMENT
WASHINGTON

VR/WSS/26840

February 7, 1918.

From: Secretary of the Navy
To: Commissioner of Patents, Washington, D. C.

SUBJECT: Case of Arnold v. Langmuir, No. 40,380.

1. Both Dr. Arnold and Dr. Langmuir are engaged in important work for the Navy Department.

2. The case of Arnold v. Langmuir was postponed for a period of six months because of this fact. Both of these gentlemen are still actively engaged practically for a great majority of their time and, if it can be consistently done, it is requested that a further extension of six months in the taking of testimony be granted.

3. It is understood that both of these gentlemen and their counsels will be glad to agree to this extension if you can see fit to grant it.

F. W. ROOSEVELT,
Acting

PLAINTIFF'S EXHIBIT No. 201.

Exhibit.

OPTION.

AGREEMENT made this Sixteenth day of December, 1912, between PETER COOPER HEWITT, of New York City, and the AMERICAN TELEPHONE AND TELEGRAPH COMPANY, a New York corporation, hereinafter called the Telephone Company.

In consideration of the sum of Thirty Thousand Dollars ($30,000.), paid by the Telephone Company to the said Hewitt, the receipt of which is hereby acknowledged, the said Hewitt agrees for himself, his legal representatives and assigns, as follows:

1. If, within one year from the date hereof, the Telephone Company pays to Hewitt One Hundred and Ten Thousand Dollars ($110,000) in addition to the amount mentioned above, and executes and delivers to Hewitt agreements in the forms A and B hereto attached (excluding some of the patents therein mentioned or referred to, if the Telephone Company so elects), Hewitt will thereupon execute (and cause the Cooper Hewitt Electric Company to execute) both of said agreements, (and the Westinghouse Cooper Hewitt Company, Limited, to execute Agreement B,) in the form delivered by the Telephone Company, and also duplicate originals thereof, and will deliver to the Telephone Company such executed duplicate originals.

2. Hewitt will not object to the Telephone Company making and using, for purposes of experiment, test and demonstration, C. H. T. devices, as defined in attached agreements, embodying or containing or operating in accordance with the inventions referred to in the attached form of license up to the date of exercise of said option by the Telephone Company, but not beyond a period of one year from the date hereof, if said option is

not exercised within said period; and Hewitt will make no claim against the Telephone Company, or those operating under its authority, because of such making and using.

If the said option is exercised, the Telephone Company, its successors and assigns, may continue to use and may sell or lease to others for use and sale, or rental, the apparatus made during the option period, upon paying $30 per installation, as provided in the attached form of license.

3. Hewitt warrants that he has full power and authority to grant this option and to enter into the license agreement hereto attached, and that he has not made and will not make any agreement in conflict herewith or with his ability to execute and carry out the provisions of the attached license agreement.

IN WITNESS WHEREOF, the said Hewitt has executed this instrument the day and year first above written.

(Signed) Peter Cooper Hewitt.

The Cooper Hewitt Electric Company, holding the legal title to some of the patents referred to in the foregoing option and attached form of licenses hereby, upon behalf of itself and on behalf of the Westinghouse Cooper Hewitt Company, Limited, which also holds the legal title to some of the said patents, all of the capital stock of which Company, is held and owned by the Cooper Hewitt Electric Company, acknowledges to and agrees with the American Telephone and Telegraph Company that so far as concerns the Cooper Hewitt Electric Company and the Westinghouse Cooper Hewitt Company, Limited, or others claiming under it or them, the above mentioned Peter Cooper Hewitt has full right and power to grant the foregoing option and to enter into the attached license agreements A and B, and the Cooper Hewitt Electric Company to the same extent hereby ratifies and confirms the foregoing option and the attached license agreements upon its own behalf and on behalf of the Westinghouse Cooper Hewitt Company, Limited, and it agrees that it and said last mentioned Company will execute said agreements when requested so to do by the said Peter Cooper Hewitt.

COOPER HEWITT ELECTRIC COMPANY,
By
(Signed) Charles B. Hill,
Vice President.

Attest:
(Signed) Charles A. Terry,
Secretary.
COOPER HEWITT ELECTRIC CO.
By
(Signed) Charles B. Hill.

Attest:
(Signed) Charles A. Terry,
Secretary.

State of New York,
County of New York. } ss.:

On this Sixteenth day of December, 1912, before me personally came PETER COOPER HEWITT, to me known and known to me to be the individual described in and who executed the foregoing instrument, and he acknowledged to me that he executed the same.

(Signed) ROBERT FOSTER JAMES,
Notary Public,
N. Y. Co. No. 13 etc.

State of New York, } ss.:
County of New York. }

On this Sixteenth day of December, 1912, before me personally came CHARLES B. HILL and CHARLES A. TERRY, to me known, who being by me severally duly sworn did depose and say; the said Charles B. Hill that he resides in Montgomery, New York; that he is Vice President of the Cooper Hewitt Electric Company, the corporation described in and which executed the above instrument; the said Charles A. Terry that he resides in New York City; that he is the Secretary of the said corporation; that they know the seal of said corporation; that the seal affixed to said instrument are such corporate seal; that they were so affixed by order of the Board of Directors of said corporations, and that they signed their names thereto by like order.

(Signed) ROBERT FOSTER JAMES,
Notary Public, etc.

PLAINTIFF'S EXHIBIT No. 201-A.

Agreement A.

UNITED STATES LICENSE.

AGREEMENT made this day of 191 , between PETER COOPER HEWITT of New York City and the AMERICAN TELEPHONE and TELEGRAPH COMPANY, a New York Corporation, herein called the Telephone Company.

WHEREAS, the said Hewitt has made many inventions, among which are those set forth in the following patents of the United States:

No. 749,791, dated January 19, 1904,
No. 749,792, dated January 19, 1904,
No. 749,793, dated January 19, 1904,
No. 758,650, dated May 3, 1904,
No. 781,001, dated January 31, 1905,
No. 781,002, dated January 31, 1905,
No. 954,434, dated April 12, 1910,
No. 991,304, dated May 2, 1911,

and

WHEREAS, said enumerated patents and other patents for the inventions of said Hewitt were assigned to the Cooper Hewitt Electric Company, a New York corporation, under certain agreements dated March 7, 1900 and November 7, 1902, between the said Hewitt and George Westinghouse, but the said Hewitt retained under said agreements and now owns, for himself and his assigns, the exclusive rights under all of said patents for certain uses, among which is their use for C. H. T. devices as hereinafter defined; and

WHEREAS, the Telephone Company desires a license to utilize said inventions in such apparatus as hereinafter set forth;

Now, in consideration of the mutual agreements herein contained, it is agreed as follows:

1. Hewitt hereby grants to the Telephone Company the right and license to make or cause to be made for it and to use gas or vapor electric apparatus for creating, transmitting or receiving or relaying or repeating or amplifying or boosting telephonic or telegraphic electric currents, waves or impulses in telephone or telegraph systems employing wires or metallic conductors connecting stations (all of which devices are, for convenience, herein called C. H. T. devices), embodying or made or operating in accordance with any and all inventions which he has heretofore made, and to sell or lease such C. H. T. devices to others and to license them to sell, use or lease the same, which license shall continue to the end of the terms of all patents of the United States which have been or may be obtained on inventions which have been made by Hewitt up to the present date for which applications for United States patents shall have been filed prior to two years from the date hereof.

The foregoing licenses are granted and agreed to be granted for and throughout the United States of America and its territories and dependencies, and shall be exclusive (subject to the provisions hereinafter contained) in the field of telephony and telegraphy using wires or metallic conductors connecting stations on land lines, including communication over sub-aqueous cables, such as extend through rivers, lakes and seas, and to the immediate outlying land, and shall be non-exclusive for trans-oceanic cable lines; nothing herein shall prevent Hewitt from granting to others rights under his inventions to use C. H. T. devices in trans-oceanic cable lines at intermediate landing points, nor from granting to others the right to make C. H. T. devices for such uses.

2. Hewitt further agrees that as and when, up to January, 1921, he hereafter makes inventions useful in or applicable to C. H. T. devices, he will endeavor to promptly and fully disclose the same to the Telephone Company, and each such invention shall come under this agreement, if the Telephone Company so elects from time to time within one year after the date of each such disclosure. If the Telephone Company does so elect, the Telephone Company shall have, with reference to such inventions, the licenses above expressed to the end of the terms of the United States patents to be granted upon the several inventions so disclosed and brought under his agreement. If Hewitt or the Cooper Hewitt Electric Company does not desire to file and prosecute applications for United States patents upon any such inventions so disclosed to the Telephone Company, Hewitt shall give the Telephone Company an opportunity of filing and prosecuting the same. If the Telephone Company elects to prosecute the same, Hewitt agrees to execute all proper papers in connection therewith and assign to the Telephone Company the invention and United States patents to be issued for the same, the Telephone Company agreeing to grant to Hewitt, free of expense, rights under

said patents for uses in fields other than those of telephony and telegraphy in a broad sense as defined in the last paragraph of this Clause 2.

The Telephone Company agrees that when and if it makes commercial installations of C. H. T. devices embodying any inventions under which this license is granted, it will, up to January 19, 1921, give to Hewitt, but not to his assigns or representatives the opportunity of examining the same and witnessing the operation thereof. Information received by Hewitt from or through the Telephone Company or its interests shall be utilized by Hewitt in his discretion in the interest of the Telephone Company and not to the detriment of that Company.

The Telephone Company further agrees that it will give to Hewitt, but not to his assigns or representatives, an opportunity of acquiring a right to use and of granting to others the right to use any improvements which the Telephone Company may make in C. H. T. devices embodying inventions under which this license is granted, such rights being limited, however, to users for other than telephony or telegraphy in a broad sense, namely, including transmission over conductors on land or transoceanic cables or wireless transmission. Such rights may be acquired by Hewitt on terms to be agreed upon from time to time; it is recognized that no basis for such acquisition can be fixed at present; but the understanding is that Hewitt shall have an opportunity of acquiring such rights or of purchasing such apparatus from the Telephone Company at a fair price, and at a price at least as low as any price, acceptable to the Telephone Company, offered by others.

3. The Telephone Company agrees that it will keep books showing the manufacture of said C. H. T. devices by or for it, and the installations of such apparatus made by it or under its authority, which books shall at all reasonable times be open to the inspection of Hewitt or his duly authorized agents.

An "installation" is defined as an apparatus employed to create, transmit, receive, relay, repeat, amplify or boost electric currents, waves or impulses in a circuit or between lines connected or interconnected to form a circuit for transmission of sounds or signals, whether a one-way or two-way working apparatus, and without regard to the number of tubes employed or the particular circuit arrangement of connections, provided, however, that

(a) if the apparatus employed in a given connection or circuit is located at two or more places separated by outside line construction, the apparatus in each such location shall be counted as a separate installation;

(b) If a circuit divides into several branches not reuniting, and independent apparatus is installed in more than one branch of the circuit, then each such apparatus shall count as a separate installation, even although not separated from the others by outside line construction;

(c) if there should be employed apparatus capable of operating simultaneously for several independent circuits, although using one or more parts in common, such apparatus shall be considered as a number of installations equal to the number of independent circuits upon which it is arranged to work simultaneously.

4. The Telephone Company agrees that it will on or before the twentieth day of each January and July, during the term of this agreement, render to Hewitt a statement in writing setting forth the number of installations of C. H. T. devices (embodying or operating in accordance with any of the inventions under which this license is granted, leased, sold or put into use by it or under its authority in the six calendar months immediately preceding that in which each such statement is rendered.)

The Telephone Company further agrees that, subject to the provisions hereinafter contained, it will, at the time of rendering each such statement up to January 19, 1921, the date of expiration of said patents Nos. 749,791 and 749,792, pay to Hewitt an amount in royalties equal to Thirty Dollars ($30) for each such installation so reported. After said date the royalty shall be Ten Dollars ($10) for each additional installation embodying the invention of any unexpired patent or patents in force at the time of each such installation.

Royalties are payable only with reference to installations as above defined and not on tubes or other parts for replacement or renewal, nor upon the same apparatus when transferred to a new location or to other circuits.

5. If the royalties paid under this license with reference to the year 1914 and each year thereafter up to and including 1920 do not amount to at least as much as Ten Thousand Dollars ($10,000) for each year, and the Telephone Company does not, at the time of ren-

dering the statement for the last half of any such year, pay an amount which, added to the royalties then due, brings the total payments for the year up to said sum, Hewitt may, by notice in writing delivered to the Telephone Company on or before March 1 of the year following that for which the payments have been less than said sum, change the exclusive license, herein granted, to a non-exclusive one.

6. If the Telephone Company fails to render statements and pay the royalties due as and when stated above, and fails to repair its default within sixty days after the receipt of written notice thereof from Hewitt, Hewitt may cancel and terminate this agreement by serving on the Telephone Company written notice of his election so to do.

7. In case at any time or times, during the continuance of this license, any of the patents under which this license is granted, are being infringed by the use of apparatus within the field of telegraphy and telephony covered by this license, then the Telephone Company shall have the right to cause a suit or suits for infringement to be brought and prosecuted under such patent at its own cost and expense using the name of Hewitt or the Cooper Hewitt Electric Company, or both, if it so desire. If the attorneys employed by the Telephone Company for prosecuting the suit shall be unsatisfactory to the said Hewitt or to the Cooper Hewitt Electric Company, in case the latter has an interest in such patent, he or it may employ an attorney to take part in the prosecution of the case.

If any patent with reference to which royalty is payable hereunder is held to be invalid by any Court of final jurisdiction or by any inferior Court from whose decree no appeal is taken and prosecuted within the time prescribed by law, the Telephone Company shall thereafter be under no obligation to pay royalties with reference to such patent. If the patent is held to be valid but limited in scope, the Telephone Company shall thereafter be under no obligation to pay royalties with reference to its utilization of the C. H. T. devices or method of operation held not to be covered by such patent.

8. Hewitt warrants that he has full right to grant the licenses and make the agreements herein set forth, and that he has not made and will not make any agreement in conflict herewith.

9. Hewitt agrees that he will, at any time or times on request of the Telephone Company, execute and deliver to the Telephone Company such further or other instruments as the latter may desire for fully vesting in it the license and rights herein conveyed.

10. It is agreed that the recognition of the validity of patents, arising out of the acceptance of this license, is limited to their validity in connection with C. H. T. devices as herein defined.

11. This agreement and license shall be binding upon and shall inure to the benefit of the parties hereto, and their several successors, legal representatives and

assigns. The Telephone Company's rights hereunder shall not be assignable or transferrable except to an assignee or transferee who shall agree in all respects to be bound by the obligations of the Telephone Company hereunder; and Hewitt agrees that he will cause any assignee or transferee of his rights hereunder or of his patents under which this license is granted, to be bound by all of his obligations as expressed herein.

IN WITNESS WHEREOF, Hewitt has executed this instrument and the Telephone Company has caused this instrument to be executed by its proper officers thereunto duly authorized, on the day and year first above written.

____

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,

By ____________________

Attest:

____

Secretary.

The Cooper Hewitt Electric Company referred to in the preamble of the foregoing license hereby acknowledges and agrees with the American Telephone and Telegraph Company that, so far as concrns itself or others claiming under it, the above-mentioned Peter Cooper Hewitt has full right and power to grant the licenses and to make the agreements set forth in the foregoing instrument, and it hereby, to the same extent, ratifies and confirms the granting of the licenses and the said license agreement.

COOPER HEWITT ELECTRIC COMPANY,
By

Attest:
Secretary.

State of New York, County of New York, } ss.:

On this day of , 191 , before me personally came PETER COOPER HEWITT, to me known and known to me to be the individual described in and who executed the foregoing instrument, and he acknowledged to me that he executed the same.

Notary Public.

United States License.

AGREEMENT made this fifteenth day of December, 1913, between PETER COOPER HEWITT, of New York City and the AMERICAN TELEPHONE AND TELEGRAPH COMPANY, a New York corporation, herein called the Telephone Company.

WHEREAS, the said Hewitt has made many inventions, among which are those set forth in the following patents of the United States:

No. 749,791, dated January 19, 1904,
No. 749,792, dated January 19, 1904,
No. 749,793, dated January 19, 1904,
No. 758,650, dated May 3, 1904,
No. 781,001, dated January 31, 1905,
No. 781,002, dated January 31, 1905,
No. 954,434, dated April 12, 1910,
No. 991,304, dated May 2, 1911,

and

WHEREAS, said enumerated patents and other patents for the inventions of said Hewitt were assigned to the Cooper Hewitt Electric Company, a New York corporation, under certain agreements dated March 7, 1900, and November 7, 1902, between the said Hewitt and George Westinghouse, and an agreement, dated December 31, 1912, was entered into between said Hewitt and the Cooper Hewitt Electric Company, a New Jersey corporation (both of the Cooper Hewitt Electric Companies being hereinafter referred to as the Cooper Hewitt Electric Company, the New Jersey Company being the successor of the New York Company), but the said Hewitt retained under said agreements and now owns, for himself and his assigns, the exclusive rights under all of said patents for certain uses, among which is their use for C. H. T. devices as hereinafter defined; and

WHEREAS, the Telephone Company desires a license to utilize said inventions in such apparatus as hereinafter set forth:

Now, in consideration of the mutual agreements herein contained, it is agreed as follows:

1. Hewitt hereby grants to the Telephone Company the right and license to make or cause to be made for it and to use, in telephone or telegraph systems employing wires or metallic conductors connecting stations, gas or vapor and so called vacuum electric apparatus for creating, transmitting, receiving, relaying, repeating, modifying, amplifying or boosting telephonic or telegraphic electric currents, waves or impulses, or (in so far as not in conflict with the agreements above referred to) for lightning arresters, or strong current discharger or protector, or charge or voltage limiters, embodying or made or operating in accordance with any and all inventions which he has heretofore made either alone or jointly with others (all of which devices are, for convenience, herein called C. H. T. devices), and to sell or lease such C. H. T. devices to others and to license them to sell, use or lease the same, which license shall continue to the end of the terms of all patents of the United States

which have been or may be obtained on inventions which have been made by Hewitt up to the present date for which applications for United States patents shall have been filed prior to two years after the date hereof.

The foregoing licenses are granted and agreed to be granted for and throughout the United States of America and its territories and dependencies, and shall be exclusive (subject to the provisions hereinafter contained) in the field of telephony and telegraphy using wires or metalic conductors connecting stations on land lines, including communications over sub-aqueous cables, such as extend through rivers, lakes and seas, and to the immediate outlying land, and shall be non-exclusive for trans-oceanic cable lines; nothing herein shall prevent Hewitt from granting to others rights under his inventions to use C. H. T. devices in trans-oceanic cable lines at intermediate landing points and terminals, nor from granting to others the right to make C. H. T. devices for such uses.

2. Hewitt further agrees that as and when, up to January, 1921, he hereafter makes inventions, useful in or applicable to C. H. T. devices, he will, upon filing application for patent for any such invention, endeavor to promptly and fully disclose the same to the Telephone Company and deliver to the Telephone Company a copy of such application, and each such invention made by him alone shall come under this agreement (and likewise his interest in those made jointly with others), if the Telephone Company so elects from time to time within

one year after the date of each such disclosure. If the Telephone Company does so elect the Telephone Company shall have, with reference to such inventions, the license above expressed to the end of the terms of the United States patents to be granted upon the several inventions so disclosed and brought under this agreement. If Hewitt or the Cooper Hewitt Electric Company does not desire to file and prosecute applications for United States patents upon any such invention hereafter made, Hewitt shall disclose the same to the Telephone Company, and give the Telephone Company an opportunity of filing and prosecuting the same. If the Telephone Company elects to prosecute the same, Hewitt agrees to execute all proper papers in connection therewith and to assign to the Telephone Company the invention and United States patents to be issued for the same, the Telephone Company agreeing to grant to Hewitt, free of expense, rights under said patents for uses in fields other than those of telephony and telegraphy in a broad sense as defined in the last paragraph of this Clause 2.

The Telephone Company agrees that when and if it makes commercial installations of C. H. T. devices embodying any inventions under which this license is granted, it will, up to January 19, 1921, give to Hewitt, but not to his assigns or representatives, the opportunity of examining the same and witnessing the operation thereof. Information received by Hewitt from or through the Telephone Company or its interests shall be utilized by Hewitt in his discretion in the interest of the Telephone Company and not to the detriment of that Company.

The Telephone Company further agrees that it will give to Hewitt, but not to his assigns or representatives, an opportunity of acquiring a right to make, use and sell, and of granting to others the right to make, use and sell any improvements which the Telephone Company may make in C. H. T. devices embodying inventions under which this license is granted, such rights being limited, however, to manufacture, sale and use for other than telephony or telegraphy in a broad sense, which "broad sense" here includes transmission over conductors on land and trans-oceanic cables and wireless transmission. Such rights may be acquired by Hewitt on terms to be agreed upon from time to time; it is recognized that no basis for such acquisition can be fixed at present; but the understanding is that Hewitt shall have an opportunity of acquiring such rights or of purchasing such apparatus from the Telephone Company at a fair price, and at a price at least as low as any price, acceptable to the Telephone Company, offered by others.

3. The Telephone Company agrees that it will keep books showing the manufacture, lease and sale of said C. H. T. devices by or for it, and the installations of such apparatus made by it or under its authority, which books shall at all reasonable times be open to the inspection of Hewitt or his duly authorized agents.

An "installation" is defined as an apparatus employed to create, transmit, receive, relay, repeat, modify, amplify or boost electric currents, waves or impulses in a circuit or between lines connected or interconnected to form a circuit for transmission or sounds or signals, whether a one-way or two-way working apparatus, and without regard to the number of tubes employed or the particular circuit arrangement or connections, or employed as a lightning arrester, or strong current discharger or protector, or charge or voltage limiter in telephone or telegraph systems, provided, however, that

(a) if the apparatus employed in a given connection or circuit is located at two or more places separated by outside line construction, the apparatus in each such location shall be counted as a separate installation;

(b) if a circuit divides into several branches not re-uniting, and independent apparatus is installed in more than one branch of the circuit, then each such apparatus shall count as a separate installation, even although not separated from the others by outside line construction;

(c) if there should be employed apparatus capable of operating simultaneously for several independent circuits, although using one or more parts in common, such apparatus shall be considered as a number of installations equal to the number of independent circuits upon which it is arranged to work simultaneously.

4. The Telephone Company agrees that it will, on or before the twentieth day of each January and July, during the term of this agreement, render to Hewitt a statement in writing setting forth the number of installations of C. H. T. devices (embodying or operating in accordance with the inventions of any unexpired patent or patents under which this license is granted,

and in force at the time of each such installation), leased, sold or put into use by it or under its authority in the six calendar months immediately preceding that in which each such statement is rendered.

The Telephone Company further agrees that, subject to the provisions hereinafter contained, it will, at the time of rendering each such statement, pay to Hewitt an amount in royalties to be computed in accordance with Schedule A hereto attached, for each such installation so reported.

Each sale of C. H. T. devices for an installation shall, for the purpose of royalty payments, be considered to be an installation whether or not actually installed at time of sale and royalty shall then accrue.

Royalties are payable only with reference to installations as above defined and not on tubes or other parts for replacement or renewal, nor upon the same apparatus when transferred to a new location or to other circuits.

5. If the royalties paid under this license with reference to the year 1914 and each year thereafter up to and including 1920 do not amount to at least as much as Ten Thousand Dollars ($10,000) for each year, and the Telephone Company does not, at the time of rendering the statement for the last half of any such year, pay an amount which, added to the royalties when due, brings the total payments for the year up to said sum, Hewitt may, by notice in writing delivered to the Telephone Company on or before March 1 of the year fol-

lowing that for which the payments have been less than said sum, change the exclusive license, herein granted, to a non-exclusive one.

6. If the Telephone Company fails to render statements and pay the royalties due as and when stated above, and fails to repair its default within sixty days after the receipt of written notice thereof from Hewitt, Hewitt may cancel and terminate this agreement by serving on the Telephone Company written notice of his election so to do.

7. In case at any time or times, during the continuance of this license, any of the patents under which this license is granted, are being infringed by the use of apparatus within the field of telegraphy and telephony covered by this license, then the Telephone Company shall have the right to cause a suit or suits for infringement to be brought and prosecuted under such patent at its own cost and expense using the name of Hewitt or the Cooper Hewitt Electric Company, or both, if it so desires. If the attorneys employed by the Telephone Company for prosecuting this suit shall be unsatisfactory to the said Hewitt or to the Cooper Hewitt Electric Company, in case the latter has an interest in such patent, he or it may employ an attorney to take part in the prosecution of the case

If any patent with reference to which royalty is payable hereunder is held to be invalid by any Court of final jurisdiction or by any inferior Court from whose decree no appeal is taken and prosecuted within the time prescribed by law, the Telephone Company shall thereafter be under no obligation to pay royalties with reference to such patent. If the patent is held to be valid but limited in scope, the Telephone Company shall thereafter be under no obligation to pay royalties under that patent, with reference to its utilization of the C. H. T. devices or method of operation held not to be covered by such patent.

8. Hewitt warrants that he has full right to grant the licenses and make the agreements herein set forth, and that he has not made and will not make any agreement in conflict herewith.

9. Hewitt agrees that he will, at any time or times on request of the Telephone Company, execute and deliver to the Telephone Company such further or other instruments as the latter may desire for fully vesting in it the license and rights herein conveyed.

10. It is agreed that the recognition of the validity of patents, arising out of the acceptance of this license, is limited to their validity in connection with C. H. T. devices as herein defined.

11. This agreement and license shall be binding upon and shall inure to the benefit of the parties hereto, and their several successors, legal representatives and assigns, except as otherwise specifically stated in this agreement. The Telephone Company's rights hereunder shall not be assignable or transferable except to an assignee or transferee who shall agree in all respects

to be bound by the obligations of the Telephone Company hereunder; and Hewitt agrees that he will cause any assignee or transferee of his rights hereunder or of his patents under which this license is granted, to be bound by all of his obligations as expressed herein.

IN WITNESS WHEREOF, Hewitt has executed this instrument and the Telephone Company has caused this instrument to be executed by its proper officers thereunto duly authorized, on the day and year first above written.

(Signed) PETER COOPER HEWITT.

Witnesses:
CHARLES A. TERRY,
CHARLES B. HILL.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
By (Signed) H. B. THAYER,
Vice-President.

Attest:
(Signed) ALFRED E. HOLCOMB,
Assistant Secretary.
(Seal)

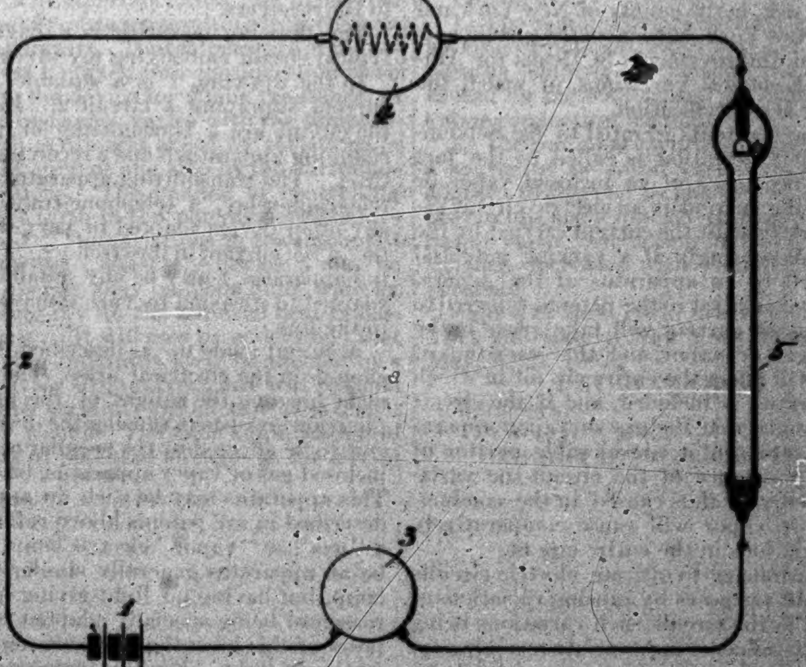
PLAINTIFF'S EXHIBIT No. 202.

No. 781,001. PATENTED JAN. 31, 1905.

P. C. HEWITT.

MEANS FOR AMPLIFYING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 28, 1902.



Witnesses
Frank S. Ober.

Inventor
Peter Cooper Hewitt
By his Attorney
Charles A. Terry

No. 781,001. Patented January 31, 1905.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR AMPLIFYING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 781,001, dated January 31, 1905.

Application filed May 16, 1902. Serial No. 107,004.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Means for Amplifying Electrical Variations, of which the following is a specification.

In certain patents granted to me September 17, 1901, attention is called to the fact that the resistance of an inclosed vapor or gas carrying current in an electric circuit varies inversely with the current carried by the vapor. Accordingly if a varying potential be applied to an apparatus of the general character described in the patents referred to a variation of current will take place in the inclosed gas or vapor, and this variation of current will affect the entire circuit in which the apparatus is included, and if the circuit is so arranged that the gas or vapor apparatus shall represent a considerable portion of the total resistance of the circuit the variations of current thus caused in the conducting gas or vapor will cause comparatively large variations in the entire circuit.

It is customary to operate electric circuits for various purposes by causing variations of potential in the circuit, such variations being utilized to influence appropriate receiving apparatus. In the present invention I avail myself of the peculiar features of electrical resistance in a gas or vapor conductor to vary or magnify the effects produced by potential variations in a circuit. By virtue of the described characteristics of gas or vapor conductors it is possible, for instance, to translate variations of potential in a circuit into variations of current or quantity, and inasmuch as the conducting gas or vapor responds practically instantaneously to the applied variations of potential, currents of any practical rapidity or frequency can be made to undergo the described transformation and produce their effects upon a suitable receiving apparatus. As the practical result of an increase of applied potential is an increased flow of current, the original electrical impulses in the circuit may produce magnified effects as compared with those which the same impulses would produce if applied directly to the receivers.

The drawing herewith is a diagram of a typical circuit embodying my invention.

In the drawing, 1 is a suitable source of current supplying a circuit 2. Included in the circuit are a transmitting or potential-changing apparatus 3 and a receiving apparatus 4. The transmitting apparatus may be a telegraph-relay, a telephone-transmitter, or any other device adapted to vary the potential of the current in the circuit 2. The receiving apparatus 4 may be any suitable receiver adapted to respond to variations of current in the line.

A circuit made up as described is common enough in the electrical arts. The improvement forming the subject of the present application consists in causing the described circuit to be affected by the peculiar action of an inclosed gas or vapor apparatus, (shown at 5.) This apparatus may be such an apparatus as described in my patents above referred to as a "gas" or "vapor" electric lamp, or it may be an apparatus generally similar to such a lamp, but having no light-giving quality by reason of being specially adapted to the purposes of this invention without regard to the matter of light. For this purpose the device may be made with a comparatively short gas or vapor path and having such cross-section that with the current normally traversing it the vapor or gas may become but faintly luminous. The resistance of the circuit outside the device 5 is practically constant except for the slight variations introduced through the instrumentality of the potential-changing apparatus 3. As the resistance of the device 5 varies substantially inversely with the quantity of the current flowing, or, to put it another way, requires a definite voltage to pass a definite current therethrough, any diminution, for instance, of the potential applied to its terminals by reason of an increase of resistance on the part of the device 3 will result in not only the diminution of flow of current due to the increased resistance of the device 3, but also to an additional diminution due to the change brought about in the device 5 by the decreased current resulting from the decreased potential at the terminals of the device 5. Likewise an increase of potential at the terminals of the device 5, due to a change of resistance in the outside circuit, will cause an increase of current-flow therethrough greatly in excess of the change due to the change of resistance in the other portions of the circuit. In other words, the changes of resistance in other portions of the circuit than the device 5 bring about such variations of conditions in the device 5 as to augment the variations of current-flow through the entire circuit. It should be borne in mind, however, that the resistance of the other portions of the circuit than the device 5 serves in a measure as a balancing resistance for the device 5; otherwise a decrease of resistance in the external circuit might result in a continuing unchecked decrease of the total resistance of the circuit including the device 5. The device 5 itself, however, has in a measure a self-corrective tendency within certain limits, due to internal variations of resistance resulting from changes in its temperature. The temperature of the device 5 may be taken into consideration when measuring the device for ohmic resistance, as its ohmic resistance varies with the temperature which is brought about by variations in the flow of current and also by the surrounding conditions. The method of controlling these is set forth in the patents hereinbefore referred to. The variations in the amount of current through which the device 5 may be made to operate may be made quite wide by constructing it with the required heat-radiating capacity. It will now be understood that the receiving apparatus 4 will be affected by a comparatively large current and will respond with greater certainty and effectiveness than it otherwise would. The same amplification of the effects of potential changes in the circuit takes place whatever be the degree of potential increase or variation.

When the resistance of the element 5 is made a considerable portion of the total resistance of the circuit, the effect of the changes of resistance in the element named will be very marked, especially when the source of supply is great.

By reason of the gaseous condition of the conducting medium employed the gas or vapor apparatus responds instantly to potential changes in the current without essential loss of energy. In this respect it differs from other materials or substances, because in such other materials or substances work has to be done in the process of reducing the resistance whereby a loss of energy is caused and the time element becomes a considerable factor, while in my apparatus the amount of material so affected is so small that the energy required to produce the result may be practically neglected.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. The combination in an electric circuit, of a source of potential variation, a receiving apparatus adapted to translate the variations caused by the source, and an inclosed gas or vapor conducting medium.

2. The combination in an electric circuit, of a source of potential variations, a receiver adapted to respond to changes of current in the circuit, and a quickly-responding inclosed gas or vapor conducting medium whose resistance decreases with increments of temperature.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
Wm. H. Capel,
George H. Stockbridge.

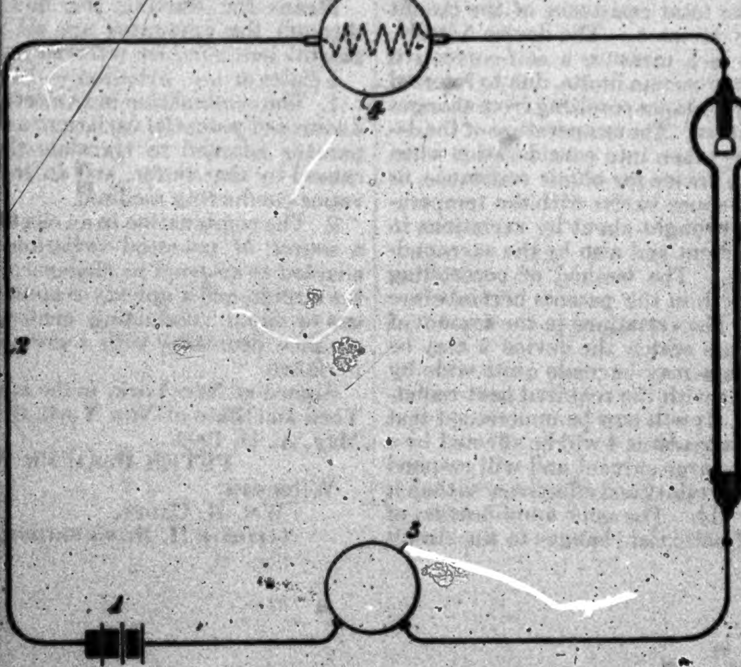
PLAINTIFF'S EXHIBIT No. 203.

No. 781,002. PATENTED JAN. 31, 1905.

P. C. HEWITT.

METHOD OF AMPLIFYING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 16, 1903.



Witnesses
Frank S. Ober
George H. Stockbridge jr

Inventor
Peter Cooper Hewitt
By his Attorney
Charles A. Terry

No. 781,002. Patented January 31, 1905.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AMPLIFYING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 781,002, dated January 31, 1905.

Application filed May 16, 1902. Serial No. 107,[illegible].

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Amplifying Electrical Variations, of which the following is a specification.

In certain patents granted to me September 17, 1901, notably in the patents numbered 682,695, 682,696, and 682,697, attention is called to the fact that the resistance of an inclosed vapor or gas carrying current in an electric circuit varies inversely with the current carried by the vapor. Accordingly if a varying potential be applied to an apparatus of the general character described in the patents referred to a variation of current will take place in the inclosed gas or vapor, and this variation of current will affect the entire circuit in which the apparatus is included, and if the circuit is so arranged that the gas or vapor apparatus shall represent a considerable portion of the total resistance of the circuit the variations of current thus caused in the conducting gas or vapor will cause comparatively large variations in the entire circuit.

It is customary to operate electric circuits for various purposes by causing variations of potential in the circuit, such variations being utilized to influence appropriate receiving apparatus. In the present invention I avail myself of the peculiar features of electrical resistance of a gas or vapor conductor to vary or magnify the effects produced by potential variations in a circuit.

By virtue of the described characteristics of gas or vapor conductors it is impossible, for instance, to translate variations of potential in a circuit into variations of current or quantity, and inasmuch as the conducting gas or vapor responds practically instantaneously to the applied variations of potential currents of any practical rapidity or frequency can be made to undergo the described transformation and produce their effects upon a suitable receiving apparatus. As the practical result of an increase of applied potential is an increased flow of current, the original electrical impulses in the circuit may produce magnified effects as compared with those which the same impulses would produce if applied directly to the receivers.

The drawing herewith is a diagram of a typical circuit embodying my invention.

In the drawing, 1 is a suitable source of current supplying a circuit 2. Included in the circuit are a transmitting or potential changing apparatus 3 and a receiving apparatus 4. The transmitting apparatus may be a telegraph-relay, a telephone-transmitter, or any other device adapted to vary the potential of the current in the circuit 2. The receiving apparatus 4 may be any suitable receiver adapted to respond to variations of current in the line.

A circuit made up as described is common enough in the electrical arts.

The improvement forming the subject of the present application consists in causing the described circuit to be affected by the peculiar action of an inclosed gas or vapor apparatus, (shown at 5.) This apparatus may be such an apparatus as described in my patents above referred to as a "gas" or "vapor" electric lamp, or it may be an apparatus generally similar to such a lamp, but having no light-giving quality by reason of being specially adapted to the purposes of this invention without regard to the matter of light. For this purpose the device may be made with a comparatively short gas or vapor path and having such cross-section that with the current normally traversing it the vapor or gas may become but faintly luminous. The resistance of the circuit outside the device 5 is practically constant except for the slight variations introduced through the instrumentality of the potential-changing apparatus 3. As the resistance of the device 5 varies substantially inversely with the quantity of the current flowing, or, to put it another way, requires a definite voltage to pass a definite current therethrough, any diminution, for instance, of the potential applied to its terminals by reason of an increase of resistance on the part of the device 5 will result in not only the diminution of flow of current due to the increased resistance of the device, but also to an additional diminution due to the change brought about in the device 5 by the decreased current resulting from the decreased potential at the terminals of the device 5. Likewise an increase of potential at the terminals of the device 5 due to a change of resistance in the outside circuit will cause an increase of current-flow therethrough greatly in excess of the change due to the change of resistance in the other portions of the circuit. In other words, the changes of resistance in other portions of the circuit than the device 5 bring about such variations of conditions in the device 5 as to augment the variations of current-flow through the entire circuit. It should be borne in mind, however, that the resistance of the other portions of the circuit than the device 5 serves in a measure as a balancing resistance for the device 5. Otherwise a decrease of resistance in the external circuit might result in a continuing unchecked decrease of the total resistance of the circuit including the device 5. The device 5 itself, however, has in a measure a self-corrective tendency within certain limits due to internal variations of resistance resulting from changes in its temperature. The temperature of the device 5 must be taken into consideration when measuring the device for ohmic resistance, as its ohmic resistance varies with the temperature which is brought about by variations in the flow of current and also by the surrounding conditions. The method of controlling these is set forth in the patents hereinbefore referred to. The variations in the amount of current through which the device 5 may be made to operate may be made quite wide by constructing it with the required heat-radiating capacity.

It will now be understood that the receiving apparatus 4 will be affected by a comparatively large current and will respond with greater certainty and effectiveness than it otherwise would.

The same amplification of the effects of potential changes in the circuit takes place whatever be the degree of potential increase or variation.

When the resistance of the element 5 is made a considerable portion of the total resistance of the circuit, the effect of the changes of resistance in the element named will be very marked, especially when the source of supply is great.

By reason of the gaseous condition of the conducting medium employed the gas or vapor apparatus responds instantly to potential changes in the current without essential loss of energy. In this respect it differs from other materials or substances, because in such other materials or substances work has to be done in the process of reducing the resistance, whereby a loss of energy is caused and the time element becomes a considerable factor, while in my apparatus the amount of material so affected is so small that the energy required to produce the result may be practically neglected.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. The method of amplifying potential variations caused in an electric circuit, which consists in applying the said variations to a quickly-responding medium in the circuit, thereby causing a change in current-flow through such medium, and by such change of current-flow producing in such medium a change of specific resistance resulting in a still further change in current-flow through the circuit.

2. The method of amplifying energy variations caused in an electric circuit of which an inclosed gas or vapor forms part, and of translating the effects of such amplified variations, which consists in affecting the conducting gas or vapor by variations of current, transforming such variations of current into variations of resistance, and applying such currents to a suitable translating device.

3. The method of amplifying energy variations caused in an electric circuit including an inclosed conducting gas or vapor and electrodes therefor, which consists in affecting the conducting gas or vapor by variations of current, and thereby transforming such variations into corresponding amplified variations of current.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:

Wm. H. Capel,

George H. Stockbridge.

PLAINTIFF'S EXHIBIT No. 204.

No. 749,791. PATENTED JAN. 19, 1904.

P. C. HEWITT.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 16, 1902.

NO MODEL.

Fig. 1.

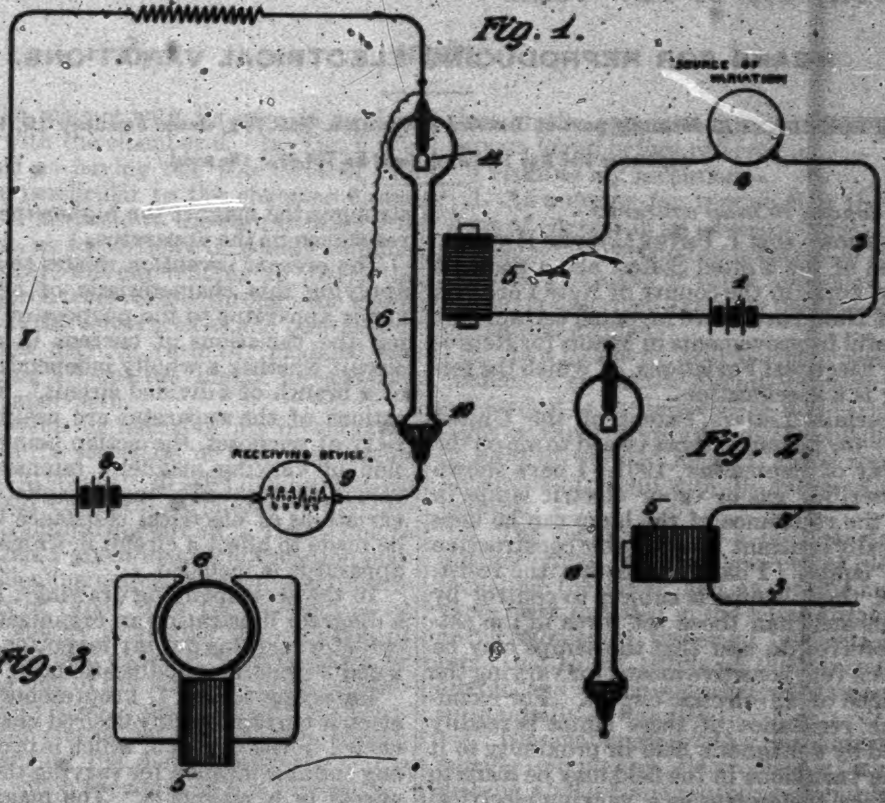

SOURCE OF VARIATION
4
3
5
1
11
6
10
7
8
RECEIVING DEVICE
9

Fig. 2.

5
3
3
6

Fig. 3.

6
5

Witnesses

Inventor
Peter Cooper Hewitt.
By his Attorney
Charles A. Brown

No. 749,791. Patented January 19, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 749,791, dated January 19, 1904.

Application filed May 16, 1902. Serial No. 107,601. (No model.)

To all whom it may concern:

Be it known that I, Peter Cooper Hewitt, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Means for Reproducing Electrical Variations, of which the following is a specification.

In certain Letters Patent of the United States—for instance, those issued to me on the 17th day of September, 1901—I have shown and described gas or vapor electric lamps in which the resistance of the lamp can be kept practically constant by a suitable construction of the lamps. I have found that the resistance of these lamps is subject to control by other means than those set forth in the patents referred to and that the lamps may be used as a very sensitive means for varying the resistance of an electric circuit. For example, the resistance of these lamps is readily affected by a magnetic field in proximity to it and the variations in the field may be made to reproduce themselves as a varying electrical resistance in the lamp. The same effect is produced by a magnet or solenoid upon an apparatus of this general character whether the apparatus is designed to operate as a lamp or light-giving medium or is especially designed as a means of varying the current in a circuit. In other words, in applying the described apparatus to the purposes of this invention I may so construct it as to make it capable of giving light, or I may prefer to inclose an appropriate gas or vapor in a container so proportioned as to accomplish the special results aimed at by this invention irrespective of whether the apparatus is then designed to produce light or not.

In order to produce the desired variations of resistance in the gas or vapor apparatus, I generally locate the magnet or solenoid at the side of the apparatus where it will distort the current passing between the positive and the negative electrodes, it being found that the active current in an apparatus of this sort tends to be deflected by a magnetic field. The stronger the magnet the higher the electrical resistance of the apparatus.

The present invention relates to means for applying this characteristic of my lamp or vapor apparatus to the purpose of reproducing the variations of current in an electric circuit whether a wholly independent circuit or a branch of a divided circuit. Such applications of the apparatus are useful for a variety of purposes, the action being a conversion of varying magnetic intensities due to varying current affecting a magnetic field into variations of electrical resistance which may be made to affect a circuit in which my vapor apparatus is included.

In the accompanying drawings, Figure 1 is a diagram illustrating an organization of circuits for carrying out my invention, and Figs. 2 and 3 illustrate modifications.

Referring to Fig. 1, 1 represents a source of electric currents of any desired character connected in the circuit 3, which is provided with any suitable means 4 for varying the magnetic effects in a magnet 5. The magnet 5 is so placed with reference to a chamber 6, containing a conducting gas or vapor, which in turn is connected in a circuit 7, provided with any suitable source 8 of electric currents. The variations in the flow of current through the circuit 7 may be caused to act upon a receiving device 9 of any desired character. The means for varying the magnetic effects in the magnet 5 may, for example, be a telephone-transmitter, and the receiving device 9 may be a telephone-receiver. The gas or vapor within the tube or container is of any appropriate character, as more fully set forth in my patents hereinbefore referred to, and the negative electrode 10 may be of mercury or of any other suitable means for receiving the current from the gas or vapor and likewise the positive electrode 11, although for convenience I have in the drawings indicated it as being of a solid material held within the chamber 6.

The location of the magnet 5 and its particular relation to the chamber 6 may be variously modified. In Fig. 1 I have represented the magnet with its core in a plane parallel with the chamber 6. In Fig. 2 it is illustrated as having one pole directed in a plane perpendicular to the chamber 6, and in Fig. 3 I have shown the core as being prolonged, so as to partially or wholly embrace the chamber, thereby tending to direct the lines of force transversely through the gas or vapor; but the constructions and positions of the magnet may be variously modified, the object being to cause the lines of force to pass into the vapor-path.

It is possible by means of my invention to produce in the secondary or receiving circuit electrical variations of greater magnitude than the original electrical variations of the primary or transmitting circuit. This is due to the fact that a given magnetic variation may cause a wider fluctuation of effective resistance in the gas or vapor than the fluctuations of electrical energy producing the variation of the magnetic field of force. Accordingly by employing one of my lamps or vapor apparatuses, as described, I may magnify the vibrations of the circuit not by inductive effects, but by varying the ohmic resistance of the circuit in which the apparatus is included.

I have mentioned a telephone-circuit merely for purposes of illustration. The amplifications due to changes in resistance of my apparatus may be applied to other circuits as well, including circuits carrying currents of large quantity.

It will further be understood that the applications of my invention are not limited to cases where it is desired to amplify the primary variations, but are useful also where it is merely desired to reproduce them in the same or even less magnitude.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. As a means for reproducing the variations of current in an electric circuit, an electromagnet subject to the influence of said variations, and a gas or vapor apparatus of the character described located in the field of force of the said magnet.

2. As a means for reproducing current variations in an electric circuit, an electromagnet subject to the influence of said variations, a gas or vapor apparatus located in the field of force of the said magnet, and a receiving apparatus in circuit with the gas or vapor apparatus.

3. The combination of a telephonic transmitting-circuit, a telephone-receiver, a circuit including the latter, and an inclosed gas or vapor path included in the latter circuit, and an electromagnet traversed by electric currents due to the effects of the transmitting-circuit, and acting upon the gas or vapor path, substantially as described.

4. The combination with a telephonic transmitting-circuit, an electromagnet included therein, a telephonic receiving-circuit having an inclosed gas or vapor path inserted therein, the gas or vapor path and the electromagnet occupying such relative positions that a portion at least of the lines of force from the electromagnet act upon the gas or vapor path.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
Wm. H. Capel,
George H. Stockbridge.

PLAINTIFF'S EXHIBIT No. 205.

No. 749,792. PATENTED JAN. 19, 1904.

P. C. HEWITT.

METHOD OF REPRODUCING ELECTRICAL VARIATIONS.

APPLICATION FILED MAY 16, 1902.

NO MODEL.

Fig. 1.

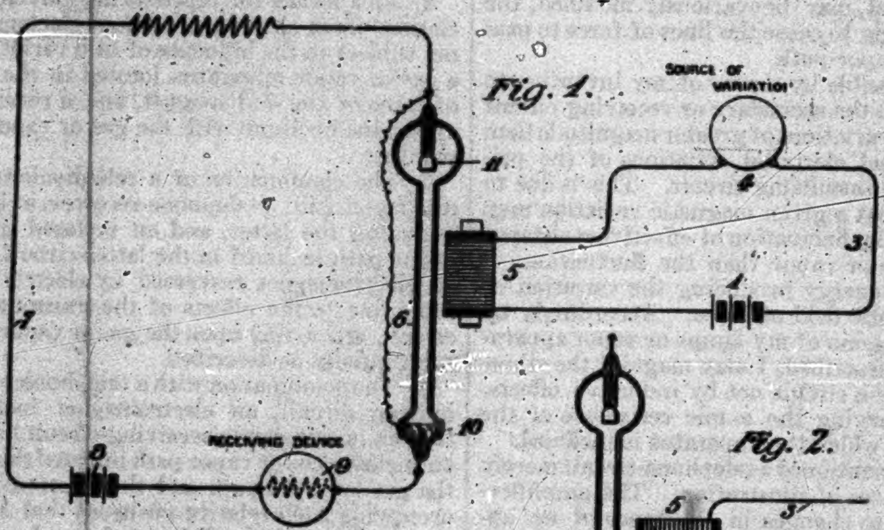

SOURCE OF VARIATION
4
3
1
5
11
6
7
10
8
RECEIVING DEVICE
9

Fig. 2.

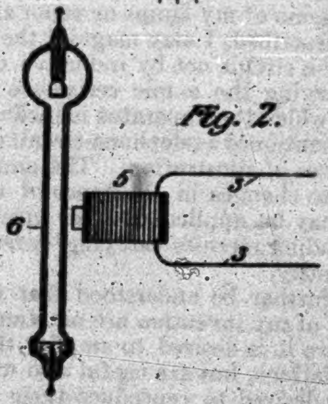
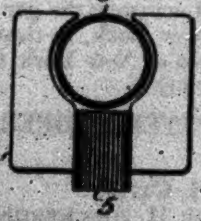


Fig. 3.



Witnesses
Frank S. Ober
George H. Stockbridge

Inventor
Peter Cooper Hewitt.
By his Attorney
Charles A. Terry

No. 749,792. Patented January 19, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF REPRODUCING ELECTRICAL VARIATIONS.

SPECIFICATION forming part of Letters Patent No. 749,792, dated January 19, 1904.

Application filed May 16, 1902. Serial No. 107,602. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Reproducing Electrical Variations, of which the following is a specification.

In certain Letters Patent of the United States—for instance, those issued to me on the 17th day of September, 1901—I have shown and described gas or vapor electric lamps in which the resistance of the lamp can be kept practically constant by a suitable construction of the lamps. I have found that the resistance of these lamps is subject to control by other means than those set forth in the patents referred to and that the lamps may be used as a very sensitive means for varying the resistance of an electric circuit. For example, the resistance of these lamps is readily affected by a magnetic field in proximity to it, and the variations in the field may be made to reproduce themselves as a varying electrical resistance in the lamp. The same effect is produced by a magnet or solenoid upon an apparatus of this general character whether the apparatus is designed to operate as a lamp or light-giving medium or is especially designed as a means of varying the current in a circuit. In other words, in applying the described apparatus to the purposes of this invention I may so construct it as to make it capable of giving light, or I may prefer to inclose an appropriate gas or vapor in a container so proportioned as to accomplish the special results aimed at by this invention irrespective of whether the apparatus is then designed to produce light or not. In order to produce the desired variations of resistance in the gas or vapor apparatus, I generally locate the magnet or solenoid at the side of the apparatus, where it will distort the current passing between the positive and the negative electrodes, it being found that the active current in an apparatus of this sort tends to be deflected by a magnetic field. The stronger the magnet the higher the electrical resistance of the apparatus. The present invention relates to means for applying this characteristic of my lamp or vapor apparatus to the purpose of reproducing the variations of current in an electric circuit whether a wholly independent circuit or a branch of a divided circuit. Such applications of the apparatus are useful for a variety of purposes, the action being a conversion of varying magnetic intensities, due to varying current affecting a magnetic field into variations of electrical resistance which may be made to affect a circuit in which my vapor apparatus is included.

In the accompanying drawings, Figure 1 is a diagram illustrating an organization of circuits for carrying out my invention, and Figs. 2 and 3 illustrate modifications.

Referring to Fig. 1, 1 represents a source of electric currents of any desired character connected in the circuit 3, which is provided with any suitable means 4 for varying the magnetic effects in a magnet 5. The magnet 5 is so placed with reference to a chamber 6, containing a conducting gas or vapor, which in turn is connected in a circuit 7, provided with any suitable source 8 of electric currents. The variations in the flow of current through the circuit 7 may be caused to act upon a receiving device 9 of any desired character. The means for varying the magnetic effects in the magnet 5 may, for example, be a telephone-transmitter, and the receiving device 9 may be a telephone-receiver. The gas or vapor within the tube or container is of any appropriate character, as more fully set forth in my patents hereinbefore referred to, and the negative electrode 10 may be of mercury or of any other suitable means for receiving the current from the gas or vapor and likewise the positive electrode 11, although for convenience I have in the drawings indicated it as being of a solid material held within the chamber 6. The location of the magnet 5 and its particular relation to the chamber 6 may be variously modified. In Fig. 1 I have represented the magnet with its core in a plane parallel with the chamber 6. In Fig. 2 it is illustrated as having one pole directed in a plane perpendicular to the chamber 6, and in Fig. 8 I have shown the core as being prolonged, so as to partially or wholly embrace the chamber, thereby tending to direct the lines of force transversely through the gas or vapor; but the constructions and positions of the magnet may be variously modified, the object being to cause the lines of force to pass into the vapor-path.

It is possible by means of my invention to produce in the secondary or receiving circuit electrical variations of greater magnitude than the original electrical variations of the primary or transmitting circuit. This is due to the fact that a given magnetic variation may cause a wider fluctuation of effective resistance in the gas or vapor than the fluctuations of electrical energy producing the variation of the magnetic field of force. Accordingly by employing one of my lamps or vapor apparatuses as described I may magnify the vibrations of the circuit not by inductive effects but by varying the ohmic resistance of the circuit in which the apparatus is included.

I have mentioned a telephone-circuit merely for purposes of illustration. The amplifications due to changes in resistance of my apparatus may be applied to other circuits as well, including circuits carrying currents of large quantity. It will further be understood that the application of my invention is not limited to cases where it is desired to amplify the primary variations, but is useful also where it is merely desired to reproduce them in the same or even less magnitude.

Means for starting the flow of current through the apparatus are set forth in the patents hereinbefore referred to.

I claim as my invention—

1. The method of reproducing current variations in an electrical circuit, which consists in transforming these variations into a varying field of force, causing the said field of force to act magnetically upon an inclosed gas or vapor so as to produce variations of electrical resistance in another circuit.

2. The method of producing in a circuit containing an inclosed conducting gas or vapor, variations of electrical resistance corresponding to variations of current in another circuit, which consists in causing the variations of current in the second-named circuit to act magnetically upon the said gas or vapor and thereby vary the electrical resistance thereof and of the circuit.

3. The method of reproducing in a translating device included in a circuit containing an inclosed gas or vapor path, effects corresponding to electrical variations in another circuit, which consists in converting said electrical variations into magnetic variations, and causing such magnetic variations to act upon an inclosed gas or vapor path, thereby producing variations in the current-flow of the first-named circuit.

4. The method of reproducing in a translating device included in a circuit containing an inclosed gas or vapor, effects corresponding to variations of electrical resistance in another circuit, which consists in causing in the last-named circuit variations of current adapted to affect the translating device, converting these variations of current into magnetic variations, and causing such magnetic variations to act upon the inclosed gas or vapor.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:

WM. H. CAPEL,

GEORGE H. STOCKBRIDGE.

PLAINTIFF'S EXHIBIT No. 206.

No. 749,793. PATENTED JAN. 19, 1904.

P. C. HEWITT.

REGULATOR FOR GAS OR VAPOR ELECTRIC APPARATUS.

APPLICATION FILED MAY 18, 1902.

NO MODEL.

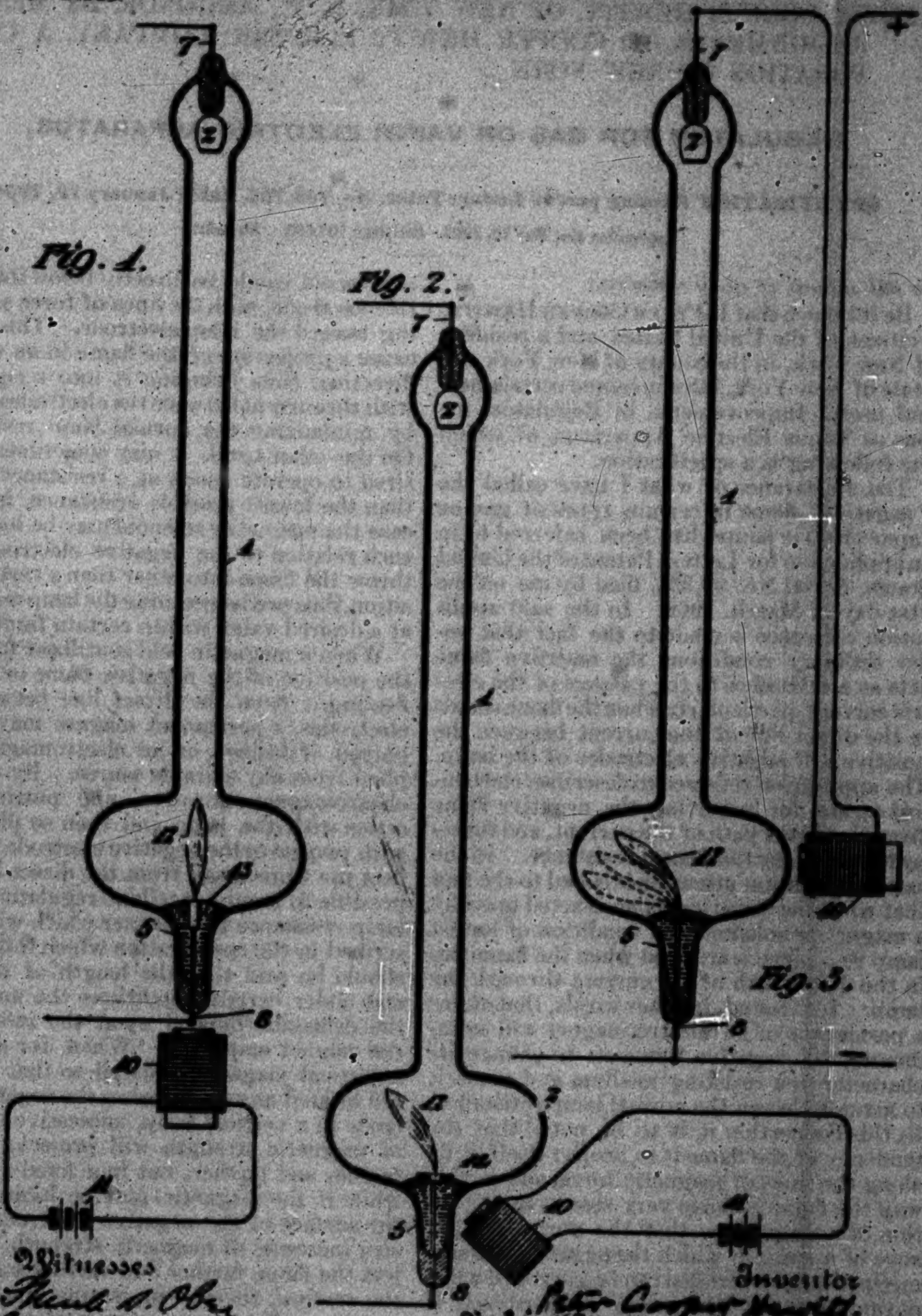


Fig. 1.
7
2
1
12
13
5
8
10
11
Fig. 2.
7
2
1
12
2
5
8
10
11
Fig. 3.
7
2
1
12
5
8
10
+
−

Witnesses
Frank A. Ober
George H. Stockbridge

Inventor
Peter Cooper Hewitt
By his Attorney
Charles A. Terry

No. 749,793. Patented January 19, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

REGULATOR FOR GAS OR VAPOR ELECTRIC APPARATUS.

SPECIFICATION forming part of Letters Patent No. 749,793, dated January 19, 1904.

Application filed May 16, 1902. Serial No. 107,603. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Regulators for Gas or Vapor Electric Apparatus, of which the following is a specification.

The appearance of what I have called the "negative" flame in certain types of gas or vapor electric lamps has been referred to in an application for Letters Patent of the United States, Serial No. 99,333, filed by me on the 21st day of March, 1902. In the said application reference is made to the fact that under ordinary conditions the negative flame acts as a resistance to the passage of the electric current, particularly when the flame stands in the direct line of the current between the positive and negative electrodes of the lamp. The application referred to describes mechanical means for removing the negative flame from the direct path of the current, and thereby lessening the total lamp resistance. In the same application attention is called to the fact that when the negative flame is acted upon by a magnet or solenoid the condition of lowest lamp resistance is attained when the flame lies in the direct path of the current through the lamp. It is found, in other words, that either a permanent or an electro magnet will so influence the negative flame as to change its character as a resisting medium and cause it to actually lessen the normal lamp resistance. In this connection it is to be noted that the tendency of the flame is to project itself or lie along the lines of magnetic force, and in this way the flame is made very steady by the action of a magnet, so that the normal resistance of a lamp in which the negative flame is mechanically controlled can be governed without any essential fluctuation. Accordingly if it be desired to construct a lamp with as low a normal resistance as possible, assuming a vertical type of lamp in which the negative electrode is at the bottom of the transparent container, the proper position for the magnet or solenoid would be directly below the negative electrode, with the lines of force projecting toward the lamp-electrode. This would cause a projection of the flame in an upward direction, thus bringing it into a right line with the current between the electrodes, thereby minimizing the normal lamp resistance. On the other hand, it may sometimes be desired to operate lamps at a resistance higher than the lowest possible resistance, in which case the magnet or solenoid may be located in such relation to the negative electrode as to throw the flame into other than a vertical position, thus predetermining the lamp resistance at a desired value within certain limits.

When a magnetic field is utilized for fixing the position of the negative flame or for deflecting it from the direct line between the electrodes, a permanent magnet may be employed, if desired, or an electromagnet supplied from any suitable source. By using an electromagnet, however, and putting it in series with the lamp and then so placing it with respect to the negative electrode as to deflect the flame away from the direct line it is possible to secure excellent regulation of the lamp resistance in a manner which will be described in the specification which follows. It should be said that the length of the flame and under certain conditions the amount of the deflection depend upon the strength of the magnet employed. When, for example, a vertical magnet is placed so that its poles are located anywhere below the negative electrode in a vertical lamp, successive increases of magnetic strength will project the flame farther and farther, but in a fixed direction, while if the magnetic pull be located above the surface of the negative electrode successive increases of magnetic strength will project the flame farther and farther away from the vertical, thereby increasing the lamp resistance. By these means variations in the circuit of the electromagnet, if an independent circuit, may be recreated in the circuit of the lamp with varying intensity, depending on the magnetic circuit and on the lamp-circuit.

My invention is illustrated in the accompanying drawings, in which—

Figure 1 is an elevation of one of my vertical lamps in which the flame is projected vertically upward by an electromagnet underneath the lamp. Fig. 2 is a similar view of a vertical lamp in which the flame is projected at an angle, and Fig. 3 is a diagram illustrating electromagnetic means for automatically regulating the resistance of a lamp.

In Fig. 1 the main lamp-tube is shown at 1, the respective positive and negative electrodes at 2 and 5, the same being severally connected with leading-in wires 7 and 8. Below the negative electrode 5 is arranged an electromagnet 10, energized by a suitable source 11. Under the conditions illustrated in this figure the negative flame 12 is projected vertically upward, thus giving to the lamp its lowest resistance.

In Fig. 2 the relations are changed only to the extent that the magnet 10 is shifted a little to one side, thereby causing the flame to be projected at an angle to the vertical, under which conditions the lamp has an increased resistance as compared with the lamp shown in Fig. 1.

In Fig. 3 the magnet 10 is arranged at the side of the lamp and somewhat above the surface of the negative electrode 5. Here the flame 12 is deflected, as shown, the deflection being still more marked in case the strength of the magnet 10 increases. The magnet is here arranged in series with the lamp, so that any change of potential on the line will be felt not only in the lamp but also in the magnet 10. For example, should the conditions of the circuit be so altered as to cause too great a flow of current the strength of the magnet 10 will be increased, the flame 12 will be deflected, so as to increase the lamp resistance, in consequence of which the excessive flow of current is checked. Thus the arrangement illustrated in Fig. 3 is adapted to cause a very sensitive regulation of the lamp-circuit. When the electromagnet is in an independent circuit, variations in the magnet-circuit will be reproduced in the lamp-circuit, and this arrangement may be used for many purposes—for instance, as a relay.

Means for starting the flow of current through the apparatus are set forth in certain patents issued to me on the 17th day of September, 1901.

The results described above are more readily accomplished when the flame is proceeding from a projecting point, as shown at 13 in Fig. 1, or is fixed by a plate floating on the mercury, the plate having a hole in its center, as illustrated at 14 in Fig. 2.

It is manifest that the operation of the device forming the subject of the present invention is the same whether the apparatus is used as a lamp or a source of light or for any other purpose.

I claim as my invention—

1. In an electric vapor apparatus in which a path is provided for the electric current between a positive and a negative electrode, and in whose normal operation a negative flame is developed at the negative electrode, magnetic means for projecting the flame in such a direction with relation to the path of the current between the electrodes as to produce a definite normal resistance in the apparatus.

2. In an electric circuit, an electric vapor apparatus and an electromagnet in series therewith, the magnet being placed at the side of the apparatus and in operative proximity thereto.

3. The combination with an electric circuit containing a gas or vapor apparatus, of an electromagnet, placed in such relation to the negative electrode of the apparatus that electrical variations in the magnet-circuit will be reproduced in the circuit of the apparatus.

Signed at New York, in the county of New York and State of New York, this 9th day of May, A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
Wm. H. Capel,
George H. Stockbridge.

PLAINTIFF'S EXHIBIT No. 207.

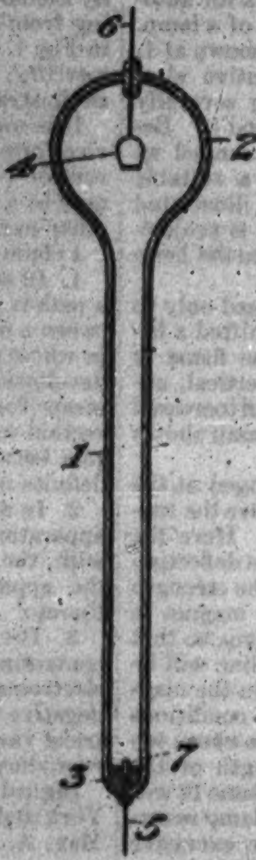
No. 758,650. PATENTED MAY 3, 1904.

P. C. HEWITT.

ELECTRODE FOR VAPOR ELECTRIC APPARATUS.

APPLICATION FILED JAN. 12, 1904.

NO MODEL.



Witnesses
Chas. H. Clagett
W. H. Capel

Inventor
Peter Cooper Hewitt.
By his Attorney
Charles A. Terry

No. 758,650. Patented May 3, 1904.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRODE FOR VAPOR ELECTRIC APPARATUS.

SPECIFICATION forming part of Letters Patent No. 758,650, dated May 3, 1904.

Application filed January 13, 1904. Serial No. 188,838. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, county of New York, State of New York, have invented certain new and useful Improvements in Electrodes for Vapor Electric Apparatus, of which the following is a specification.

In the operation of a vapor electric device where the "negative electrode resistance" is comparatively small this resistance is apt to be irregular. The current enters the negative electrode at a spot and has the tendency to be constantly wandering over its surface, being visible as a bright wandering spot or flame. I have found that this may be overcome under the same conditions and that the resistance may be made stable. I have also discovered that physical or chemical disintegration takes place at the point where the current enters the negative electrode and that by constructing the electrode so that physical or chemical change will take place at a predetermined spot more easily than another the current can be made to enter this spot and cease wandering over the surface of the negative electrode. In the case where the negative electrode consists of a volatilizable material this may be done by extending from it a point of metal or other material. This point when it becomes heated by the current will cause vaporization of the material forming the electrode on or at its surface of contact and consequent fixing of the entering of the current at that place. If this point be of such a material as becomes wetted by the material of the negative electrode, it then will act somewhat in the same manner as a wick and its operation appears certain and stable. The disintegration of the negative electrode at a particular spot may be brought about by chemical means and also by the physical character and shape of the electrode.

In the accompanying drawing I have shown one form of vapor device illustrating the invention.

Referring to the drawing, 1 represents an inclosing chamber, in the present instance in the form of a tube having an enlargement 2 at one end. This enlargement serves as a condensing and cooling chamber for the vapor of the negative electrode, which for convenience in this instance will be referred to as "mercury." The negative electrode is here shown as located at the end of the tube remote from the condensing-chamber 2, which has the negative electrode 3. The positive electrode 4 is represented within the condensing-chamber. Suitable leading-in conductors 5 and 6 are connected with the respective electrodes 3 and 4. The leading-in conductor 5 is here shown as being provided with an extension of platinum, as 7, projecting slightly above the surface of the negative electrode. This extension may be comparatively thin and, in fact, may be virtually a wire. When mercury is used as the negative electrode, platinum serves excellently as the material from which to form the point 7.

The particular device here shown is represented in the form especially suited for electric illuminating purposes; but the same principle applies when the device is used for transformers or other purposes.

I claim as my invention—

1. In an electric vapor device of the character described, a fluid electrode, and a point of solid conducting material projecting above the surface thereof.

2. In an apparatus of the class described, an electrode of mercury having a solid conducting material projecting above the surface thereof.

3. In an apparatus of the class described, an electrode of mercury having a body of platinum projecting above the surface thereof.

4. In a gas or vapor electric device having a liquid negative electrode, steadying means at the negative electrode comprising a solid wetted material in contact therewith, the general surface of the solid being in a different plane from the general surface of the liquid.

Signed at New York, in the county of New York and State of New York, this 6th day of January, A. D. 1904.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
GEORGE H. STOCKBRIDGE.

PLAINTIFF'S EXHIBIT No. 203.

P. C. HEWITT.

MEANS FOR SUPPRESSING THE RESISTANCE OF THE NEGATIVE ELECTRODE FLAME IN ELECTRIC VAPOR APPARATUS.

APPLICATION FILED MAR. 21, 1902.

954,434. **Patented Apr. 12, 1910.**

Fig. 1.

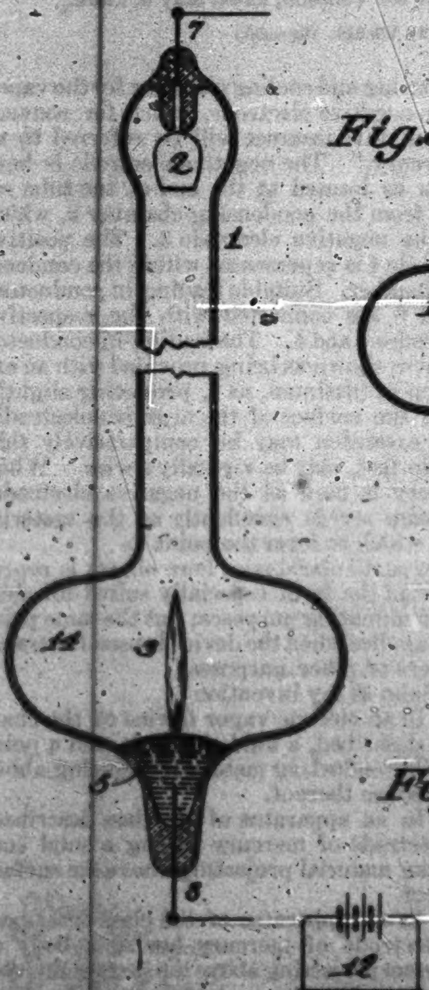

7
2
1
14
3
5
8
12

Fig. 3.

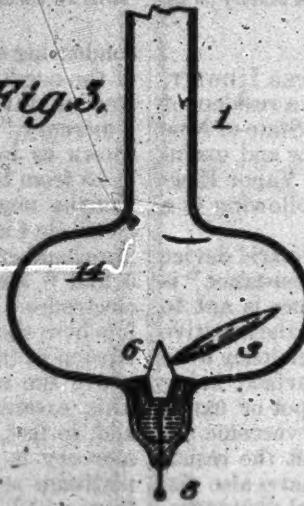


Fig. 2.

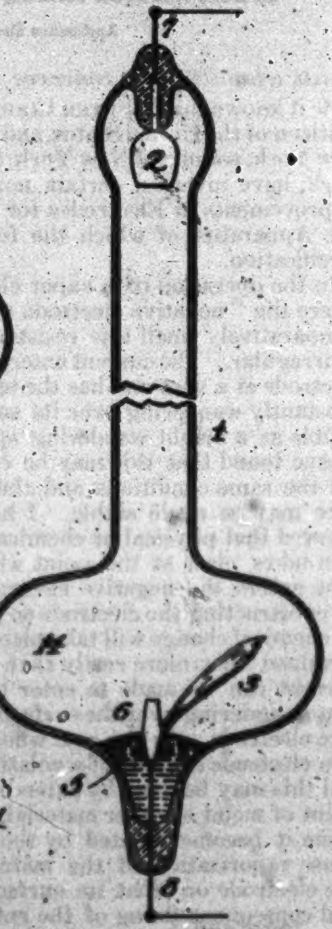
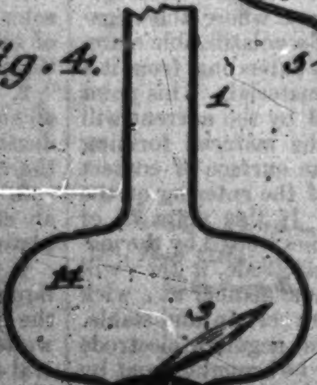

7
2
1
1
14
3
6
5
8

Fig. 4.



Witnesses:

Thos. D. Brown

Harvey T. Tuttle

Inventor

Peter Cooper Hewitt

by Charles A. Terry

Atty.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO COOPER HEWITT ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR SUPPRESSING THE RESISTANCE OF THE NEGATIVE-ELECTRODE FLAME IN ELECTRIC VAPOR APPARATUS.

954,434. Specification of Letters Patent. **Patented Apr. 12, 1910.**

Application filed March 21, 1902. Serial No. 99,333.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Means for Suppressing the Resistance of the Negative-Electrode Flame in Electric Vapor Apparatus, of which the following is a specification.

This invention relates to improvements in the class of vapor apparatus described and shown in various patents issued to me on the 17th day of September and the 3rd day of December, 1901.

The operation of electric vapor lamps, such for instance, as that type of the Cooper-Hewitt lamp in which mercury is used as the negative electrode, is generally accompanied by the appearance at the negative electrode of a flame which, while being somewhat unstable when the surface of the negative electrode is irregular or subject to alteration, proceeds from the negative electrode in a direction at right angles to the surface at which the current enters the said electrode. By a proper selection of the plane of the negative electrode surface, the direction which this negative flame shall take, can, accordingly, be predetermined. The investigation of the resistance of a vapor lamp, such as described, shows that when this negative flame takes the direction of the path of the current between the positive and negative electrodes of the lamp, the total resistance of the lamp is considerably greater than when the negative flame puts off at an angle to the current path. The excess in resistance under the conditions first named, may equal or exceed fifteen per cent. of the total resistance. It will be understood that the negative flame referred to is practically useless as a source of light, for which reason the electromotive-force required to overcome the resistance occasioned by this flame serves no useful function in the lamp and is not only practically wasted but is detrimental. In order to insure that the energy applied to a lamp of this class shall be utilized in the light-giving portion thereof, without needless waste, I provide means whereby the surface of the negative electrode shall be so arranged as to insure the projection of the negative flame outside the path of current through the lamp.

The present invention relates to means for accomplishing that end.

It is also found that the direction of the negative flame is changed by the action of a magnet or solenoid, the flame tending to lie in and along the lines of force. Where it is desired that the negative flame should be out of a right line to the main path of the current, a magnet or a solenoid may furnish a convenient means for accomplishing this result but the deflection of the flame in this way by a magnet or solenoid has the effect of increasing the resistance of the lamp instead of decreasing it. In general it may be said that a wide deflection of the negative flame is desirable when produced by mechanical means, and a condition of no deflection is desirable when produced by magnetic means. The effect of the magnetic action is to maintain the flame in a stable condition.

The provisions referred to in the foregoing paragraphs are based upon the fact that the negative flame proceeds substantially at right angles to the entrance plane of the current. This means that the entrance surface of the negative electrode should be out of a plane at right angles to the path of the current, in order to cause a suitable position of the negative flame.

I have illustrated my invention in the accompanying drawings, in which—

Figure 1 is a longitudinal section of a mercury vapor lamp showing the negative flame in line with the path of current between the electrodes; Fig. 2 is a similar view of a lamp so constructed as to cause the negative flame to put off at an angle to the current path; Fig. 3 is a section of the lower part of one of my lamps, illustrating a particular form of negative electrode; and Fig. 4 is a longitudinal section of a lamp similar to that shown in Fig. 1, combined with a deflecting electro-magnet.

In the drawings, 1 is a tube or container of glass and 2 and 5 are, respectively, the positive and negative electrodes of my lamp. The electrodes are connected through the walls of the lamp to the respective lead-wires, 7 and 8. In Figs. 1, 2 and 3, the positive electrode is of iron and the negative electrode is of mercury, or mercury in combination with a projecting piece of metal, generally iron. In Fig. 1, the negative electrode is of pure mercury. The negative flame is shown at, 3, projecting at right angles from the upper surface of the mercury in the direction of the path of the current between the electrode 2 and the electrode 5. In practice, it is found that the surface of the mercury electrode is subject to more or less distortion at the point where the current enters the electrode, for which reason the surface at that point may not be in a plane at right angles to the main path of the current, so that the negative flame, when the negative electrode consists entirely of mercury, may not always take the direction indicated in Fig. 1. But inasmuch as the negative flame may take the direction indicated in Fig. 1, it is desirable that this should be guarded against, by providing an entering surface for the current which shall always lie in a direction other than a right angle from the path of the current. I have found that, while the current appears to enter the negative electrode at a small point on its surface, yet it prefers to enter at a point upon a plane surface rather than at an edge or actual mechanical point or summit. A suitable formation of the negative electrode is illustrated in Fig. 2 wherein a piece of iron, 6, projects up through the mercury 5 and has perpendicular surfaces at which the current enters. With this construction the negative flame is thrown off nearly or quite at right angles to the path of the current between the electrodes.

Fig. 3 illustrates a modification of the negative electrode, in which a piece, 6, of iron, projects above the mercury and is provided with a conical or pyramidal shape, the current entering the iron at an angle other than a right angle to the main path of the current, thus causing a deflection of the negative flame.

As a simple mode of illustrating the deflection of the flame by means of magnetic force, I have shown in Fig. 4, a magnet, 12, outside the enlargement in which the negative electrode surface lies. The effect of the magnet is to deflect or turn the negative flame approximately as indicated in the drawing. The magnet may be a permanent magnet or an electro-magnet supplied from a separate source or in a series or shunt relation to the lamp. In another application, Serial Number 107,608, filed May 16, 1902, and issued as a patent on January 19, 1904, Number 749,793, I have shown and described this feature in greater detail and have claimed it as a regulating device. Also in a divisional application Serial Number 123,873, filed September 18, 1902, claims are made upon the horizontal lamp described herein.

It is manifest that this invention would apply equally well to a gas or vapor electric lamp and to a gas or vapor electric apparatus designed for any other use.

In another application Serial Number 548,071, filed March 11, 1910, which is a division of this application, I have made claims involving certain features shown and described herein.

I claim as my invention:

1. In a vapor electric apparatus, a container of suitable shape and dimensions, a positive and a negative electrode therein, and means for causing the surface of the negative electrode at which the current enters it to lie in a plane at an oblique angle to the path of the current between the two electrodes whereby the flame is caused to project itself out of the path of the current.

2. In a vapor electric apparatus, a suitable container, a positive and a negative electrode within the same, an enlargement surrounding the exposed surface of the negative electrode, and means for so shaping the surface of the negative electrode as to cause it to present an entering plane for the current traversing the lamp, which plane lies at an oblique angle to the direct path of the current between the electrodes.

3. In a gas or vapor apparatus of the character described, a container, a positive electrode, a liquid negative electrode, and a solid electrode extension projecting above the surface of the negative electrode, the surface of the projection forming an oblique angle with reference to the surface of the liquid negative electrode.

Signed at New York in the county of New York and State of New York this nineteenth day of March A. D. 1902.

PETER COOPER HEWITT.

Witnesses:
Wm. H. Capel,
George H. Stockbridge.

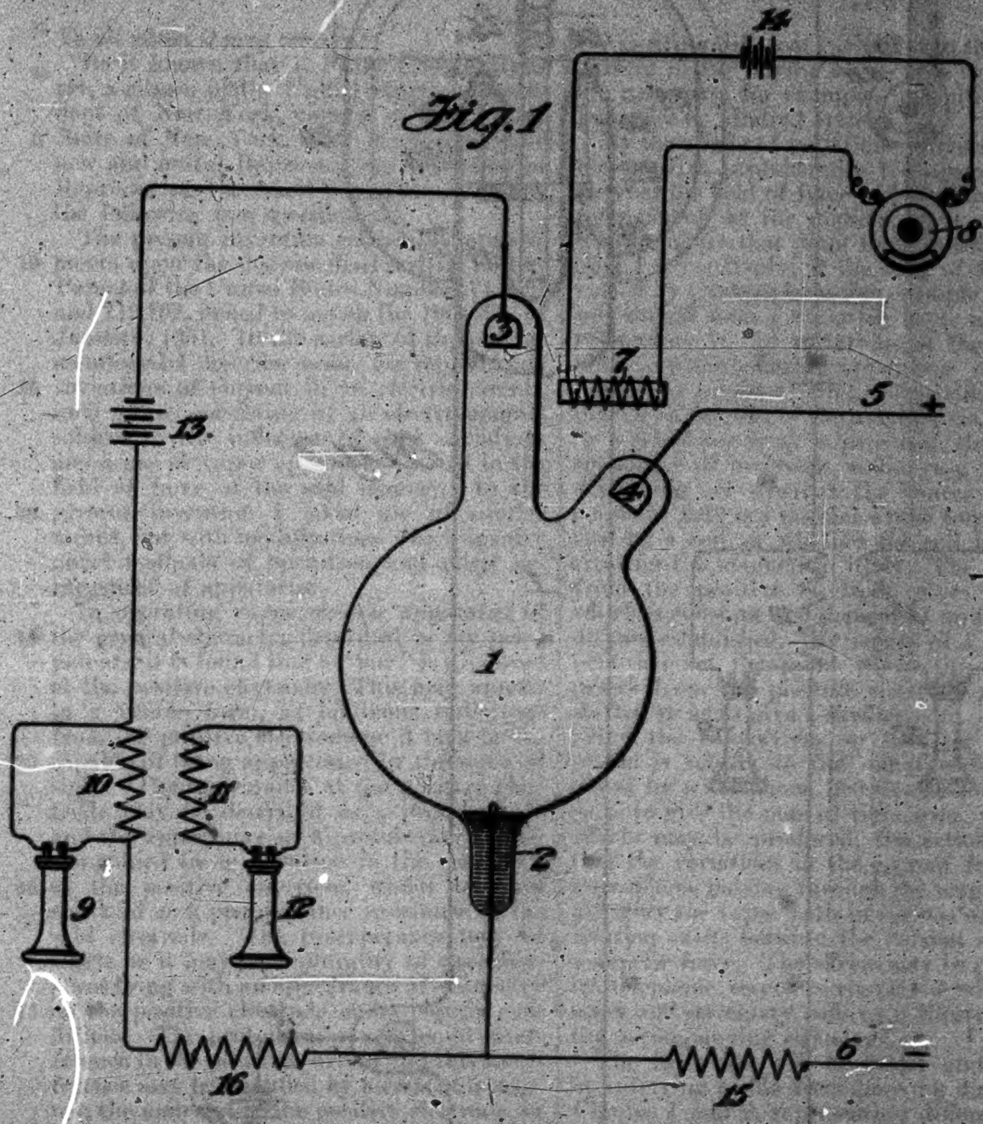
PLAINTIFF'S EXHIBIT No. 209.

P. C. HEWITT.
MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.
APPLICATION FILED JULY 7, 1904.

991,304.

Patented May 2, 1911.
2 SHEETS—SHEET 1.

Fig. 1



Witnesses
Chas. J. Clagett
W. H. Capel

Inventor
Peter Cooper Hewitt
By his Attorney
Charles A. Terry.

P. C. HEWITT.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

APPLICATION FILED JULY 7, 1904.

991,304. Patented May 2, 1911.

2 SHEETS—SHEET 2.

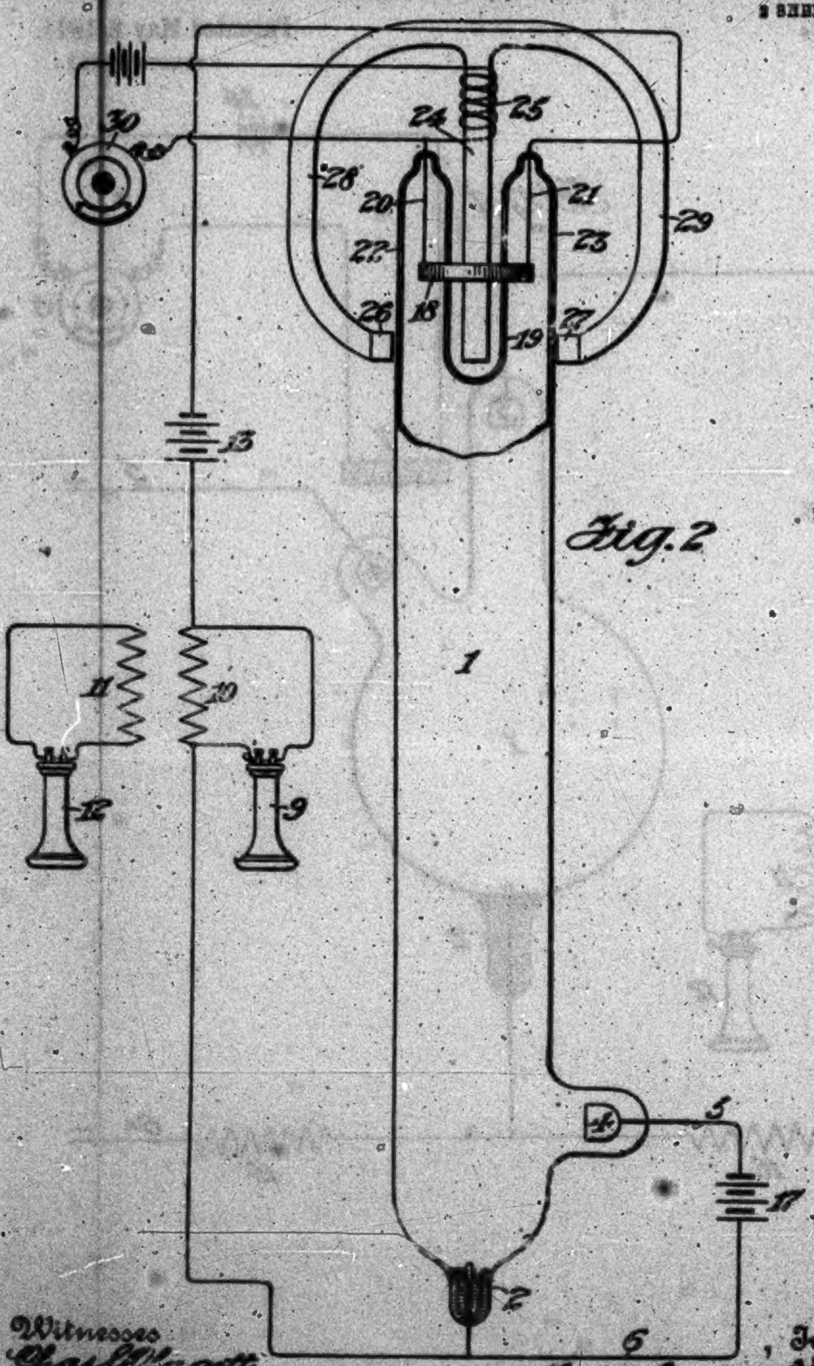

30
28
24
25
20
21
22
23
29
26
18
27
19
13
1
11
10
12
9
4
5
17
2
6

Fig. 2

Witnesses
Chas. H. Wagott
Wm. H. Capel

, Inventor

Peter Cooper Hewitt

By his Attorney

Charles A. Terry

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR TO COOPER HEWITT ELECTRIC COMPANY, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

MEANS FOR REPRODUCING ELECTRICAL VARIATIONS.

991,304. Specification of Letters Patent. Patented May 2, 1911.

Application filed July 7, 1904. Serial No. 215,377.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and resident of New York, county of New York, State of New York, have invented certain new and useful Improvements in Means for Reproducing Electrical Variations, of which the following is a specification.

The present invention relates to improvements upon the devices disclosed in Letters Patent of the United States Numbers 749,791 and 749,792, issued to me on the 19th day of January, 1904. In the earlier of the patents mentioned I describe means for reproducing variations of current in an electric circuit, such means consisting of an electro-magnet subject to the influence of said variations and a gas or vapor apparatus located in the field of force of the said magnet. In the present invention I make use of similar means, but with modifications which involve novel methods of operation and novel arrangment of apparatus.

In operating vapor electric apparatus of the general character described in my prior patents, it is found that a "bur" is produced at the positive electrode. This may appear in a visible form, as luminous radiations from the positive electrode or it may be incapable of being appreciated by the sense of sight. The appearance at the positive electrode may be described as a protuberance and the appearance of a protuberance is accompanied by a variation in the resistance at the positive electrode, which we may speak of as a protuberance resistance at the said electrode. The protuberance may be single or it may be a plurality of protuberances lying with an appearance of symmetry on the positive electrode under certain conditions. The protuberance acts as an interference to the positive current and this interference may be modified by means of a magnet, the material of the positive electrode, or by means of a particular construction of the surroundings of the positive electrode, so as to create variations of period in the current through the apparatus. By a proper proportioning of the various forces at work, the variations may be made very long, or may be superimposed on each other, or they may be variations so rapid as to be inaudible. The arrangement as a whole may be utilized for creating different variations in the direct current in any circuit where such variations are necessary, for example, in multiplex telegraphy or kindred systems.

By the effects of variations produced upon the positive protuberance the operation of varying the field of force will produce a note commencing at the audible point and extending above that point to an indefinite region. Accordingly, if the field of force be varied by a microphone for example, the result should show a variation in its note corresponding to the variations of the microphone, whereby the apparatus may be caused to produce notes corresponding or inverse to the note of the microphone, whereby a telephone relay is provided, the correspondence or inversion, as the case may be, depending on whether the source of the magnetic field is a magnet whose force is varied by a coil, or whether the coil is a coil creating the magnetism itself. The current from the positive electrode gives a note which is constant and dependent on the conditions established. By means of a permanent magnet the point where the current passes from the positive electrode may be shifted so as to give a shriller note. By varying the connections so that the microphone is subject to the sound waves produced by a telephone instrument connected so as to give the note of the source, varying effects may be produced, the action being that the variations in the current from the microphone passing through the magnet coil influence the vapor path in various ways. A relation exists between the current and the magnetic force. The effects may be received by telephone receivers connected with primary and secondary coils as is illustrated in the accompanying drawings.

The invention will be better understood by referring to the accompanying diagrams, Figures 1 and 2, representing different embodiments of my invention.

Referring to the first figure of the drawing, 1 is a hermetically sealed vessel of glass or other suitable material containing a negative electrode 2, and positive electrodes, 3 and 4. The latter may be of some suitable material, such as iron, and the negative electrode may be of mercury or other conductor and preferably capable of low electrical resistance and having a point or equivalent projection from the surface. The electrode 4 is a supplemental electrode, the main electrodes being 2 and 3. The apparatus having been started, the negative electrode resistance may be maintained in a condition of being broken down by means of current flowing between the electrodes 4 and 2 and supplied through mains 5 and 6, connected with a source furnishing a supply of current in one direction. I may now place so as to influence the container 1, a magnet, 7, connected in circuit with a telephonic transmitter, 8, or other source of variation. In circuit with the main electrodes I may place a telephone receiver, or other receiver, 9, in shunt to a reactance coil, 10, which may be the primary of a transformer, the secondary of which is shown at 11 as being connected in a circuit with a second telephonic receiver, 12, in which case the first may be omitted, if desired. If, now, the transmitter 8 be affected by vibrations, say through the human voice, the variations of magnetic effect in the circuit including the magnet 7 will be reproduced in the vapor device 1 and consequently in the circuit connected with the main electrodes 3 and 2 of the said vapor device. Effects of the variations caused by the changes in the field of force of the magnet 7 being thus reproduced can be observed in the receiver 9 or the receiver 12, as the case may be. Inasmuch as a slight variation in the field of force of the magnet 7 may cause a considerable variation in the resistance of the vapor device, which last named variation will be reproduced in the receiving circuit, the apparatus as a whole may serve as a relay adapted to magnify the effects originally produced at the transmitter 8. In the circuit between the main electrodes 3 and 2 I include any suitable source of current, such, for example, as the battery, 13, indicated on the drawing, and further these effects may be amplified by including in the circuit a vapor device such as my lamps, care being taken to keep the negative electrode resistance in a state of good conductivity in which the resistance varies substantially inversely with the current, which forms a suitable proportion of the resistance of its circuit for augmenting the variations. The transmitter circuit also contains the usual battery, 14. In the circuit of the direct current source I may insert the resistance, as 15, and I may also insert the resistance, 16, in the circuit between the main electrodes. When placed in a similar manner as shown and described in Fig. 1 the magnet 7 will directly influence what I have called the protuberance resistance at the positive electrode. By thus influencing this resistance, the interference of the protuberance with the positive current is modified and thus variations of period in the current through the apparatus are produced. It will be understood that a different location of the magnet 7, as by placing it lower down along the container would still produce variations in the resistance of the apparatus, which variations would be reproduced in the external circuit. The effects produced by such a relation of the parts has already been made the subject of patents issued to me; namely, 749,791 and 749,792.

In Fig. 2 I show a different embodiment of my invention, the parts 2 and 4 and the circuit 5 serving substantially the same function as before. In the circuit described I show in this instance a direct current source, 17, serving to keep the apparatus alive. The main positive electrode in this embodiment of the invention appears at 18 as a ring of conducting material surrounding a reëntrant portion 19 of the tube or container 1. The ring 18 is supported upon lead-wires, 20 and 21, leading into the apparatus through tubular extensions, 22 and 23, respectively. Into the reëntrant portion of the device I insert the core, 24, of a magnet, 25, the core may be provided with pole-pieces, 26 and 27, formed, respectively on arms, 28 and 29, which are in one piece with the core, 24, instead of a plain straight core. The pole pieces are so arranged as to lie outside the tube or container 1 in proximity to the positive electrode 18. The coils of the magnet 25 are connected with the terminals of a microphone or telephonic transmitter, 30. As before, the positive electrode is connected with a battery or other source 13 with one side of a reactance device 10, the other side of which is connected with the negative electrode 2. The reactance device 10 is, in this instance as before, the primary of a transformer and in shunt to the said primary is a telephonic receiver 9 while the secondary 11 of the said transformer is connected with a telephonic receiver 12. From what has been said respecting the action of the apparatus illustrated in Fig. 1, the action of this apparatus will be clearly understood.

I claim as my invention:—

1. As a means for reproducing the variations of current in an electric circuit, an electromagnet subject to the influence of said variations, and a gas or vapor apparatus of the character described located in the field of force of the said magnet, the magnet being placed in such relation to the positive electrode as to cause the variation of the protuberance resistance to be large relative to any variation produced by the said magnet in the vapor column resistance.

2. As a means for reproducing the variations of current in an electric circuit, an electro-magnet subject to the influence of said variations, and a gas or vapor apparatus, of the character described located in the field of force of the said magnet, the

magnet being placed in proximity to the positive electrode, a main circuit through the gas or vapor apparatus, and supplemental means for keeping the said apparatus alive.

3. As a means for reproducing current variations in an electric circuit, an electromagnet subject to the influence of said variations, a gas or vapor apparatus located in the field of force of the said magnet, means for passing electric current through said apparatus, and a receiving apparatus subject to the influence of variations of resistance in the circuit of the gas or vapor apparatus, in combination with supplemental means for maintaining the gas or vapor apparatus alive.

4. The combination with a vapor device including a hermetically sealed and completely exhausted container and an anode, and vaporizable reconstructing cathode therein, the said anode and the protuberance therefrom being located in a relatively narrow extension of the main body of said container, of a magnet adapted to receive and transmit variations of energy placed adjacent to said protuberance and varying the resistance thereof in relation to the variation of its received energy.

5. The combination with a telephonic transmitting circuit, a telephone receiver, a circuit including the latter, a gas or vapor path, means for passing electric current therethrough, said path being so related to the latter as to affect the same by variations of resistance in the circuit of the gas or vapor apparatus, and an electro-magnet traversed by electric currents due to effects in the transmitting circuit, and acting upon the gas or vapor path, and supplemental means for maintaining the gas or vapor electric apparatus alive.

6. The combination with a vapor device including a hermetically sealed and completely exhausted container, an anode, a vaporizable reconstructing cathode and a surface extending upward from the main surface of said cathode therein, of a magnet adapted to receive and transmit variations of energy located adjacent to said protuberance and producing therein a change of resistance corresponding to variations in its received energy, said resistance changes being relatively great as compared to any variations in the resistance of the vapor column.

7. The combination with a hermetically sealed and completely exhausted container, a plurality of anodes and a vaporizable reconstructing cathode in said container, a solid in contact with the surface of said cathode, means for passing continuous current from one of the said anodes to said cathode and means for varying the resistance of a vapor path to another of said anodes by ether waves from an outside source of electrical variations, of a receiving circuit including a telephone and a source of electromotive force in circuit with said last named anode and said cathode.

8. The combination with a generator of energy variations in the ether, of a vapor electric device including a cathode and an anode, a source of current therefor and a receiving circuit sensitive to rapid variations of electrical energy, said circuit including a separate anode in said vapor electric device, together with means for causing said energy variations in the ether to produce variations in the vapor path to said separate anode.

9. The combination with a generator of energy variations in the ether, of a vapor electric device, including a cathode, an anode, and a relatively excessive condensing chamber, a suitable source of current therefor and a receiving circuit sensitive to rapid variations of electrical energy, said circuit including a separate anode in said vapor electric device, together with means for causing said electrical variations in the ether to produce variations in the vapor path to said separate anode.

10. In a system of electrical distribution the combination with a hermetically sealed exhausted container and a mercury cathode therein, of anodes therein, each anode being in a tubular extension of said container together with a separate source of current connected with each anode and the said cathode.

Signed at New York, in the county of New York, and State of New York, this 30th day of June A. D. 1904.

PETER COOPER HEWITT.

Witnesses:
Wm. H. Capel,
George H. Stockbridge.

PLAINTIFF'S EXHIBIT No. 210.

281

Bancroft Gheraridi—For Defendant—Direct.

By the Court:

Q10. What was that repeater? A. That was a mechanical repeater.

By Mr. Neave:

Q11. Was it a Shreeve repeater? A. It is known as the Shreeve repeater.

Q12. To what extent has the Bell System put mechanical repeaters into use, or sold them to others for use in the United States; how many were in service each year from the beginning? A. Under my direction a statement has been prepared by one of my assistants which shows that. The statement is as follows:

MECHANICAL REPEATER INSTALLATIONS
1904-1918

	On Toll Circuits		Amplifiers for Loud Speaking Receivers			Service Observing Circuits.
Repeater Sets Installed as of	2-way type	1-way type	Sub-station type for deaf persons	Central-ized Testing.	R.R. use etc.	
Dec. 31, 1904	2					
Dec. 31, 1905	8		1			
Dec. 31, 1906	20		3			
Dec. 31, 1907	22		3			
Dec. 31, 1908	22		3			
Dec. 31, 1909	25		5			
Dec. 31, 1910	32		7			
Dec. 31, 1911	28		6			
Dec. 31, 1912	29		9			
Dec. 31, 1913	32		11			
Dec. 31, 1914	81	12	11		2	1
Dec. 31, 1915	89	12	12		6	2
Dec. 31, 1916	90	10	12	13	62	3
Dec. 31, 1917	86	10	12	13	82	3
Dec. 31, 1918	70		15	58	90	3

PLAINTIFF'S EXHIBIT No. 210-A.

290

Bancroft Gherardi—For Defendant—Direct.

fiers". I have been meaning the same thing by the words; have you? A. I have been, in this case, yes.

Q. You have produced in tabulated form a statement showing the number of mechanical repeaters in use each year since you began to use them. Can you give a similar tabulated statement showing the use each year of the audion and the mercury type repeaters by the Bell System, and with that same tabulated statement I would like to have a resume of the use of mechanical repeaters that you have already given in another form. A. I have had such a stattement prepared. It is as follows:

REPEATER INSTALLATIONS

1904-1918

Repeater Sets Installed as of	Mechanical 2-way type	Mechanical 1-way type	Audion 2-way type	Audion 1-way type	Mercury Arc 2-way type	Mercury Arc 1-way type
Dec. 31, 1904	2					
Dec. 31, 1905	8	1				
Dec. 31, 1906	20	3				
Dec. 31, 1907	22	3				
Dec. 31, 1908	22	3				
Dec. 31, 1909	25	5				
Dec. 31, 1910	32	7				
Dec. 31, 1911	28	6				
Dec. 31, 1912	29	6				
Dec. 31, 1913	32	11	2			
Dec. 31, 1914	81	26	11	12	1	
Dec. 31, 1915	89	32	43	15		12
Dec. 31, 1916	90	100	150	12		10
Dec. 31, 1917	86	120	463	12		10
Dec. 31, 1918	70	166	978			

PLAINTIFF'S EXHIBIT No. 211.

Pring & Parker Article, Philosophical Magazine, 1912, Vol. 23, pp. 192-200.

IONIZATION PRODUCED BY CARBON AT HIGH TEMPERATURES

XVI. *The Ionization produced by Carbon at High Temperatures. By* J. N. Pring, *D.Sc., and* A. Parker, *University of Manchester.*[*]

The escape of negative electricity from heated carbon was noticed by Edison[†] when making experiments with lamp filaments. This leak of current from a heated filament to an adjacent electrode which is at a positive potential relative to the filament can, in some cases, become of the same order as that conducted through the filament. Edison found that when these filaments have been used for some time the ionization effect diminishes, but increases again if the carbon is allowed to stand.

O. W. Richardson[‡] made systematic measurements of the ionization produced by carbon. Use was made of a carbon filament and a surrounding metal cylinder, and between these a potential difference varying from 30 to 300 volts was maintained, the heated carbon being made negative. The current produced by ionization was conducted across to the surrounding metal. By exhausting to very low pressures, from 0.1 to 0.001 mm. the influence of the ionization of the surrounding gas was supposed to be eliminated, and the currents produced were considered to be due to the liberation of corpuscles from the carbon.

It had previously been stated by M'Clelland[§] that the negative ionization from metals is independent of the pressure over a range from 0.04 to 0.004 mm. The ionization currents found by Richardson, and attributed to the liberation of corpuscles, ranged from 10^{-8} to

---

[*] Communicated by Prof. E. Rutherford, F.R.S.

[†] Engineering (1884), p. 553.

[‡] Phil. Trans. (1903) A. cci. p. 497.

[§] Proc. Cambr. Phil. Soc. x. p. 241; xi. p. 299.

2 amps. per square cm. of carbon, according to the temperature. A formula which had been deduced to show the relation between ionization and temperature was found to be in good agreement with the experimental results. In this equation $I = A\theta^{1/2} e^{-\frac{b}{\theta}}$ where I denotes the ionization, A and b are constants, and θ is the absolute temperature. In the case of carbon, Richardson found that $A = 10^{34}$ and $b = 9.5 \times 10^4$. According to this formula, the ionization will increase at a rate which at 1500° is about equal to the 50th power of the temperature. As is well known, there are no means of precisely estimating the temperature of thin filaments.

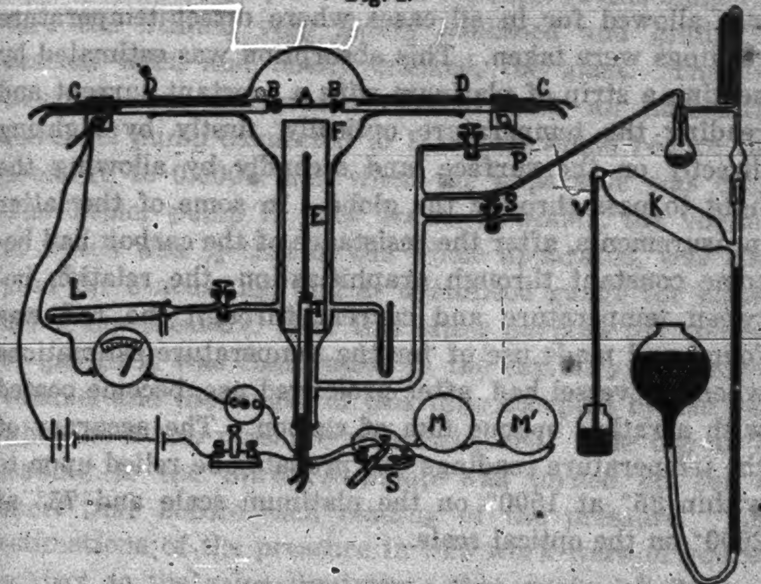
F. Deininger[†] investigated the ionization from carbon and various metals alone, and in presence of lime, and concluded that Richardson's formula applied in every case up to 1450°. Thus $\log I - \frac{1}{2} \log \theta$ was plotted against $\frac{1}{\theta} 10^4$, and found to give a straight line. No mention is made of the pressure.

H. A. Wilson[‡] investigated the ionization from platinum and found that this varied very much with the previous treatment of the metal. Thus, by long continued heating, or else by previously submitting to the action of nitric acid, the ionization was largely diminished. He concluded that the ionization from platinum is independent of the pressure from 0.2 to 0.001 mm., but that a reduction to $\frac{1}{250,000}$ of the original ionization is produced by removing the last traces of occluded hydrogen. Wilson states that in some experiments carried out with carbon he confirmed the general results of Richardson.

The present work was undertaken with a view to examine the ionization from carbon at temperatures which were more accurately measured than in previous work, to extend these up to about 2000°, and, at the same time, to notice what influence is exerted by the pressure of the surrounding gas and the condition of the carbon. No attention seems to have been paid by previous workers to the chemical purity of the carbon.

[†] *Ber. deutsch. physik. Gesell.* (1907) ix. p. 674.
[‡] Phil. Trans. (1904) A. ccii. p. 243.

Fig. 1.



The apparatus used in the present work (fig. 1) was designed primarily for examining the phenomena at the anode during the discharge with high currents, and consisted of a tubular glass flask, in which a carbon rod (A) was supported by inserting in the graphite plugs B, B, which themselves were soldered into the water-cooled brass tubes C, C. An air-tight joint was made at D, D, by means of soft wax. The water-cooled tubes served for leading in the current which was used to heat the carbon. The carbon rod used was 5.1 cm. long and 0.50 mm. diameter, or 8.01 sq. cm. surface. This arrangement of the apparatus enabled the rod to be heated to 2200°.

Temperature Readings.—Accurate temperature readings were taken with a Wanner optical pyrometer. This was directly calibrated against a standardised thermocouple up to 1400°, and at the "black body" melting-point of platinum, 1545° *, and as carbon has been found to radiate approximately as a "black body," the temperature readings will follow closely the platinum scale. The small amount of absorption through the glass vessel was allowed for in all cases where direct temperature readings were taken. This absorption was estimated by heating a strip of platinum with a constant current and reading the temperature optically, firstly by sighting directly on the surface, and secondly by allowing the light to pass through the globe. In some of the latter measurements, after the resistance of the carbon had become constant through graphitization, the relation between temperature and current through the rod was found and made use of for the temperature estimations when the vessel had, after prolonged use, become coated with a rather opaque film of carbon. The accuracy of the temperature readings can probably be relied upon to within 35° at 1500° on the platinum scale and 75° at 2000° on the optical scale..

---

* Holborn and Henning, *Sitzungsber. k. Acad. Wiss. Berlin* (1905) xii. p. 311.

For the anode, a graphite rod (E) was soldered into the water-cooled brass tube (T), the top being placed at 4.8 cm. distance from the carbon (A). During the experiment, a large difference of potential (usually 330 volts) was maintained between E and A; the high-potential circuit being connected through the galvanometers M and M′ which were of different ranges, one giving a deflexion of one scale-division for 4.1×10^{-9} amp. and the other of one division for 6×10^{-7} amp. For higher currents these were replaced by a milliammeter reading to 0.5 amp. and for measuring currents during discharge an ammeter reading to 30 amps. was used. By means of the two-way switch S the galvanometers were thrown out of circuit except during the moment when readings were being taken.

Exhaustion of Apparatus.—In the early experiments use was made of lithium for reducing the pressure. For this purpose the metal was placed in an iron boat contained in a tube of Jena glass (L). By surrounding this tube by an electrical furnace, and using a thermo-junction pyrometer, it was found that beginning with low pressures absorption of the gas to within one per cent. of the volume took place at 450°, though at this temperature the lithium very slowly sublimed and gradually reacted with, and finally cracked, the glass. The exhaustion was afterwards effected with an automatic Sprengel pump connected to P, which would reduce the pressure to 0.0001 mm. when the apparatus was cold. The Töpler pump K (not drawn to scale), the volume of which was ⅙ that of the whole apparatus, was also used for evacuating, and as a McLeod gauge for measuring the pressure. For this latter purpose the volume of gas in K was compressed in the capillary, of known volume, and the length of this tube occupied by the gas when at 5 cm. pressure was measured. The tap at P leading to the Sprengel pump was turned off for a short time before each reading of the pressure. The estimations of the pressure in this work were of course subject to the same limitations that apply in all cases where use is made of the McLeod gauge, through the presence of condensible gases and surface condensation on glass.

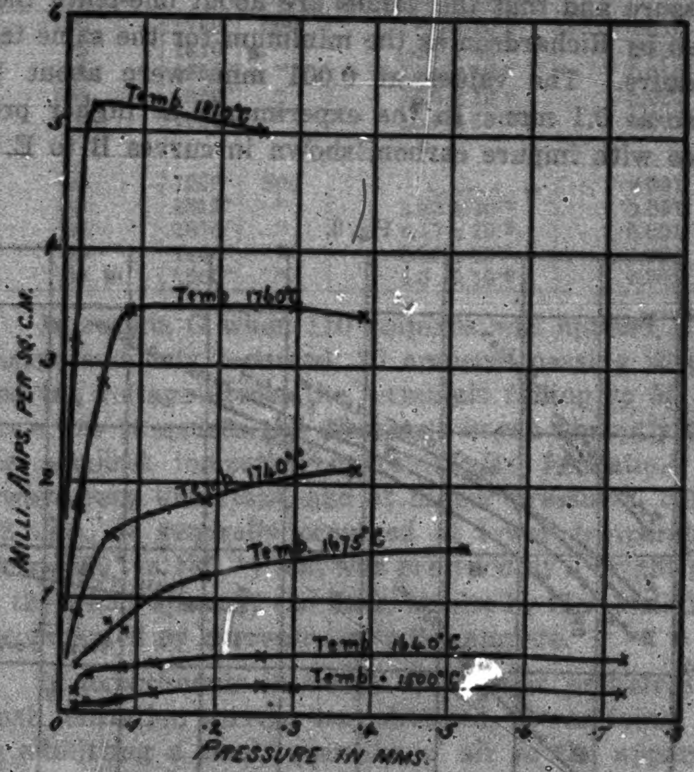
Purification of Carbon.—The carbon used consisted of amorphous retort carbon and contained about 2.5 per cent. ash (oxides of iron, silicon, &c.), and 0.2 per cent. of combined hydrogen. The method of purification employed consisted in heating for long intervals at temperatures varying from 1700° to 2000°, and maintaining very low pressures. In this way impurities are gradually volatilized away and occluded gases expelled. It has never been found possible to purify carbon completely *, on account of the tenacity with which it holds many elements in large quantities at temperatures greatly above their points of volatilization. (After use in the experiments below, the carbon was analysed by combustion in oxygen and found to contain 0.091 per cent. of ash.) The graphite rod E was occasionally heated during the above treatment by causing a discharge to pass between

* *Cf.* Pring, Trans. Chem. Soc. (1910). xcvii. p. 504.

this and the heated carbon rod. Suitable conditions of temperature of the rod and pressure were arranged, and a potential difference of about 250 to 350 volts was applied between the carbon and the graphite. When the discharge was once started, a voltage of 40 to 60 was sufficient to maintain a current of 20 to 30 amperes, and the graphite was gradually raised to a bright white heat at the end, and the inside glass cylinder (F) to the softening point. After heating the carbon rod in this manner for some 20 to 30 hours it was found possible, at any time when the apparatus was cold, to reduce the pressure in the vessel to 0.0001 mm. within 2 hours. On raising the temperature of the rod, however, the pressure always rose immediately and amounted to about 0.01 mm. when at 1800°. This could not be reduced any further by long continued heating and exhausting. After the globe had become coated with a thin film of carbon, the pressures obtained when the rod was heated were higher than before, and for a given temperature of the rod remained constant, even after heating and pumping for several days. This residual gas is probably due either to carbon monoxide which would be formed by reaction between the oxides of the glass and the deposited film of carbon, a reaction which would proceed to a certain equilibrium value at any given temperature, or else it is due to oxygen resulting from slight dissociation of the oxides in the glass, though the temperature of the latter, of course, never reached the softening point.

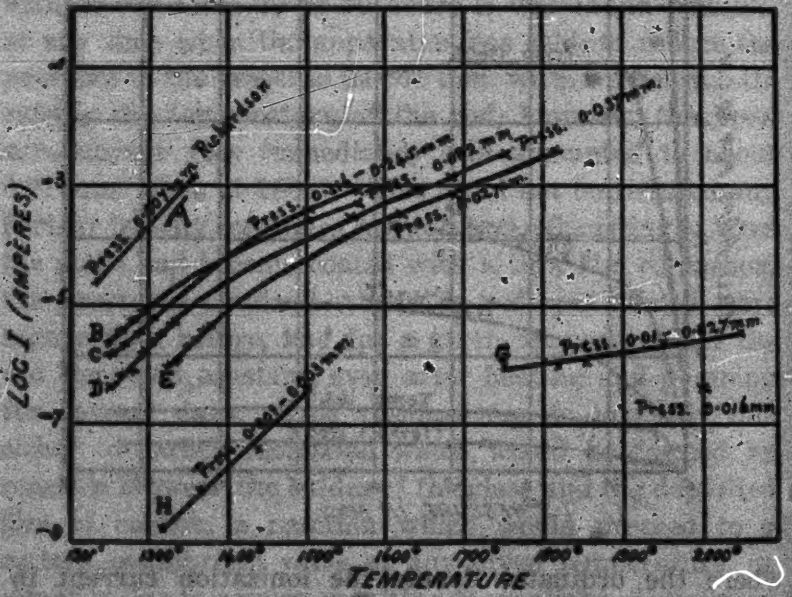
Measurement of Ionization.—A potential difference of about 330 volts was applied between E and A (fig. 1) except where otherwise stated, and the latter made negative. In this way it was hoped to collect most of the ions coming from the carbon. At this voltage, however, the original ionization must have been increased by collision, as only about half the current was obtained on using 200 volts. It was found that by placing the graphite rod E at 11 cm. instead of 4.8 cm. from the carbon, a fall in the ionization current of not more than one-fifth was caused. The results obtained when using impure carbon are shown in the form of curves in fig. 2,

Fig. 2.



where the ordinates denote the ionization current in milliamperes per 1 sq. cm. surface of carbon and the abscissæ, the pressures. In fig. 3 are seen the results of another series of experiments which were extended to much lower pressures, and where a higher degree of purity of the carbon was obtained. In this diagram the ordinates denote the logarithm of the ionization currents (in amperes) for one square cm. of cathode surface, and the abscissæ, the temperatures. The results obtained by Richardson are shown in this diagram at A. In the present work it was found that the minimum of ionization is not obtained at the pressures used by Richardson, but that the values fall continuously with diminution of pressure and with continued use of the same carbon as it becomes progressively purer. Beginning with higher pressures and unpurified carbon, it was found that the maximum ionization current is obtained at about 0.1 mm. pressure and that the values are about one-tenth those given by Richardson as the minimum for the same temperature. The values at 0.001 mm. were about 1/60 those at 0.1 mm. In the experiments at higher pressures with impure carbon, shown in curves B to E, at temperatures between 1250° and 1820°, if the values of log I — ½ log θ are plotted against $\frac{1}{\theta}\,10^4$, a straight line is obtained; but at higher temperatures, which were taken up to 2050°, and lower pressures, the ionization increased with the temperature far less than is required by Richardson's formula, and varied very much with the condition of the carbon. Curves B to E were carried out with impure carbon, and G and H after heating at temperatures between 1500° and 2100° and pressure between 0.005 and 0.05 mm. for a total period of about 40 hours. The values obtained in G and H, as typical experiments, are given in the table below.

Fig. 3.



Amps. through rod.	Temp.	Field (volts).	Ionization, amperes per sq. cm. cathode.	Pressure in mm.
G.				
80	1750°	200	8.0×10^{-6}	0.010
85	1810°	"	8.6×10^{-6}	0.021
90	1850°	"	10.6×10^{-6}	0.010
100	1950°	"	16.0×10^{-6}	0.020
110	2050°	"	16.0×10^{-6}	0.027
H.				
40	1250°	300	......	0.001
45	1315°	"	1.23×10^{-8}	0.001
50	1370°	"	6.17×10^{-8}	0.001
55	1440°	"	3.29×10^{-7}	0.002
60	1500°	"	4.0×10^{-6}	0.003

In results G when 110 amperes was applied, a discharge suddenly occurred, 20 amperes passing through and the voltage across the terminals falling to 50. At these low pressures the discharge began abruptly from the smallest ionization current. Its formation was always very uncertain, and at higher pressures, 0.05 to 0.2 mm., it generally occurred at lower temperatures (*i. e.* 1550° to 1850°) and was preceded by a bright glow in the whole space of the flask, or else by blue striations, accompanied by currents up to 0.5 ampere.

In experiments in which at the low pressures the small ionization current was obtained, it was found that on admitting a small quantity of air to the apparatus the current immediately rose to values similar to those shown in curves B to E. There was no measurable positive ionization produced from the carbon, up to 2000°, when the field (of 200 volts) was reversed.

Summary.

Measurements were made of the ionization produced by heated carbon at definitely known temperatures between 1300° and 2050°, and at various pressures.

The negative ionization from heated carbon was found to fall continuously both with reduction of the pressure and with progressive purification of the carbon.

The lowest value found at 1300°, with a potential difference of 330 volts, was 1.5×10^{-9} ampere per square cm. surface of carbon, whereas Richardson found at this temperature 1.3×10^{-4}. At 2000° with a potential difference of 200 volts, the lowest value found was 4×10^{-7} ampere, while Richardson's formula gives, at this temperature, about 100,000 amperes.

Above 1800° the ionization only increased very slightly with the temperature.

These results clearly show that the large currents hitherto obtained with heated carbon cannot be ascribed to the emission of electrons from carbon itself, but that they are probably due to some reaction at high temperatures between the carbon or contained impurities and the surrounding gases which involves the emission of electrons.

We are deeply indebted to Prof. Rutherford and Dr. H. Geiger for much valuable advice during the course of this work.

Physical Laboratories,
Victoria University,
Manchester.

Addendum.

Effects similar to the above results obtained with carbon have been noticed by Soddy [*] in the case of the Wehnelt lime cathode. It was found that, at very low pressures, this cathode ceased to produce ions, whereas, according to previous experimenters, greater saturation currents were given the lower the pressure. Soddy concludes that electronic emission can only account for a negligible fraction of the total current, the remainder being carried by the residual gas.

Richardson [†] reaffirms the opinion that the negative leak from hot platinum is independent of the pressure at low pressures, and that these gases "only appear to increase the fundamental electronic discharge from the hot cathode by a process involving the occurrence of ionization by collisions."

Wehnelt [‡] also contradicts the above inference of Soddy, and states that in the best possible vacuum the total current is sustained by the electrons emitted from the glowing oxides, and indeed at all pressures below about 0.1 mm.

---

[*] 'Nature,' lxxv[illegible], p. 58 (1907).

[†] 'Nature,' lxxv[illegible], p. 197 (1907).

[‡] *Phys. Zeitsch*[illegible] ix. p. 134 (1908).

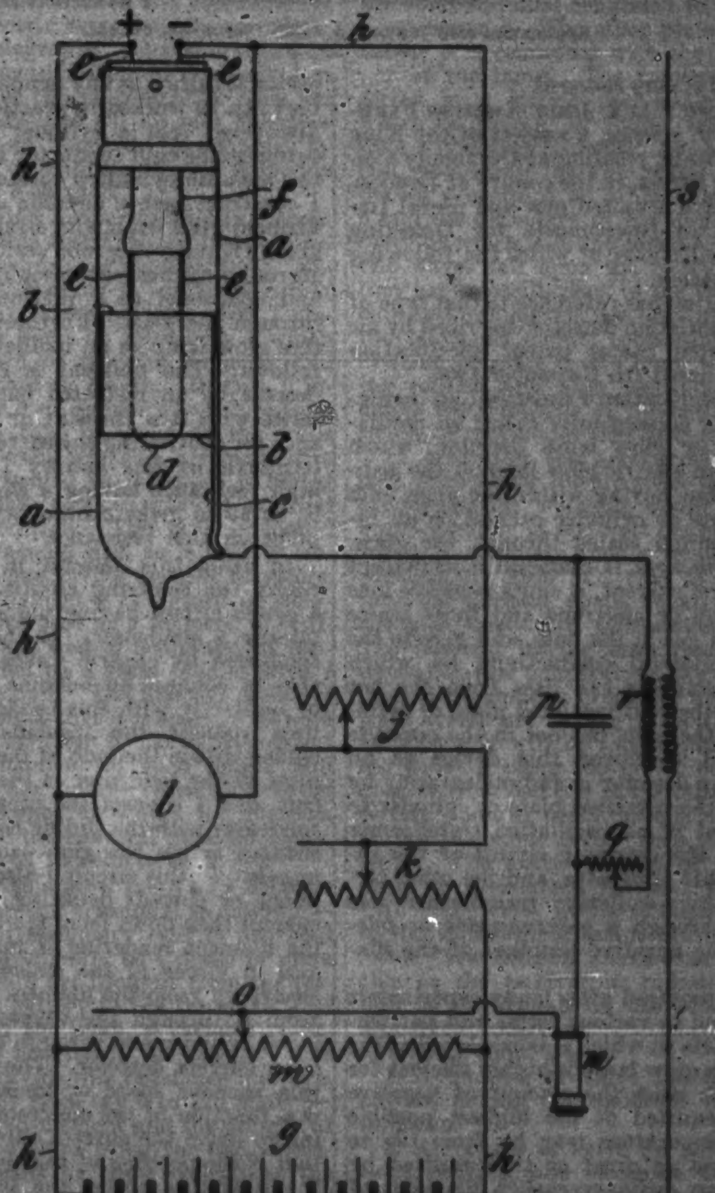
PLAINTIFF'S EXHIBIT No. 212.

J. A. FLEMING.

INSTRUMENT FOR DETECTING ELECTRIC OSCILLATIONS.

APPLICATION FILED JAN. 9, 1906.

954,619. Patented Apr. 12, 1910.


+
−
e
e
h
h
f
a
s
e
e
b
b
d
b
c
a
h
h
p
r
j
l
q
k
o
m
n
h
g
h
+
−

Witnesses.
Edw. W. Vaill Jr.

Inventor.
John Ambrose Fleming
By his Attorneys

UNITED STATES PATENT OFFICE.

JOHN AMBROSE FLEMING, OF LONDON, ENGLAND, ASSIGNOR TO MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA, OF NEW YORK, N. Y., A CORPORATION OF NEW JERSEY.

INSTRUMENT FOR DETECTING ELECTRIC OSCILLATIONS.

954,619. Specification of Letters Patent. Patented Apr. 12, 1910.

Application filed January 2, 1908. Serial No. 409,484.

To all whom it may concern:

Be it known that I, John Ambrose Fleming, doctor of science, a subject of the King of Great Britain, residing at University College, Gower Street, in the county of London, England, have invented new and useful Improvements in Instruments for Detecting Electric Oscillations, of which the following is a specification.

My invention has reference to that type of electrical oscillation detector described by me in the United States patent specification No. 803684 dated 7th November 1905.

In this specification I described an oscillation detector subsequently called an oscillation valve or glow lamp detector, which consists of an electric glow lamp of the ordinary type, but having within the glass bulb a metal plate or cylinder carried on an insulated terminal sealed through the glass. When the filament is rendered incandescent by an electric current, it emits negative ions or corpuscles or electrons and these ionize the residual gas in the bulb, and give to the space a unilateral conductivity by which negative electricity can pass from the hot filament to the cold insulated plate or cylinder within the bulb, but not in the opposite direction. I employed this device as an electric wave detector in radiotelegraphy by connecting the insulated plate or cylinder to one terminal of an oscillation transformer inserted in the receiving circuit of the radiotelegraphic apparatus, and the other terminal of this oscillation transformer was connected through a galvanometer or telephone to the negative terminal of the filament.

I have discovered after many experiments that tungsten in various forms and particularly in a form in which it is employed as the filament in a glow lamp is highly efficient for this purpose since the amount of negative electricity emitted at the highest possible working temperature may be from ten to twenty times as great as that emitted by carbon in an ordinary carbon filament. I am unable to explain the reason of this superiority; it is not merely that a tungsten filament can be raised to a higher temperature than a carbon filament, for metals such as tantalum which are closely analogous to tungsten and which can be raised to an equally high temperature are not much superior to carbon at any temperature at which they can be worked in practice. I have also discovered that a cylinder of carbon acts better as the cold conductor in the bulb than the metallic cylinders heretofore employed. I construct such a metallic or semi-metallic filament glow lamp with a tubular glass bulb and a cylinder of carbon sealed into the bulb, surrounding but not touching the filament, and connected to a platinum wire sealed through the glass. Furthermore, I employ this glow lamp as an oscillation detector as follows:—The filament is rendered incandescent by an insulated battery having in series with it a rheostat or variable resistance for controlling the current. Across the terminals of this battery I place another high resistance having a sliding contact in it, so as to make contact with any desired point on this resistance.

In using this detector in wireless telegraphy the receiving circuit must comprise a closed circuit having inductance and containing a condenser. If the telegraphy is conducted by electric waves it is necessary also to connect an antenna either directly or indirectly with this condenser circuit. I then connect the insulated cylinder included within the bulb of the lamp with one plate of the condenser in the oscillation circuit, and I connect the other plate of this condenser with the sliding contact on the resistance across the glow lamp battery terminals. In this circuit I also include a telephone or current detecting instrument. A current then flows from the battery through the filament rendering it incandescent, and also in virtue of the emission of negative electricity from the filament a current flows from it through the vacuous space to the metal cylinder and through the telephone or other current detector. The conductivity of this vacuous space or ionized rarefied gas is a function of the electromotive force acting to drive the current through it. I find that if the position of the sliding contact on the resistance across the terminals of the battery is so adjusted that corresponding thereto the conductivity curve of the ionized gas has a very sudden change in curvature, the superposition of an oscillatory potential difference between the filament and cylinder upon the steady potential difference causes very sudden changes in the current strength through the telephone and therefore an emission of sound provided that the steady potential difference is of the necessary critical value. The arrangement described is therefore a very sensitive detector of oscillations in the condenser circuit to which the glow lamp is attached and therefore can serve as an electric wave detector in inductive or radiotelegraphy, since the sound in the telephone or indication of the equivalent current detector can be controlled from the transmitting end and cut up into Morse or other signals as required, to transmit by electric waves or magneto electric induction intelligence to a distance.

In the drawing accompanying and forming a part of this specification, I have illustrated one embodiment of my invention. Referring to this drawing it will be seen that in carrying my invention into effect I employ a tubular form of glass bulb *a* which may be an inch or more in diameter and five or six inches in length. In this I insert a cylinder *b* of carbon which is sprung into the glass tube so as to fit the walls tightly. This cylinder has a platinum wire *c* twisted or welded to it which is sealed through the glass, so as to make an external electrical connection. The bulb *a* should have a good vacuum such as is usually employed with lamps having metallic filaments. The metallic filament *d* is formed of tungsten in the form used as a filament in ordinary glow lamps and is connected to conductors *e* carried on a glass tubular stem *f* sealed into the bulb. The filament *d* should be of such a length that it is entirely covered by the metal cylinder *b*. It is convenient to have the filament of such length and thickness that the voltage required to bring it to incandescence at which its duration may not be less than several hundred hours, is of the order of 18 volts or so.

In applying this glow lamp as a detector in radiotelegraphy I arrange it as follows:— A battery *g* of secondary cells is provided which may conveniently be a dozen or more cells, and wires *h* are brought from the terminals of this battery to the terminals *e* of the filament of the lamp, a variable resistance *j k* being inserted in the circuit. It is convenient to divide this resistance into two, one namely *j* of from say 0 to 120 ohms being for coarse adjustment and the other *k* of from say 0 to 5 ohms being for fine adjustment. By means of these resistances the current of the lamp may be adjusted to have any required value. A voltmeter *l* should also be placed across the terminals of the filament to regulate the voltage. In addition I place across the terminals of the battery *g* a high resistance *m* of the potentiometer type, that is to say, a resistance which may be two or three hundred ohms or more, the terminals of which are connected to the terminals *h* of the battery. A double high resistance telephone *n* (the resistance of each telephone being at least five or six hundred ohms) has one terminal connected to a slider *o* which can make contact with any required point on the resistance *m* and the other terminal connected to one plate of a condenser *p*. The other plate of the condenser *p* is connected with the metal cylinder of the lamp. The condenser *p* is inserted in a circuit possessing inductance, which is directly or inductively connected with a receiving antenna. As shown the circuit connecting the two plates of the condenser *p* contains an adjustable inductance *q* and the secondary of the jigger *r* the primary of which is in the aerial *s*. When electric waves fall upon the receiving antenna they excite oscillations in the condenser circuit and oscillations are thus imposed upon the telephone circuit connecting the metal cylinder or plate in the lamp with the sliding contact and high resistance connected across the terminals of the battery or other source of continuous electric current.

In operating the arrangement, the first step is to bring the filament to a high incandescence at which it would be working approximately at one watt per candle and at which it will have such a temperature, approximately 2800° C., that it will diffuse into the vacuous space negative ions discharged from the incandescent filament. The filament having been rendered incandescent to this temperature, the observer applies the telephone to his ear and if electric wave trains are falling upon the receiving antenna *s*, it will be found that on moving the slider *o* along the potentiometer resistance *m* from one end to the other, there is a certain point at which sounds will be heard in the telephone better than at any other point. The exact position of the slider *o* must be determined by trial for it varies with every valve owing to slight differences in the vacuum and temperature of the filament. The detector above described is suitable as the receiver in radiotelephony, as well as for signals on the Morse or other alphabetic code.

What I claim is:—

1. A rectifier or valve for electric oscillations, having one electrode composed of tungsten.

2. A rectifier or valve for electric oscillations, having one electrode composed of tungsten and one element composed of carbon.

3. A rectifier or valve for electric oscillations, comprising a metallic filament constituting one electrode, means for heating said filament, and a plate of carbon constituting another electrode thereof.

4. A rectifier or valve for electric oscillations, comprising a metallic filament consti-

tuting one electrode, means for heating said filament, and a curved plate of carbon circumferentially situated in relation to the longitudinal axis of said filament.

5. An oscillation valve in which the hot conductor is a filament of tungsten.

6. An oscillation valve comprising a heated electrode in combination with a cold electrode consisting of a mass of carbon.

7. An oscillation valve comprising a heated electrode in combination with a cold electrode consisting of a cylinder of carbon.

8. An oscillation valve in which the hot conductor is a filament of tungsten and the cold conductor is a cylinder of carbon.

9. The combination of an oscillation valve, a source of electricity heating the filament of the valve, a resistance across the terminals of the source, a circuit connected at one end to the cold conductor of the valve and at the other to an adjustable point of the resistance, means for producing oscillations and means for detecting an electric current in the circuit.

10. In combination with an oscillation valve, a source of electric current for energizing the filament thereof, an oscillatory circuit having one terminal connected with one element of said oscillation valve, the other terminal of said oscillatory circuit being adjustably connected with a resistance which is connected with opposite terminals of another element of said valve, and a translating device operatively connected with said circuits for indicating the presence of electric oscillations.

JOHN AMBROSE FLEMING.

Witnesses:
GEO. J. B. FRANKLIN,
T. J. OSMAN.

PLAINTIFF'S EXHIBIT No. 213.

No. 879,532. PATENTED FEB. 18, 1908.

L. DE FOREST.

SPACE TELEGRAPHY.

APPLICATION FILED JAN. 29, 1907.

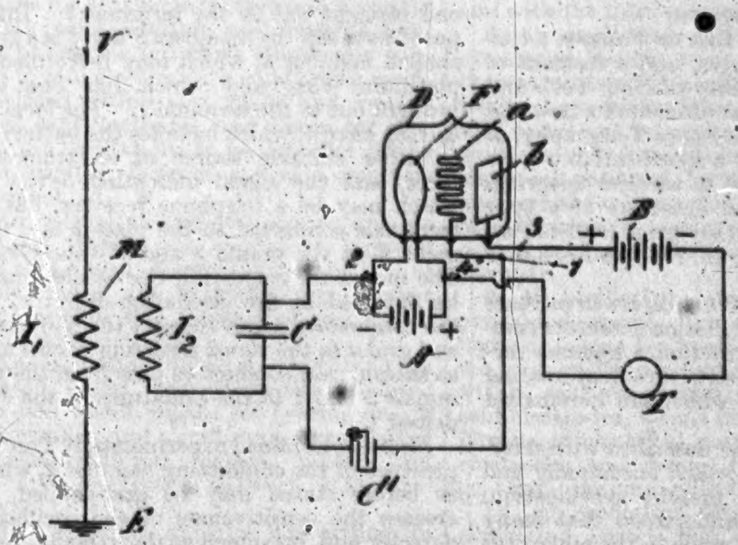
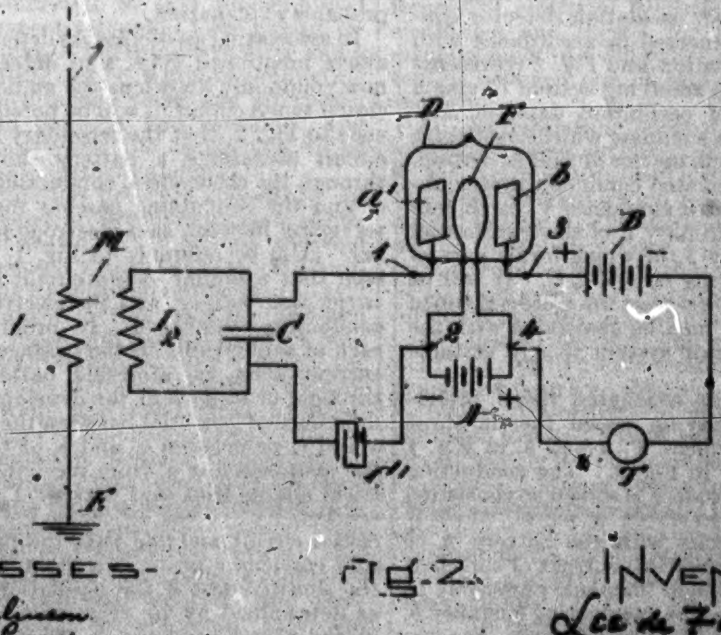

V
D
F
a
b
3
B
+
-
2
E
1
M
I1
I2
C'
-
+
B'
T
C''
E

Fig-1-


1
D
F
a'
b
3
B
+
-
M
1
I2
C'
2
4
-
B'
+
T
C''
E

Witnesses-

E. B. Tomlinson

Fig-2-

Inventor:

Lee de Forest

by Geo. K. Woodworth Atty

UNITED STATES PATENT OFFICE.

LEE DE FOREST, OF NEW YORK, N. Y., ASSIGNOR, BY MESNE ASSIGNMENTS, TO DE FOREST RADIO TELEPHONE CO., A CORPORATION OF NEW YORK.

SPACE TELEGRAPHY.

No. 879,532. Specification of Letters Patent. Patented Feb. 18, 1908.

Application filed January 29, 1907. Serial No. 354,662.

To all whom it may concern:

Be it known that I, LEE DE FOREST, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented a new and useful Improvement in Space Telegraphy, of which the following is a specification.

My invention relates to wireless telegraph receivers or oscillation detectors of a type heretofore described in my prior Letters Patent Nos. 824,637, June 26, 1906 and 836,070, November 13, 1906.

The objects of my invention are to increase the sensitiveness of oscillation detectors comprising in their construction a gaseous medium by means of the structural features and circuit arrangements which are hereinafter more fully described.

My invention will be described with reference to the drawings which accompany and form a part of the present specification, although it is to be understood that many modifications may be made in the apparatus and systems herein described without departing from the principles of my invention.

In the drawings, Figure 1 represents in diagram a wireless telegraph receiving system comprising an oscillation detecter constructed and connected in accordance with the present invention and Fig. 2 represents a space telegraph receiving system having a modified form of oscillation detector connected therein in a manner which constitutes one of the subjects matter of said invention.

V I_1 E is an elevated conductor system including the elevated conductor V, earth connection E, and primary I_1 of the transformer I, the secondary I_2 of which forms part of the tuned receiving circuit I_2 C. It will be understood of course that the aforesaid tuned receiving circuit may be associated with the elevated conductor system in any suitable manner.

D represents an evacuated vessel, preferably of glass, having sealed therein three conducting members, F, *a* and *b*, in Fig. 1 and F, *a'* and *b* in Fig. 2. The conducting member or electrode F is shown as consisting of a filament, preferably of metal, which is connected in series with the battery A or other source of electrical current of sufficient strength to heat said filament, preferably to incandescence. The conducting member *b*, which may be a plate of platinum, has one end brought out to the terminal 3. Interposed between the members F and *b* is a grid-shaped member *a*, which may be formed of platinum wire, and which has one end brought out to the terminal 1. The local receiving circuit, which includes the battery B, or other suitable source of electromotive force, and the signal indicating device T, which may be a telephone receiver, has its terminals connected to the plate *b* and filament F at the points 3 and 4 respectively. The means for conveying the oscillations to be detected to the oscillation-detector, are the conductors which connect the filament F and grid *a* to the tuned receiving circuit and, as shown, said conductors pass from the terminals 2 and 1 to the armatures of the condenser C.

I have determined experimentally that the presence of the conducting member *a*, which as before stated may be grid-shaped, increases the sensitiveness of the oscillation detector and, inasmuch as the explanation of this phenomenon is exceedingly complex and at best would be merely tentative, I do not deem it necessary herein to enter into a detailed statement of what I believe to be the probable explanation.

In associating an oscillation detector of the above mentioned type, said detector being now commonly known as the audion, with a closed tuned circuit, it will be noted by reference to Fig. 2, that the secondary I_2 closes a circuit containing a battery shown at B through the electrode *b*, conducting member *a'* and the conducting gaseous medium intervening between said electrode and member. Also by reference to Fig. 1, it will be seen that a similar closed circuit exists between said battery, and the electrode *b* and conducting member *a*. In order to close each of said circuits to the passage of direct current from the aforesaid battery therethrough, or to prevent the development of a difference of potential between the members *a* and *b*, or between *a'* and *b*, or to prevent the members *a* or *a'* from receiving an electrical charge from said battery, I insert the condenser C' in said otherwise mechanically closed circuit and find that the presence of said condenser produces a great increase in the sensitiveness of the oscillation detector as determined by the very marked increase in the sound produced in the telephone T when said condenser is present over the sounds produced therein under the same conditions when said condenser is not employed.

It will be understood that the circuit arrangements herein described with reference to the particular forms of audion herein disclosed may with advantage also be employed with various other types of audion.

I claim.

1. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals electrically connected to said electrodes, a conducting member inclosed within said vessel and located between said electrodes, and means for conveying the oscillations to be detected to the first mentioned electrode and said conducting member.

2. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, and a conducting member inclosed within said vessel and interposed between said electrodes.

3. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, and a grid-shaped member of conducting material inclosed within said vessel and interposed between said electrodes.

4. An oscillation detector comprising an evacuated vessel, a filament sealed therein, a source of electrical energy connected in series with said filament, an electrode sealed in said vessel, a local circuit having its terminals connected to said filament and electrode, respectively, said local circuit including a source of electromotive force and a signal indicating device, a grid of conducting material sealed in said vessel and interposed between said filament and electrode, and means for conveying the oscillations to be detected to said filament and grid.

5. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals connected to said electrodes, a conducting member inclosed within said vessel and located between said electrodes, a closed circuit for conveying the oscillations to be detected to said first mentioned electrode and conducting member, and a condenser in said closed circuit.

6. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing said conducting member from becoming electrically charged.

7. An oscillation detector comprising an evacuated vessel inclosing a sensitive conducting gaseous medium, three conducting members inclosed therein, a closed oscillation circuit, a circuit connecting an element of said oscillation circuit with two of said members, a condenser in said circuit, a signal-indicating device, and a circuit connecting said device with one of said two members and with the third member.

8. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing the establishment of a difference of electrical potential between one of said electrodes and said conducting member.

9. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing said grid from becoming electrically charged.

10. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, means for establishing a difference of electrical potential between said electrodes and means for preventing the establishment of a difference of electrical potential between one of said electrodes and said grid.

11. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals electrically connected to said electrodes, a grid of conducting material inclosed within said vessel and located between said electrodes, and means for conveying the oscillations to be detected to the heated electrode and grid.

12. An oscillation detector comprising an evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals connected to said electrodes, a grid of conducting material inclosed within said vessel and located between said electrodes, a closed circuit for conveying the oscillations to be detected to the heated electrode and grid, and a condenser in said closed circuit.

13. An oscillation detector comprising an

evacuated vessel, an electrode inclosed therein, means for heating said electrode, a second electrode inclosed within said vessel, a local circuit having its terminals electrically connected to said electrodes, said local circuit including a source of electromotive force and a signal indicating device, a grid of conducting material inclosed within said vessel and located between said electrodes, and means for conveying the oscillations to be detected to the heated electrode and grid.

14. An oscillation detector comprising an evacuated vessel, two electrodes, one of which is a filament, inclosed within said vessel, means for heating said filament, and a conducting member inclosed within said vessel and interposed between said electrodes.

15. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, a local circuit connecting said electrodes, and a source of electromotive force and signal indicating device in said local circuit.

16. An oscillation detector comprising an evacuated vessel, two electrodes, one of which is a filament, inclosed within said vessel, means for heating said filament, and a grid of conducting material inclosed within said vessel and interposed between said electrodes.

17. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, a conducting member inclosed within said vessel and interposed between said electrodes, and a local circuit including a source of electromotive force connecting said electrodes.

18. An oscillation detector comprising an evacuated vessel, two electrodes inclosed within said vessel, means for heating one of said electrodes, a grid of conducting material inclosed within said vessel and interposed between said electrodes, a local circuit including a source of electromotive force connecting said electrodes and a signal indicating device associated with said local circuit.

19. An oscillation detector comprising an evacuated vessel, two electrodes, one of which is a filament, inclosed within said vessel, means for heating said filament, a grid of conducting material inclosed within said vessel and interposed between said electrodes and a local circuit including a source of electromotive force connecting said electrodes.

20. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel, a closed oscillation circuit, a circuit connecting one element of said oscillation circuit with one of said electrodes and said conducting member, and a condenser in said circuit.

21. An oscillation detector comprising an evacuated vessel, two electrodes inclosed therein, means for heating one of said electrodes, a conducting member inclosed within said vessel, a closed oscillation circuit, a circuit connecting one element of said oscillation circuit with one of said electrodes and said conducting member, a condenser in said circuit, a signal indicating device and a circuit connecting said device with the other of said electrodes and said conducting member.

In testimony whereof, I have hereunto subscribed my name this 21st day of Dec. 1906.

LEE DE FOREST.

Witnesses:

THOMAS I. GALLAGHER,
HANS W. GOETZE.

PLAINTIFF'S EXHIBIT No. 214.

Modification
OF
License Agreement
Dated July 1, 1920

GENERAL ELECTRIC COMPANY

AND

AMERICAN TELEPHONE AND TELEGRAPH COMPANY

July 1, 1926

AGREEMENT dated July 1, 1926, between General Electric Company, a New York corporation (herein called the General Company), and American Telephone and Telegraph Company, a New York corporation (herein called the Telephone Company).

Whereas, the parties hereto heretofore entered into an agreement made the first day of July, 1920, granting certain reciprocal licenses primarily in respect of electrical apparatus, but because at said date the art in certain of the fields dealt with in said agreement had not progressed to a point at which it was possible fully to comprehend the problems involved, disputes have arisen between the parties as to the meaning of various provisions of said agreement; and

Whereas, certain provisions of said agreement are not, as a practical matter, workable in the present state of the art; and

Whereas, unless said disputes are settled and said agreement made workable in practice progress in the fields dealt with in said agreement will be greatly hampered and delayed, and the parties desire to modify said agreement for the purpose of settling said disputes and making said agreement workable in practice;

Now, in consideration of the premises and the mutual agreements herein contained, the parties agree each with the other as follows:

I. Said agreement made the first day of July, 1920, shall be and is modified to read as follows:

Agreement made the first day of July, 1920, between General Electric Company, a New York corporation (herein called the General Company), and American Telephone and Telegraph Company, a New York corporation (herein called the Telephone Company).

Whereas, the General Company is engaged in the manufacture and sale in the United States of apparatus and systems for the generation, distribution and utilization of electricity for light, heat, power, traction and associated purposes, and in the manufacture and sale of a general line of electrical and power apparatus, and, directly and through subsidiaries, is engaged in the purchase of apparatus of various kinds from others and in the sale thereof; and is also engaged in the manufacture and sale of wireless apparatus; and

WHEREAS, the Telephone Company and the Companies of the Bell System and their subsidiaries are engaged in the operation of telephone and telegraph systems and in the manufacture, purchase and sale of telephone and telegraph and other electrical apparatus; and

WHEREAS, each party is in possession of information, patents and inventions applicable to, and has research organizations engaged in investigations bearing upon, not only its own business but also the business of the other party; and

WHEREAS, various patents or applications for patents of the parties are involved in interference with each other in the United States Patent Office; and

WHEREAS, the restrictions upon each party imposed by the patent rights of the other and the uncertainties arising out of interferences have tended to, and if permitted to continue, will hamper and delay, progress in the development and production of wire and wireless telephone and telegraph and phonograph apparatus and systems; and

WHEREAS, the effective and prompt development of the arts in question can be secured only by the free and frank co-operation and exchange of information between the parties, which can not well take place if improvements and knowledge resulting from one party's co-operation with the other party may without its consent be made available in its field to the use of others;

Now, in consideration of the premises and the mutual agreements herein contained, it is agreed as follows:

ARTICLE I.

DEFINITIONS.

For the purposes of this agreement the following terms are defined as follows:

"*Wire telephony*" is the art of communicating or reproducing sound waves (created, directly or indirectly, by the voice or by musical instruments) by means of electricity, magnetism or electro-magnetic waves, variations or impulses conveyed or guided by wires, and includes all generating, measuring, switching, signaling and other means or methods incidental to or involved in such communication.

"Wireless telephony" has the same meaning as "wire telephony", except that the waves, variations or impulses are radiated through space.

"Wire telegraphy" is the art of communicating messages by code signals (such as the Morse Code, for example) and of picture transmission, by means of electricity, magnetism or electro-magnetic waves, variations or impulses conveyed or guided by wires, and includes all generating, measuring, switching, signaling and other means or methods incidental to or involved in such communication, but does not include such devices as annunciators, elevator signals, engine room telegraphs, etc.

"Wireless telegraphy" has the same meaning as "wire telegraphy," except that the waves, variations or impulses are radiated through space.

"Picture transmission" is the art of transmitting, or receiving at another point than the point of transmission, by means of electricity, magnetism or electro-magnetic waves, variations or impulses, the aspect or shape of things, including pictures, whether still or moving, drawings, writings, forms and other graphic, printed and written matter of all kinds; and includes television.

"Programs" means pictures, news, music, speeches, sermons, advertising and entertainment, educational and similar matter, or any of them or combinations of any of them, for the purpose of exhibition, entertainment or instruction.

"Power purposes" means all prime movers and their accessories and all generation, use, measurement, control and application of electricity for light, heat, power and traction, but does not include any communication purpose.

"Public address system" means a combination of one or more telephone transmitters and one or more loud speaking telephone receivers, either adjacent to said transmitters or at a distance therefrom, operating by one-way wire telephony for the reproduction of sound with increased volume, but does not include apparatus for operation in combination or connection with or as parts of apparatus for (1) wireless telephone reception, or (2) reception of programs over electric light, electric heat, electric power or electric traction lines, or (3) the production or reproduction of sound from sound records.

"Phonographs," means all apparatus for the reproduction of sound from sound records used in or in connection with such apparatus, to be heard in the immediate vicinity of the apparatus, but does not include apparatus for the transmission to, or reception at, other points of sound reproduced from such records.

"Electric Phonograph" means a phonograph in which the sound record used therein gives rise to or controls an electric current or electromotive force in such a way that the variations of the electric current or electromotive force correspond in some way to the recorded sounds, and the electric current or electromotive force directly or indirectly brings about the production of the sound from the phonograph.

"Transoceanic" communication means all communication which crosses any ocean, gulf or sea between two continents, or between a continent and an island more than one hundred miles from its shores (islands within one hundred miles of the shores of a continent being considered parts thereof), or between two islands which are not parts of the same continent, except that communication between ships or aircraft, between ships and aircraft, or between ships or aircraft and shore, and communication between parts of the same continent, is not transoceanic communication. North America, including the Panama Canal Zone and all of Central America north thereof, is to be considered as one continent, and South America and all of Central America south of the Panama Canal Zone as another.

"The United States Government" means not only the Federal Government but also the Governments of the Philippines, Porto Rico and other federal possessions, present or future; but does not include any municipal, county or state government.

"Train dispatching" is telegraphic or telephonic conveyance of train orders or operating information between the office of a train dispatcher or similar official and railway trains or other automotive land vehicles (not including air planes or airships) or points along the line of way, for directing the movements of such automotive vehicles.

"Railway signalling" is the operation of signals, switches, brakes, stops, crossing gates, etc., controlling or signalling the movements of trains or other automotive vehicles, controlled by or in accordance with train or vehicle movements or track conditions, including block signalling, cab signals and train stops. It does not include train dispatching.

"Apparatus" includes machines, devices and appliances and the materials entering into the construction thereof.

"Household devices" are electric or electrically operated apparatus, not herein otherwise specified, designed primarily for domestic use, but do not include apparatus for communication purposes.

"Homes" means all places of residence, permanent or temporary, including, however, as to hotels, hospitals and club houses only the private living rooms thereof.

"Amateur" means one, not a professional investigator, who is more than a mere broadcast listener and who evidences his interest in the art of wireless telephony by study, investigation or experiment in the art.

"Subsidiaries" of either party are corporations a majority of whose stock having power to vote for the election of directors is owned, directly or indirectly, either by such party, or by such party and one or more of its other subsidiaries, or by one or more of its other subsidiaries. The party hereto so controlling, directly or indirectly, any subsidiary is herein called the *"parent company"* of such subsidiary.

"Companies of the Bell System" are those companies which, in connection directly or indirectly with the Telephone Company, provide a telephone service throughout the United States, or from the United States to foreign countries. These companies at present comprise the Telephone Company, Western Electric Company, Incorporated, Cuban American Telephone and Telegraph Company, and the so-called Associate Companies and Connecting Companies, and their several subsidiaries.

Any dispute arising as to the meaning or application of the foregoing definitions shall be settled by arbitration, as hereinafter provided.

ARTICLE II.

THE PATENTS INCLUDED IN THIS AGREEMENT.

The licenses provided for herein are granted and agreed to be granted under all patents, and rights to or under patents, of the United States now or hereafter during the term of this agreement owned or controlled by the parties hereto, and under all such patents hereafter issued upon inventions now or hereafter during said term so owned or controlled, and to the extent to which the parties have or may have the right to grant licenses, in so far as the inventions covered by such patents are or shall be applicable to the respective fields for which said licenses are expressed as granted or to be granted, excepting (1) as otherwise specified in connection with the several grants hereinafter contained, and (2) such patents and inventions as may hereafter be excluded from the operation of this agreement in the following manner:

A list of all United States patents under which it now holds transferable rights shall be furnished by each party to the other within sixty days from the date of this agreement. Such lists shall separately identify those patents, and shall also include those applications, as to which rights, if granted hereunder, would be restricted in scope or would involve continuing obligations not implied by law. Copies of all contracts creating such restrictions or obligations shall, upon request, be furnished by each party to the other. Thereupon, and within six months after the receipt of the lists to be furnished as aforesaid, each party may in writing advise the other as to the patents and applications described in such list, furnished by the other, which (or the patents to issue on which) it desires to exclude from this agreement; and no licenses are granted by this agreement under any patents so excluded.

Each party shall thereafter, at such periods as may be agreed upon, or whenever requested by the other party, furnish to such other party like lists of subsequent patents and applications, and upon request therefor like copies of contracts; and each party may, within six months after the receipt of any such list, advise the other in writing as to the patents and applications described in such list which (or the patents to issue on which) it desires to exclude from this agreement; and no licenses are granted by this agreement under any patents so excluded.

ARTICLE III.

SCOPE OF LICENSES.

1. All of the licenses herein granted are, unless otherwise expressed in connection with the several grants, licenses to use methods and processes, and to make, use, sell, lease or otherwise dispose of apparatus and systems in the fields in which the licenses are granted.

2. A license to make apparatus includes a license to have such apparatus manufactured for the licensee by others, subject to the provisions of this article III and article X of this agreement. No rights are granted to either party to manufacture or to have manufactured, under patents under which it receives licenses hereunder, apparatus of the character at the time manufactured by the other party, except in factories owned or operated by one or the other of the parties hereto, or by their subsidiaries, without the written consent of the party granting such licenses.

3. Every license herein granted to either party includes, unless otherwise herein provided, all incidental rights necessary to the full enjoyment and exercise of the license granted, notwithstanding that such incidental

rights may lie primarily in a field in which the other party is herein granted a license which is denominated exclusive.

4. The making, using, selling, leasing or otherwise disposing of parts is subject to the same restrictions and conditions as are applicable under this agreement to apparatus of which they are or may be parts.

ARTICLE IV.

RESERVATIONS AND EXCEPTIONS TO WHICH THE LICENSES ARE SUBJECT

1. Each party reserves, under its own patents, a non-exclusive right to make for and sell or lease to the United States Government wireless apparatus and systems for use only for other than commercial or toll purposes, and to grant to that government non-exclusive licenses to make or have made for it and to use wireless apparatus and systems, but only for other than commercial or toll purposes; and all exclusive licenses herein granted are subject to this reservation.

2. Each party reserves, under its own patents, rights in the fields and for the purposes with reference to which, and to the extent to which, it receives licenses under patents of the other party.

3. All exclusive licenses herein granted to either party are subject to licenses specifically herein granted to the other party and to rights incidental to the full enjoyment and exercise of all licenses granted to the other party, except as herein otherwise expressly provided.

4. No licenses are granted by either party with reference to the manufacture or sale of wire or cable for the transmission of electric current for light, heat, traction or other power purposes, or for telephone or telegraph purposes.

5. No licenses are granted to the Telephone Company for electric lamps or other lighting apparatus (except non-exclusive licenses with reference to telephone and telegraph signal lamps and telephone and telegraph ballast lamps for use solely in fields in which the Telephone Company is otherwise licensed under this agreement), nor for the working of tungsten. But the Tele-

phone Company is licensed to use, in the fields for which it receives licenses hereunder, tungsten purchased from the General Company, or from others having the right to make and sell tungsten, and to make, use, sell or lease (for such fields only) devices embodying such tungsten. The General Company agrees to sell and deliver such tungsten for such purposes, in wire or other practicable form to be specified by the purchaser from time to time, on the terms specified in article X hereof.

The Telephone Company agrees that, on all sales of telephone and telegraph signal lamps or telephone and telegraph ballast lamps, hereunder, to others than Companies of the Bell System, (other than lamps licensed under paragraph (*d*) of subdivision C of section 4 of article V hereof), it will pay to the General Company a royalty of 2% on the net sales price thereof.

6. The licenses herein granted to the Telephone Company, in so far as they cover rights to sell or lease carrier current, wireless or vacuum tube apparatus for use on electric railroads, are limited to sales or leases of said apparatus to the railroads; the sale of such apparatus to be installed in electric cars and electric locomotives designed or built by the General Company, as part of the original construction and equipment thereof, shall be through the General Company only.

ARTICLE V.

LICENSES GRANTED.

Subject to the foregoing reservations, each party grants and agrees to grant to the other the following licenses in the following fields of use:

1. Government Uses.

Each party grants to the other non-exclusive licenses to make for, and sell or lease to, the United States Government wireless apparatus and systems for use only for other than commercial or toll purposes.

2. Wireless Telegraphy.

(*a*) The General Company grants to the Telephone Company licenses in the field of wireless telegraphy, exclusive except as in this paragraph (*a*) provided, for combined wireless telephone and telegraph sets for use on ships; but where such combined sets are for use on ocean-going and coastwise ships of American registry (excluding harbor tug-boats and other harbor craft) the exclusive right to use, lease, sell or otherwise dispose of the same is granted by the Telephone Company to the General Company. The Telephone Company agrees upon request to make such sets and sell them for such use to the General Company upon reasonable terms.

(*b*) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy to make and use (but not to sell, lease or otherwise dispose of, except to Companies of the Bell System) apparatus and systems for its own communication or that of Companies of the Bell System, and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, but not for transmission of messages for the public except temporarily in emergencies due to storms or other catastrophes.

(c) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy to make and use (but not to sell, lease or otherwise dispose of, except leases to subscribers in connection with a service given by Companies of the Bell System in t[illegible] paragraph described) apparatus and systems for the purpose of giving within the continental United States, and between the continental United States and other parts of continental North America, a business, commercial or official service limited to a particular customer or class of customers and analogous to the service given by Companies of the Bell System by wire telegraphy at the date of this agreement, commonly designated as leased wire or special contract service, but said licenses do not include the making or using of such apparatus for (1) transmission or reception for the public generally or (2) transoceanic communication or (3) transmission or reception of programs; and the licenses granted to, and the rights reserved by, the Telephone Company for the purposes covered by this paragraph (*c*) include only apparatus for the reception of such service which shall be adapted for reception only upon the wave lengths (not exceeding as to any set three specific wave lengths) upon which such service is given.

(*d*) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy to make and use (but not to sell, lease or otherwise dispose of, except to Companies of the Bell System) apparatus and systems for television for use solely in combination with apparatus and systems for two-way telephony for the purpose of giving a public service combining television and speech, but said licenses do not include the making or using of such apparatus for transmission or reception of programs.

(*e*) The General Company grants to the Telephone Company non-exclusive licenses in the field of wireless telegraphy for combined wireless telephone and telegraph sets, other than sets for transoceanic communication, (1) for use in communication by, with and between airplanes, airships and other automotive devices other than ships and railway vehicles, and (2) for export from the continental United States for use for any purpose other than transoceanic communication.

(*f*) Subject to non-exclusive rights reserved for the purposes described in paragraphs (*b*), (*c*), (*d*) and (*e*) of this section 2, the Telephone Company grants to the General Company exclusive licenses for all purposes in the field of wireless telegraphy other than for the purposes covered by paragraph (*a*) of this section 2 and by section 8 of this article V.

(*g*) The licenses granted to the General Company in this section 2 do not cover the use of wireless telegraph stations for giving a telephone service, except as licensed in section 4 of this article V. The General Company agrees that the surplus facilities of said stations of the General Company shall, upon request of the Telephone Company, be made available to the Telephone Company or its sub-licensees, upon reasonable terms to be agreed upon by the parties, for giving a two-way telephone service; and it shall be a condition of every sub-license granted by the General Company under the licenses granted to it in this section 2 that the sub-licensee shall be under like obligation in respect of its wireless telegraph stations embodying any invention in respect of which it is granted such sub-license.

3. *Wire Telegraphy.*

(*a*) The Telephone Company grants to the General Company exclusive licenses in the field of wire telegraphy for the transmission and reception of programs over electric light, electric heat, electric power and electric traction lines, subject, however, to the provisions of paragraph (*b*) of section 5 of this article V regarding electrical interference.

(*b*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telegraphy to make (but not to sell, lease or otherwise dispose of) apparatus and systems, and (1) to use such apparatus and systems for its own communication and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, and (2) to use such apparatus and systems upon wire telegraph systems owned by it, or leased to it for its operation (other than transoceanic cables), for all purposes other than giving a service by wire telegraphy analogous to the service given by the Companies of the Bell System by wire telegraphy at the date of this agreement, commonly designated as leased wire or special contract service, and other than train dispatching; but no licenses are granted with reference to transoceanic wire telegraphy.

(*c*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telegraphy for apparatus and systems for communication only in connection with the operation of apparatus for power purposes, but not for transmission of messages for the public.

(*d*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telegraphy for apparatus and systems for communication between parts of a train (without regard to the nature of the motive power thereof), or between trains following or approaching each other upon the same system of tracks, or between trains approaching a cross-over or junction point of the systems of tracks upon which they are running, or between trains and signal towers or way-stations within short distances thereof, but in each instance only for use in connection with the operation of such trains but not for train dispatching.

(*e*) Subject to non-exclusive rights reserved for the purposes described in paragraph (*b*), (*c*) and (*d*) of this section 3, the General Company grants to the Telephone Company exclusive licenses for all purposes in the field of wire telegraphy (other than that covered by paragraph (*a*) of this section 3) on land, and over ocean cables not more than one hundred miles in length, and between the main body of the United States and Cuba; but no licenses are granted with reference to other transoceanic wire telegraphy.

4. *Wireless Telephony.*

A. IN GENERAL.

(*a*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wireless telephony to make and use (but not to sell, lease or otherwise dispose of) apparatus and systems for its own communication and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, but not for transmission of messages (as distinguished from programs) for the public except [illegible]porarily in emergencies due to storms or other catastrophes.

(*b*) The Telephone Company grants to the General Company exclusive licenses in the field of amateur wireless telephony, subject to non-exclusive rights reserved for the purposes and subject to the limitations hereinafter in this paragraph (*b*) provided; and the General Company grants to the Telephone Company non-exclusive licenses to make and sell apparatus in the field of amateur wireless telephony limited as hereinafter in this paragraph (*b*) provided. The licenses by this paragraph (*b*) granted by the Telephone Company to the General Company shall be free of royalties, but all apparatus sold by the Telephone Company under the licenses granted by this paragraph (*b*) shall be treated as if such apparatus were apparatus for one-way wireless telephone reception of programs under the provisions of paragraph (*d*) of subdivision C of this section 4 and shall be governed by all the provisions of said paragraph (*d*).

(*c*) Each party grants to the other non-exclusive licenses for headphones for all purposes in all fields covered by this agreement; provided, however, that headphones sold by the Telephone Company as part of complete apparatus for one-way wireless telephone reception of programs shall be included in the determination of the royalties payable by the Telephone Company under the provisions of paragraph (*d*) of subdivision C of this section 4.

(*d*) Each party grants to the other non-exclusive licenses in the field of wireless telephony for apparatus and systems for communication only in connection with the operation of apparatus for power purposes, but not for transmission of messages for the public.

(*e*) Each party grants to the other non-exclusive licenses in the field of wireless telephony for apparatus and systems for communication between parts of a train (without regard to the nature of the motive power thereof), or between trains following or approaching each other upon the same system of tracks, or between trains approaching a cross-over or junction point of the system of tracks upon which they are running, or between trains and signal towers or way-stations within short distances thereof, but in each instance only for use in connection with the operation of such trains but not for train dispatching.

B. TWO-WAY WIRELESS TELEPHONY.

(*a*) The General Company grants to the Telephone Company exclusive licenses in the field of two-way transoceanic wireless telephony to make and use (but not to sell, lease or otherwise dispose of) apparatus and systems for use in the continental United States; but such licenses do not include use for transmission or reception of messages offered for telephonic transmission.

(*b*) The General Company grants to the Telephone Company non-exclusive licenses in the field of two-way transoceanic wireless telephony, to make and sell to stations outside the continental United States engaged in cooperation with the Telephone Company in giving for the public a transoceanic telephone service, apparatus for use in giving such service; and subject to non-exclusive rights reserved for the purposes described in the foregoing clause of this paragraph (*b*), the Telephone Company grants to the General Company exclusive licenses in the field of two-way transoceanic wireless telephony for apparatus for export from the continental United States.

(*c*) The Telephone Company grants to the General Company non-exclusive licenses in the field of two-way wireless telephony for combined wireless telephone and telegraph sets, other than sets for transoceanic communication, (1) for use in communication by, with and between airplanes, airships and other automotive devices other than ships and railway vehicles, and (2) for export from the continental United States for use for any purpose other than transoceanic communication.

(*d*) Subject to non-exclusive rights reserved for the purposes described in paragraph (*c*) of this subdivision B, the General Company grants to the Telephone Company exclusive licenses in the field of two-way wireless telephony (other than in the field of transoceanic wireless telephony) for all purposes other than the purposes covered by subdivision A of this section 4.

(*e*) The licenses granted to the Telephone Company in this subdivision B do not include the use of wireless telephone stations for giving a telegraph service, except as licensed in section 2 of this article V. The Telephone Company agrees that the surplus facilities of said stations of the Telephone Company shall, upon request of the General Company, be made available to the General Company or its sub-licensees, upon reasonable terms to be agreed upon by the parties, for giving a wireless telegraph service, and it shall be a condition of every sub-license granted by the Telephone Company under the licenses granted to it in this subdivision B that the sub-licensee shall be under like obligation in respect of its wireless telephone stations embodying any invention in respect of which it is granted such sub-license.

C. ONE-WAY WIRELESS TELEPHONY.

(*a*) Each party grants to the other non-exclusive licenses in the field of one-way wireless telephony for apparatus and systems for the purpose of giving a business, commercial or official service limited to a particular customer or class of customers; but the licenses granted by this paragraph (*a*) do not include the making or using of such apparatus for (1) transmission or reception of messages for the public generally or to transmission or reception of programs; and the licenses granted to, and the rights reserved by, the Telephone Company for the purposes covered by this paragraph (*a*) include only apparatus for the reception of such service which shall be adapted for reception only upon the wave lengths (not exceeding as to any set three specific wave lengths) upon which such service is given and only apparatus for the transmission of such service from and within the continental United States.

(*b*) Each party grants to the other non-exclusive licenses in the field of one-way wireless telephony for apparatus and systems for use for transmitting for purposes other than that covered by paragraph (*a*) of this subdivision C, including, however, apparatus for wireless telephone reception furnished as a part of the equipment of transmitting stations; but the licenses granted by this paragraph (*b*) do not include apparatus in the field of amateur wireless telephony.

(*c*) The General Company grants to the Telephone Company non-exclusive licenses to make and use (but not to sell, lease or otherwise dispose of, except to Companies of the Bell System) apparatus for one-way wireless telephone reception (including apparatus for the reception of programs) for its own communication or that of Companies of the Bell System, and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement.

(*d*) The General Company grants to the Telephone Company non-exclusive licenses to make and sell (but not to lease or otherwise dispose of) apparatus for one-way wireless telephone reception of programs, but not for use in combination or connection with phonographs; provided, however, that the licenses granted in this paragraph (*d*) shall be subject to the following terms and conditions:

(1) Tubes (thermionic devices) sold as separate devices for use in apparatus covered by this paragraph (*d*), or in apparatus which under other provisions of this agreement shall be treated as apparatus covered by this paragraph (*d*), shall be free of royalties to the amount of $2,000,000 during each calendar year, and said tubes in excess of said amount in any year shall be subject to a royalty of fifty per cent. computed as hereinafter provided; provided that in no event shall tubes sold free of royalty exceed 1,000,000 in number during any calendar year; and provided further that where said tubes are sold as parts of receiving sets or other complete units designed for operation with such sets, such tubes shall be treated as parts of the receiving set or other unit and shall not be classified under this subparagraph (1).

(2) Receiving sets and apparatus which under other provisions of this agreement shall be treated as apparatus covered by this paragraph (*d*), or parts thereof (including loud speakers, amplifiers and tubes other than thermionic devices), shall be free of royalty to the aggregate amount of $3,000,000 in each calendar year, and such sets, apparatus or parts in excess of said amount shall be subject to a royalty of fifty per cent. computed as hereinafter provided; provided that if the sales of tubes sold as separate devices amount to less than $2,000,000 during any year, the amount of such deficiency shall be added to the amount of receiving sets, apparatus and parts which may be sold free of royalty in the same year.

(3) For any portion of the first or last calendar year of this agreement, less than an entire calendar year, during which royalties shall be payable hereunder, the amounts which may be sold free of royalty shall be that proportion of the amounts which may be sold free of royalty in the entire calendar year which said fractional part of a calendar year bears to a calendar year.

(4) The licenses granted to the Telephone Company in this paragraph (*d*) to sell apparatus for one-way wireless telephone reception of programs (and the licenses

to sell apparatus which under other provisions of this agreement shall be treated as apparatus covered by this paragraph) are licenses for sale only at retail (except as to sales for export), either directly or through the Telephone Company's own direct agents and are subject to the condition that the Telephone Company shall retain in itself, or in one or more of its subsidiaries, title to the apparatus and control of its disposition until it is so sold.

(5) The aforementioned amounts sold free of royalty, and the amounts subject to royalty, shall (except as to sales for export) be based on the actual price at which the apparatus is sold at retail.

(6) Sales for export shall be included in determining the amounts sold free of royalty, and the amounts subject to royalty, on the basis of the price at which the sale is made.

(7) In ascertaining the amount of the sales which are free from royalty and the amount of the sales upon which royalties are to be paid hereunder, where apparatus is sold any part of which embodies any invention of any of the patents included in this agreement, the selling price of the apparatus sold shall be taken as the basis; but apparatus not covered by any of the patents of the parties, when sold not assembled for operation with apparatus covered by such patents, shall not be taken into account in computing the amounts of sales which are free from royalty or the amount of sales which are subject to royalty, unless such apparatus not covered by such patents is adapted for operation with apparatus covered by such patents and is sold in such manner that its sale or its use in connection with apparatus covered by such patents would, except for the licenses granted by this agreement, constitute contributory infringement of patents of the parties under which exclusive licenses are granted to the General Company by this agreement. Where radio receiving sets are sold for use in combination with apparatus primarily designed as public address systems the sale price of the public address apparatus shall not be included in the amount of the sales which are free from royalty or the amount of the sales which are subject to royalty. Chem-

ical primary batteries, wet or dry, and chemical storage batteries, not sold as part of apparatus upon which royalties are payable hereunder, or wiring in a building in connection with a sale of such apparatus, shall not be taken into account in computing the amount of sales which are free from royalty or the amount of sales which are subject to royalty.

(*e*) Subject to non-exclusive rights reserved for the purposes covered by paragraphs (*b*), (*c*) and (*d*) of this subdivision C, the Telephone Company grants to the General Company exclusive licenses for apparatus and systems for one-way wireless telephone reception of programs.

(*f*) Subdivision A of this section 4 and paragraphs (*a*) to (*e*), inclusive, of this subdivision C are intended to make provision for all anticipated fields of use of apparatus for one-way wireless telephone reception. If it should develop that there are other fields of use of such apparatus not covered herein licenses shall be granted in such other fields of use to the respective parties in accordance with the principle underlying said other paragraphs of this subdivision C, with special reference to the interest of the General Company in the field of one-way wireless telephone reception of programs, on the one hand, and of the Telephone Company in the field of one-way wireless telephone reception for giving a service of a business, commercial or official nature, on the other hand. If the parties can not agree with respect to such licenses, their respective rights shall be determined by arbitration in accordance with the provisions of article XIII.

5. *Wire Telephony.*

(*a*) The Telephone Company grants to the General Company exclusive licenses, subject to non-exclusive rights reserved for the same purposes, and the General Company grants to the Telephone Company non-exclusive licenses, in the field of wire telephony for apparatus for carrier current telephone communication, both one-way and two-way, over electric light, electric heat, electric power and electric traction lines, or partly over such lines and partly across wireless gaps, but in each instance only for the use of the owner or operator of such line.

in the business of such owner or operator, and not for transmission of messages for the public except temporarily in emergencies due to storms or other catastrophes.

(*b*) The Telephone Company grants to the General Company exclusive licenses in the field of one-way wire telephony for apparatus for the transmission and reception of programs over electric light, electric heat, electric power and electric traction lines including the use of such lines for pick-up lines or for connecting two or more separate electric systems in connection with the transmission or reception of programs over such lines or by means of wireless telephony, but not including the use of other wires for such purposes except as licensed in paragraph (*c*) of this section 5; provided, however, that no apparatus is licensed under this paragraph (*b*), or under paragraph (*a*) of section 3 of this article V, the use of which would electrically interfere unreasonably with the Telephone Company's systems of wire communication for which it is licensed under this agreement, as the same may now exist or may hereafter normally be developed, or with the Telephone Company's exclusive field of transmitting programs by wire telephony over lines other than electric light, electric heat, electric power and electric traction lines, and the Telephone Company shall be the sole judge of the existence of such unreasonable interference. The Telephone Company agrees whenever requested by the General Company, but at the expense of the General Company consented to by it before being incurred, to co-operate with the General Company in every reasonable way to enable the General Company to develop apparatus within the licenses granted by this paragraph (*b*) which will avoid such electrical interference.

(*c*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony, both one-way and two-way, to make (but not to sell, lease, or otherwise dispose of) apparatus and systems, and to use such apparatus and systems solely upon systems owned by it, for its own communication and for use solely as an incidental facility in fields in which it is otherwise licensed under this agreement, but not for transmission of messages (as distinguished from programs) for the public except temporarily in emergencies due to storms or other catastrophes. The Telephone Company agrees to furnish to the General Company, when requested, pick-up or connecting wires, if available, for its use in the transmission of programs to or from its stations for such transmission either by means of wireless telephony or over electric light, electric heat, electric power and electric traction lines, or for its use in electrical sound recording, on terms at least as favorable as the terms given to others than the General Company, and agrees that in furnishing such pick-up and connecting wires for such service there shall be no discrimination against the General Company; and, in addition to and without limitation of the licenses granted by the foregoing clauses of this paragraph (*c*), the General Company reserves non-exclusive rights in the field of wire telephony under its own patents only, for use in connection with providing for itself or obtaining from others such service or facilities if the Telephone Company shall in any case fail to furnish the same, and the non-exclusive rights so reserved may be assigned to or otherwise availed of by any other party from which the General Company shall obtain service or facilities.

(*d*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony for apparatus for the distribution to an assembled audience, or to rooms within a building or a group of substantially adjacent buildings commonly owned or operated, of matter re-transmitted from apparatus for one-way wireless telephone reception, or from apparatus for reception in the field covered by paragraph (*b*) of this section 5, or from phonographs, in each case located in the immediate vicinity of such audience or within the building or group of buildings within which such distribution is made.

(*e*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony, both one-way and two-way, for apparatus and systems for communication only over wires used in connection with apparatus for remote control or actuation of apparatus for power purposes and only in connection with the operation of apparatus for power purposes, but not for transmission of messages for the public.

(*f*) The Telephone Company grants to the General Company non-exclusive licenses in the field of wire telephony, both one-way and two-way, for apparatus for communication between parts of a train (without regard to the nature of the motive power thereof), or between trains following or approaching each other upon the same system of tracks, or between trains approaching a cross-over or junction point of the systems of tracks upon which they are running, or between trains and signal towers or way-stations within short distances thereof, but in each instance only for use in connection with the operation of such trains but not for train dispatching.

(*g*) Subject to non-exclusive rights reserved for the purposes covered by paragraphs (*c*), (*d*), (*e*) and (*f*) of this section 5, the General Company grants to the Telephone Company exclusive licenses in the field of wire telephony, both one-way and two-way, for all purposes other than for the purposes covered by the paragraphs (*a*) and (*b*) of this section 5; provided, however, (1) that the licenses granted by this paragraph (*g*) for apparatus for reception of programs are licenses only to make and use in connection with a service of transmitting programs by wire telephony over lines other than electric light, electric heat, electric power and electric traction lines, to lease to subscribers to such a service, and to sell only at retail (except as to sales for export) either directly or through the Telephone Company's own direct agents, and said licenses are subject to the condition that the Telephone Company shall retain in itself, or in one or more of its subsidiaries, title to the apparatus and control of its disposition until it is so sold, and (2) that all apparatus made, used, sold, leased or otherwise disposed of by the Telephone Company for distributing to an assembled audience or to rooms within a building or a group of substantially adjacent buildings commonly owned or operated, programs re-transmitted from apparatus for one-way wireless telephone reception or from apparatus in the field covered by paragraph (*b*) of this section 5, in each case located in the immediate vicinity of such audience or within the building or group of buildings within which such distribution is made, shall be treated as if such apparatus were apparatus for one-way wireless telephone reception of programs under the provisions of paragraph (*d*) of subdivision C of section 4 of this article V, and shall be governed by all the provisions of said paragraph (*d*).

6. *Power Purposes and Household Devices.*

The Telephone Company grants to the General Company exclusive licenses in the fields of (*a*) distance actuation and control by wireless, (*b*) power purposes (including apparatus for distance actuation and control of apparatus for power purposes and apparatus for indicating at remote points the condition or position, of apparatus for power purposes) and (*c*) household devices, in each case for purposes other than communication purposes; provided, however, that in so far as concerns patents for inventions relating to business of the general character which any subsidiary of the Telephone Company now conducts as jobber and any extensions of that business along similar lines (except patents covering articles of the general character which such subsidiary now purchases from the General Company, or its subsidiaries, or sells as agent for the same), the Telephone Company reserves under its own patents (but is granted no license under the patents of the General Company) the non-exclusive right for such subsidiaries to make apparatus embodying the inventions of said patents, or have them made for them, and to sell them in said jobbing business.

7. *Railroad Signalling, Radio Goniometry, X-ray Devices.*

(*a*) The General Company grants to the Telephone Company non-exclusive licenses in the field of radio goniometry for apparatus for use as part of apparatus in respect of which the Telephone Company is otherwise licensed under this agreement.

(*b*) The General Company grants to the Telephone Company non-exclusive licenses in the field of railway signalling for apparatus incidental to apparatus for train dispatching, for use only by the train dispatcher or similar official for operating at will, and not automatically, signals, switches, brakes and stops.

(*c*) Subject to non-exclusive rights reserved for the purposes covered by paragraphs (*a*) and (*b*) of this section 7, the Telephone Company grants to the General Company exclusive licenses in the fields of railroad signalling, X-ray apparatus and apparatus associated therewith, and radio goniometry.

8. *Train Dispatching.*

The General Company grants to the Telephone Company exclusive licenses in the field of train dispatching.

9. *Electric Sound Recording.*

(*a*) The General Company grants to the Telephone Company exclusive licenses for electrical apparatus for the production of sound records (which records are for the private use of the maker, and not for commercial use or sale) in combination or connection with apparatus in the field of wire telephony other than in connection with apparatus in the field covered by paragraph (*b*) of section 5 of this article V.

(*b*) The Telephone Company grants to the General Company exclusive licenses for electrical apparatus for the production of sound records (which records are for the private use of the maker, and not for commercial use or sale) in combination or connection with apparatus for one-way wireless telephone reception of programs and with apparatus in the field covered by paragraph (*b*) of section 5 of this article V.

(*c*) The Telephone Company grants to the General Company exclusive licenses for electrical apparatus for the production in homes (which records are for the private use of the maker, and not for commercial use or sale) of sound records of entertainment and educational matter, other than apparatus covered by paragraphs (*a*) and (b) of this section 9.

(*d*) Each party grants to the other non-exclusive licenses for electrical apparatus for the production of sound records other than apparatus covered by paragraphs (*a*), (*b*) and (*c*) of this section 9.

(*e*) Nothing in this section 9 contained shall be construed as granting to either party any exclusive license with respect to electrical apparatus for the production of sound records for commercial use or sale, or for the production of master records intended to be used in manufacturing sound records for commercial use or sale.

10. Electrical Phonographs.

(a) The General Company grants to the Telephone Company exclusive licenses for electrical phonographs for use in combination or connection with apparatus in the field of wire telephony other than in combination or connection with apparatus in the field covered by paragraph (*b*) of section 5 of this article V; provided, however, that the licenses granted by this paragraph (*a*) for phonographs for private use in homes for entertainment and educational purposes are licenses only to make and use in connection with a service of transmitting programs by wire telephony over lines other than electric light, electric heat, electric power and electric traction lines, to lease to subscribers to such a service, and to sell only at retail (except as to sales for export) either directly or through the Telephone Company's own direct agents, and said licenses are subject to the condition that the Telephone Company shall retain in itself, or in one or more of its subsidiaries, title to the apparatus and control of its disposition until it is so sold.

(b) The Telephone Company grants to the General Company exclusive licenses for electrical phonographs in combination or connection with apparatus for one-way wireless telephone reception, and in combination or connection with apparatus in the field covered by paragraph (*b*) of section 5 of this article V.

(*c*) The Telephone Company grants to the General Company exclusive licenses for electrical phonographs for private use in homes for all entertainment and educational purposes other than those covered by paragraphs (*a*) and (*b*) of this section 10.

(*d*) Each party grants to the other non-exclusive licenses for electrical phonographs for all purposes other than those covered by paragraphs (*a*), (*b*) and (*c*) of this section 10.

11. *Apparatus for Co-ordination of Sound and Pictures.*

(a) The rights and licenses of the parties hereto in respect of apparatus for transmitting, receiving, recording or reproducing sound in co-ordination, synchronism or timed relation with the taking, transmission or projection of pictures shall, in so far as the fields of wire and wireless telegraphy and telephony, electrical sound recording and electrical phonographs are involved, be governed by the other provisions of this agreement relating to said fields.

(b) In so far as apparatus for the taking or projection of pictures and apparatus for co-ordinating, synchronizing or timing such taking or projection in relation to the recording or reproduction of sound are not covered by the provisions of paragraph (a) of this section 11, the Telephone Company grants to the General Company exclusive licenses for such apparatus for private use in homes for entertainment and educational purposes, and each party grants to the other non-exclusive licenses for such apparatus for all other purposes.

12. *Submarine Signaling, Scientific and Therapeutic Apparatus, Shop Expedients and Other Applications.*

Each party grants to the other, non-exclusive licenses in the following fields:

Submarine signaling.

Scientific apparatus for use of laboratories, colleges and scientific societies, as distinguished from commercial use.

Wireless apparatus for use of professional investigators (as distinguished from amateurs) for experimental purpose only.

Therapeutic apparatus other than X-ray devices and appliances.

Shop tools, appliances, materials and processes, but only for the production of apparatus embodying inventions which the grantee is licensed to make and use hereunder.

All applications, not herein otherwise specified, of inventions pertaining or applicable to or to the use of vacuum tubes, and to generating (directly or from other currents), modifying, amplifying, transmitting or receiving electro-magnetic waves, variations or impulses for other than power purposes.

ARTICLE VI.

PROVISIONS WITH REFERENCE TO FOREGOING LICENSES.

1. Whenever licenses granted under the terms of this agreement are based upon rights held by the licensor under any agreement requiring the payment of royalties or other deferred payments, measured by the use made of the invention, the party accepting such licenses shall make payments measured by its use of the invention at the same rate and upon the same terms as those agreed to be made by the party originally acquiring the rights.

2. Upon the termination of this agreement under the provisions of article XIV hereof all licenses herein granted shall, during the terms of the several patents, issued or to be issued, in respect of which such licenses exist at the date of termination, continue unaffected and of the same scope and character, whether exclusive or non-exclusive, herein expressed, so far as the grantor thereof has the right to grant such licenses for such terms; and such licenses shall not be limited by the term of this agreement.

3. (*a*) The Telephone Company may grant sub-licenses under its standard form of license contract (a copy of which is now delivered to the General Company) to such operating companies (but not manufacturing companies) as are now or may from time to time be operating under such form of contract. The provisions of this paragraph (*a*) shall apply to any changed form of license contract provided that, as changed, it grants rights in the fields of the General Company no broader than those granted by the present form.

(*b*) Each party hereto may grant to its subsidiaries sub-licenses under the licenses granted to it herein; provided, however, that each subsidiary to which a sub-license shall be granted (excepting, however, sub-licensees pursuant to paragraph (*a*) of this section 3) shall either have entered into an agreement with its parent company effectively subjecting to this agreement all

United States patents then or thereafter during the term of this agreement owned or controlled by it, or have executed to the party hereto other than its parent company an instrument granting to such other party licenses under said patents co-extensive with the licenses herein granted to such other party. Use by any subsidiary of any sub-license granted under this agreement shall for all purposes of this agreement, including determination of royalties payable hereunder, be deemed to be use by its parent company, and ownership, lease or operation of any telephone or telegraph system or station by any subsidiary shall be deemed to be ownership, lease or operation of such system or station by its parent company for all purposes of this agreement.

(*c*) In addition to the sub-licensing provided for in the foregoing paragraphs (*a*) and (*b*), each party hereto may assign or grant sub-licenses under any of the rights granted to it hereunder, provided that in each instance the assent of the other party is first obtained.

(*d*) Each party may, subject to the provisions of section 4 of this article VI, sell or lease to any sub-licensee having a sub-license to use granted under the provisions of any of paragraphs (*a*), (*b*), and (*c*) of this section 3, apparatus for the use of such sub-licensee under such sub-license, notwithstanding that the party granting such sub-license may not be licensed under this agreement generally to sell, lease or otherwise dispose of such apparatus.

(*e*) All sub-licenses granted hereunder shall be subject to all limitations and obligations attaching to the apparatus or system in respect of which sub-licenses are granted, whether under the patents, or under the instruments by which any party acquired the patents or licenses under them; or under this agreement.

(*f*) No disposition by either party of rights hereunder acquired by it, shall relieve such party of any of its obligations under this agreement, or restrict the rights of the parties hereto in operating under or modifying this agreement.

4. Each party agrees that, so far as it is enabled so to do, it will, in disposing of apparatus embodying inventions pertaining or applicable to vacuum tubes, or to

generating, modifying, amplifying, transmitting or receiving electro-magnetic waves, or other apparatus or material the unrestricted sale of which would deprive the other party of rights to which it is entitled hereunder, use such precautions by contracts, leases, restricted licenses or otherwise as may be necessary or advisable in order to prevent its subsidiaries, sub-licensees, customers or others from acquiring (by acquisition of apparatus from it or otherwise) licenses to use the same which the party disposing thereof has no right to grant. In case at any time either party shall claim that apparatus made by the other and capable of use in fields in which the claimant is exclusively licensed under this agreement, has been sold in an amount exceeding the amount reasonably acquired for use in fields in which the maker is licensed under this agreement, the parties shall endeavor by agreement to determine whether there has been such excess sales of apparatus and the amount of the royalties payable thereon as hereinafter provided; and if the parties shall be unable to agree upon any of said matters, the dispute shall be settled by arbitration as hereinafter provided. The party making such claim shall, if it shall prove the fact of excess sales, not be required to prove with the definiteness which would be required in a court of law or equity, the amount of such excess sales, but the arbitrators shall estimate such amount as nearly as they can from such evidence as may be furnished by the parties and the amount so estimated shall be deemed to be the amount of such excess sales. Upon any excess apparatus so determined to have been sold the party making such excess sales shall pay to the other party royalties equal to fifty per cent. of the current retail price during the period during which such excess apparatus was sold.

5. All royalties payable under any provision of this agreement shall continue to be payable to the ends of the terms of the patents in respect of which such royalties are payable, notwithstanding any termination of this agreement.

6. The admission of validity implied in the acceptance of licenses hereunder is limited to the field for which such licenses are granted or agreed to be granted.

7. No licenses under foreign patents are now granted or are to be implied; but except as herein otherwise expressly provided the licenses to make, sell, lease or otherwise dispose of, herein granted under United States patents include the right to make, sell, lease or otherwise dispose of for use abroad in the fields for which such licenses under United States patents are granted, but not for use abroad in other fields. Each party agrees not to export to any country in which the other party has an affiliated company, apparatus purchased from such other party which such other party could not itself so export, in view of existing contract obligations, after notice of such obligations and without first securing a written waiver thereof.

8. Each party represents that in its best judgment it has no outstanding obligations which would prevent it from entering into the agreements and from granting the licenses herein expressed. If, however, it is found that there are such conflicting obligations, the present agreement is made subject to the right to fulfill those obligations.

ARTICLE VII.

INTERFERENCES.

The parties agree to use reasonable endeavors to settle, without litigation, interferences now pending or which may arise involving inventions within the scope of this agreement.

ARTICLE VIII.

ACQUISITION OF PATENT RIGHTS.

Neither party shall acquire from others rights to or under United States patents or inventions, or rights to use secret processes, applicable to the fields of the other party, of such limited character that the other party does not, by the operation of this agreement, receive licenses thereunder of the scope and within the respective fields herein set forth, unless the party proposing to acquire such rights shall first have given the other party an opportunity to be represented in the negotiations and thereby to acquire rights for its field.

ARTICLE IX.

CO-OPERATION AND EXCHANGE OF INFORMATION.

1. Each party agrees that it will, from time to time during the term of this agreement, freely permit the other to have all information in its possession which it may have a right to dispose of with reference to its standardized apparatus or methods or processes applicable to the uses of the other party in fields in which such other party is granted licenses hereunder, but any secret process so disclosed shall be maintained in secrecy by the party to whom it is disclosed. Blue prints, etc., shall be furnished at the cost of preparing the same. For the purpose of acquiring such information each party shall at all reasonable times have access (through a reasonably limited number of accredited representatives who are regular employees under obligation to assign inventions to their employers), to the laboratories, factories and wireless stations of the other, to the end that development work may be expedited and rendered the more effective.

Each party shall, with reference to inventions owned or controlled by it, under which the other party is entitled to rights hereunder and which either party deems to be of sufficient value to justify such action, endeavor to obtain or permit and aid the other to obtain proper patents thereon.

2. Each party shall afford the engineering representatives of the other the fullest possible facilities, consistent with the reasonable operation of the other, for experimenting and for developing and testing apparatus and systems for use in transoceanic telephony, and each shall at all times be given such an opportunity to make such tests, experiments and observations in the transoceanic stations of the other as do not conflict with the service then being rendered by such stations, and each party shall afford to the other such facilities for test, experimentation and observations on ships as it may be able to extend.

3. In the operation of wireless and carrier-current communication, the parties shall co-operate to the end that interference with the operations of either party, due to the operations of the other, shall be minimized, it

being recognized that the available wave lengths are limited.

ARTICLE X.

PURCHASES AS BETWEEN PARTIES.

It is recognized that each party has and will normally continue to have facilities for manufacturing certain apparatus or parts thereof which may be required by the other party under its licenses hereunder, and that a duplication of such facilities may be wasteful and uneconomical. Each party agrees that it will upon request manufacture for and sell and deliver to the other, with reasonable business promptness and within its reasonable manufacturing capacity, on receipt of orders from time to time, and at favorable prices not to exceed those charged to others (except subsidiaries and, in the case of the Telephone Company, Companies of the Bell System) purchasing in like quantities for use in the United States, such apparatus and parts as the former is engaged in manufacturing from time to time and as the latter may desire for use under the licenses granted by this agreement.

ARTICLE XI.

LITIGATION.

1. Each party shall have the exclusive right to bring suits for infringement in the fields in which its licenses are herein expressed as exclusive, joining as plaintiff in any such suit the patent owner or the party which has acquired from the patent owner the right to sue thereunder.

2. Neither party shall bring suit for infringement of patents against the other party, or against the distributors and jobbing houses owned by or affiliated with either party, because of sales by such party, or by its (or its subsidiaries') distributors or jobbing houses, of apparatus made, in the United States, by others than the parties hereto, it being agreed that the remedy in case of any such infringement shall be only by suit against the manufacturer of those devices; but nothing herein contained shall be construed as the granting of a right to sell infringing apparatus manufactured by others.

8. Each party assigns and transfers to the other all claims and causes of action which it may have against others for infringement in fields in which the licenses herein granted to such assignee are exclusive, together with the right to sue for and collect for its own use all profits and damages arising out of such infringement.

ARTICLE XII.

RELEASES.

Each party reserves to itself the right to deal with the United States Government with reference to settlement for past use of its inventions in telephone and telegraph apparatus and systems. Subject to the foregoing, each party releases the other and the vendees and users of apparatus or systems made by it, from all claims growing out of past infringement of patents, by reason of the manufacture, use and sale of such apparatus and systems by the other party, and its resale or use by such vendees and users.

ARTICLE XIII.

ARBITRATION.

In case any controversy under this agreement (except in respect of interference or priority of rights to inventions or patents) shall arise between the parties to this agreement, which they are unable to adjust between themselves, it shall be settled by arbitration pursuant to the Arbitration Law of the State of New York in the following manner:

Either party may by notice in writing served on the other, appoint one arbitrator and call upon the other to appoint a second arbitrator within thirty days after the receipt of such notice; and each party agrees that upon receiving any such notice it will so appoint an arbitrator. The two arbitrators thus appointed shall, within thirty days after the appointment of the one last appointed, jointly appoint a third arbitrator. The controversy shall be submitted to the three arbitrators in such manner as they shall direct and their decision, or the decision of a majority of them, rendered in writing, shall be final, conclusive and binding upon the parties. In the event that a second arbitrator shall not be appointed as above provided or the two arbitrators first appointed shall fail to appoint a third, application may be made by either party to the Supreme Court of the State of New York, or to a judge thereof, to designate and appoint an arbitrator or arbitrators, as the case may require, as provided by said Arbitration Law. Each party shall pay its own expenses in connection with the arbitration but the compensation and expenses of the arbitrators shall be borne in such manner as may be specified in their decision in writing.

ARTICLE XIV.

TERMINATION OF AGREEMENT.

This agreement shall continue until July 1, 1933, but shall automatically continue thereafter until cancelled on three years' written notice given after July 1, 1930, by one party to the other party.

ARTICLE XV.

FURTHER ASSURANCES.

The parties agree to execute and deliver such further instruments as may reasonably be necessary for carrying out the provisions and purposes of this agreement.

ARTICLE XVI.

SUCCESSORS.

This agreement is binding upon and shall inure to the benefit of each of the parties hereto and their several successors in business, except that either party may transfer or dispose of any part or parts of its business not involving the grant of any licenses under this agreement, and in such case this agreement shall not be binding upon or inure to the benefit of the successor to that part of the business so transferred.

IN WITNESS WHEREOF, the parties hereto have caused this instrument to be executed on the day and year first above written, by their proper officers thereunto duly authorized.

GENERAL ELECTRIC COMPANY,
By E. W. RICE, JR.
President.

[SEAL]
Attest:
J. W. ELWOOD
Assistant Secretary.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
By H. B. THAYER
[SEAL] President.

Attest:
A. A. MARSTERS
Secretary.

II. The foregoing modifications shall be effective from and after the date of this agreement.

IN WITNESS WHEREOF, the parties hereto have caused this agreement to be executed as of the day and year first above written by their proper officers thereunto duly authorized.

GENERAL ELECTRIC COMPANY,
by OWEN D. YOUNG
Chairman of the Board.

[SEAL OF GENERAL ELECTRIC COMPANY]
Attest:
J. W. LEWIS
Assistant Secretary.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY,
by D. F. HOUSTON
Vice-President.

[SEAL OF AMERICAN TELEPHONE AND
TELEGRAPH COMPANY]
Attest:
A. A. MARSTERS
Secretary.

PLAINTIFF'S EXHIBIT No. 215.

313

Oct. 20, 1925.

1,558,437

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. 29, 1913   2 Sheets-Sheet 1

Fig 1

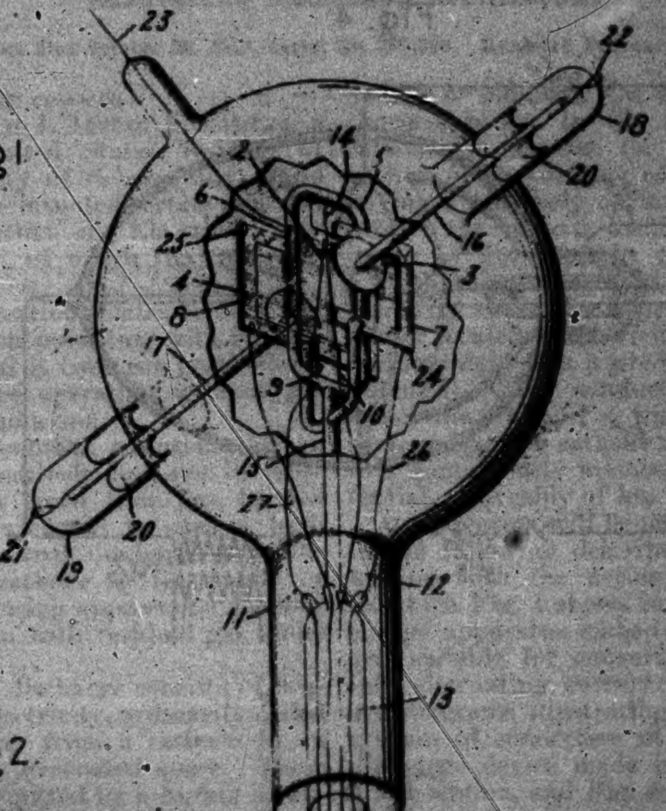

23
22
18
2
14
5
6
20
25
16
3
4
8
7
17
24
9
10
26
15
27
21
19
20
12
11
13

Fig 2

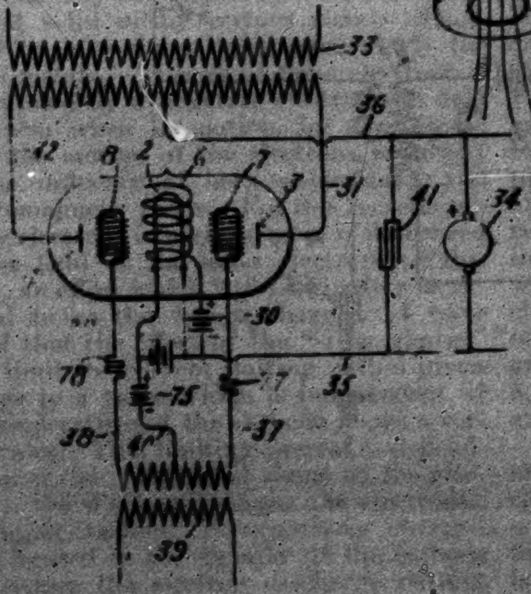
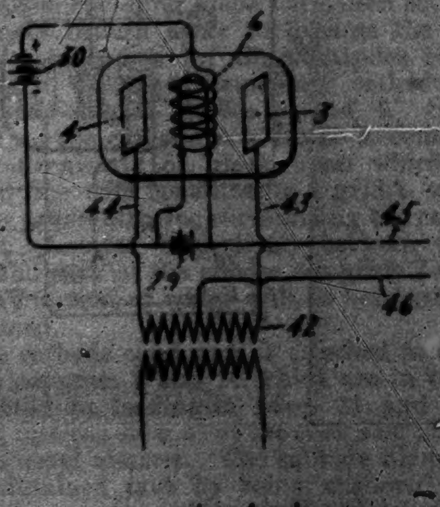

33
36
42
8
2
6
7
3
31
41
34
30
78
75
77
35
38
40
37
39

Fig.3


30
6
4
3
44
43
45
79
46
42

Witnesses:
Chas B Stokes
J. Ellis Elen

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney

314

Oct. 20, 1925.

1,558,437

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. [illegible], 1913   2 Sheets-Sheet 2

Fig. 4.

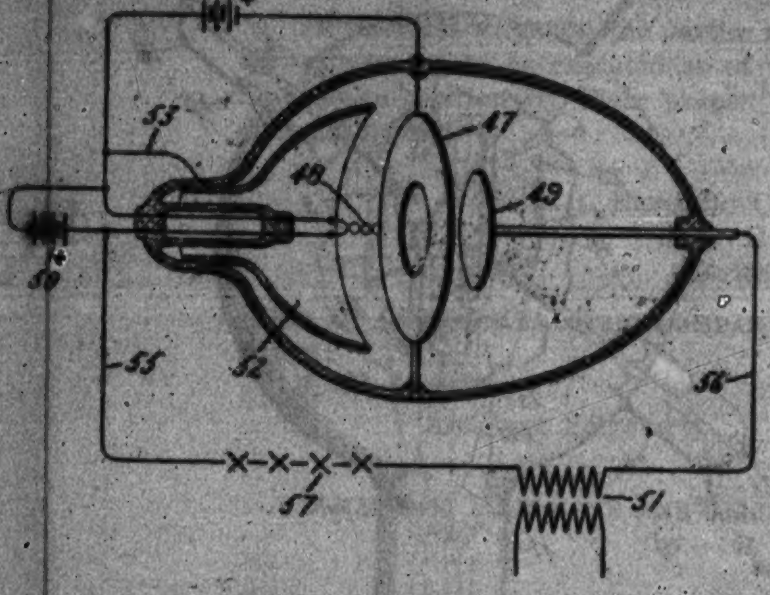
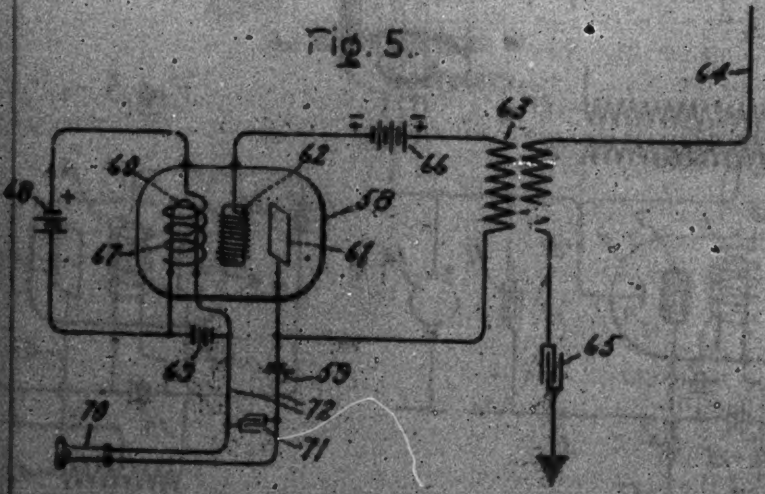

54
-
+
53
47
48
49
50
+
55
52
56
57
51

Fig. 5.


64
63
-
+
66
62
68
+
60
58
67
61
65
59
72
70
71
65

Witnesses:

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

Patented Oct. 20, 1925. 1,558,437

UNITED STATES PATENT OFFICE

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRICAL DISCHARGE APPARATUS.

Application filed October [illegible], 1913, Serial No. [illegible]. Renewed February [illegible], 1924.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical Discharge Apparatus, of which the following is a specification.

The present invention relates to electrical discharge apparatus operating with an electron discharge and it concerns particularly the type of device operating without gas ionization and conduction.

Such a device consists essentially of an electron-emitting cathode, and one or more anodes thoroughly freed from gas, located in an envelope evacuated to such a high degree that an electron discharge can take place from the cathode to the anode or anodes without causing appreciable gas ionization by collision with residual gas molecules.

A pure electron discharge consists of negative charges of electricity, ordinarily called "electrons", moving from a cathode to an anode in a highly evacuated space. These electrons may be emitted by a highly incandescent solid, or by certain metals illuminated by ultraviolet light, particularly the alkali metals. As each of these electrons is surrounded by a negative electrostatic field and, also when in motion, by a magnetic field, the motion of the electrons is subject to the influence of both electrostatic and electromagnetic forces. For this reason each of the electrons in a given space is influenced by the field of the other electrons in this space, an effect which will hereinafter be referred to as the "space charge". I have found that the effect of the "space charge" is to limit the current flowing with a given voltage to a value which is independent of the temperature of the cathode above a certain value. This limiting current is dependent upon the geometrical shape of the electrodes, the distance between the electrodes, and other factors. A negatively charged body located in the vicinity of the cathode will reduce the electron discharge current with a given impressed voltage and may also deflect the electrons dependent upon its position and configuration.

Some of the objects of the present invention are: to reduce the effect of the space charge in an electron discharge device; to modify or eliminate the effect of negatively charged bodies in the proximity of the cathode; to increase the discharge current with a given voltage; to furnish electrons having a relatively uniform velocity and to protect the cathode itself from mechanical injury or distortion by electrostatic forces.

With these objects in view the electron discharge apparatus is provided with a conductor located in the vicinity of the cathode and maintained at a predetermined positive potential. This conductor ordinarily assumes the form of a wire grid or grating surrounding the cathode and it is connected to a continuously maintained source of potential, preferably of low voltage.

My invention will be more fully explained in the following description taken in connection with the accompanying drawings in which Fig. 1 shows in perspective a discharge apparatus embodying my invention and suitable for converting direct current into alternating current; Figs. 2, 3 and 5 are diagrams illustrating various electrical systems of connection utilizing an electron discharge device made in accordance with my invention, and Fig. 4 illustrates a modified form of apparatus in which a positively charged plate is used instead of a grid.

In the electron discharge device shown in Fig. 1, the enclosing globe 1 has been shown as partly broken away to disclose the interior arrangement of the electrodes comprising a V-shaped filamentary cathode 2, and plate-shaped anodes 3 and 4. Surrounding the cathode is a frame 5, consisting conveniently of glass, upon which is wound fine wire constituting a grid 6 with closely adjacent turns surrounding the cathode 2. Located respectively between this grid and each of the anodes are grids 7 and 8, the function of which will be hereinafter explained.

The cathode conductor is attached to terminal supports 9 and 10 which are in turn connected to leading-in wires 11 and 12, sealed into the stem 13 of the enclosing globe in the usual manner. The cathode filament is maintained taut by being anchored by its bight by means of the spring 14 attached to the frame 5. The electrodes and grid wires consists preferably of ductile tungsten. The cathode and grids are all carried by glass stems attached to a pedestal 15. The anode stems 16 and 17 consist of tungsten or molybdenum and are held in position in the extensions 18 and 19 of the bulb by springs 20, which grip the walls of the bulb. Connection is made to the anodes in the usual manner by the leading-in wires 21 and 22. Connection to the grid surrounding the cathode is made by a leading-in wire 23. The grids 7 and 8 are preferably wound upon metallic frames 24 and 25 consisting, for example, of ferro-chrome which thus short-circuit the turns of the gird. Electrical connection is made thereto by conductors 26 and 27. The relative position of the anodes the cathode and the grids is more clearly indicated in a diagrammatic manner in Fig. 2; Fig. 1 illustrates particularly the structural features.

As shown in Figs. 2 and 3, the cathode 2 is maintained at incandescence by means of a battery 29, or other suitable externally located source of energy. The surrounding grid 6 is attached to the positive terminal of a source of potential, for example a battery 30, the negative terminal of which is connected to the cathode.

The discharge device is evacuated to the highest obtainable vacuum, the electrodes being freed from gas by operating the device while on the pump at a voltage below the value at which harmful gas ionization, as indicated by blue glow, takes place. As gas is driven out of the anode by electron bombardment, the impressed voltage is progressively increased, the removal of gas by the pump being continued. The impressed voltage thus attained before sealing-off should ordinarily be higher than the voltage at which the device is intended to operate. The degree of vacuum in the completed device while depending somewhat upon the character of the device should ordinarily be as low as a few hundred thousandths of a millimeter of mercury, preferably even lower.

The system shown in Fig. 2 is adapted particularly for the conversion of direct current into alternating current and for this purpose the anodes 3 and 4 are connected by means of conductors 31, 32 to the primary winding of a transformer 33. Energy is supplied by a direct current source of energy 34, for example, a dynamo, or a battery connected at its negative terminal by means of conductor 35 to the cathode and at its positive terminal by means of conductor 36 to an intermediate point upon the primary of the transformer 33. The grids 7 and 8 are connected by means of the conductors 37 and 38, to a source of alternating current 39 having the frequency desired for the alternating current to be produced by the device. This source has been diagrammatically indicated as a transformer altho of course any suitable alternating current source may be used. The cathode 2 is connected by means of a conductor 40 to an intermediate point on the secondary of the transformer 39.

The operation of the system above described is as follows:—When the cathode 2 is brought to incandescence it emits electrons, which travel under the influence of the impressed electromotive force to a positive electrode. When, however, a conductor, located between the cathode and an anode between which electrons are passing, is negatively electrified, the electrons are repelled in accordance with the degree of negative charge, thereby decreasing or interrupting entirely the discharge current. On the other hand, when a conductor, located between an electron-emitting cathode and an anode, is positively electrified the discharge is assisted and the current increased. Some of the electrons go to the positively charged conductor, but when this conductor has a relatively small obstructing surface, as in the case when a fine filament serves as the grid or other conducting body, very little energy will be absorbed thereby. For example, a tungsten wire having a diameter of about .0004 to .0010 of one inch wound with about 100 turns to the inch may be used but the turns per inch vary widely. When the impressed electromotive force between cathode and anode is high the amount of energy lost by the absorption of electrons by a grid having a relatively low pogitive charge is negligible.

As the grids 7 and 8 are made alternately negative and positive by the alternating source 39, the discharge current, or stream of negative charges, passes in turn to anodes 3 and 4, thereby setting up an alternating current in the primary of the transformer 33, and in that manner repeating in the divided output circuit, acting as the primary of the transformer, with amplified energy the electric waves in the divided input circuit, acting as the secondary of the transformer 39. If desired, a condenser 41 may be provided in order to absorb current variations and to neutralize the inductive effect of the transformer and provide a more rapid rise and fall of current. At any given instant either of input electrodes 7 or 8 will be negatively charged, and being in close proximity to the cathode, will tend to reduce the electron current flowing. However, when a positive field is established in the vicinity of the filament by the grid 6, this grid screens the cathode from the negative field, and assists the flow of electron current, thus making possible the combination of two repeating elements in a single electron discharge apparatus. The electrons are emitted by the cathode at variable speed but all being subject to the same static field which greatly increases the speed of all an equal amount, the differences of speed represent a relatively small fraction of the impressed resultant speed. As the positive field near the cathode opposes the current-reducing effect of the space charge, the distance between the cathode and the anodes may be increased without sacrifice of efficiency.

Some energy is lost by the absorption of the electrons by the positively charged grid 6 but as its surface is small and the positive potential may be made relatively small as compared with the voltage impressed between the cathode and the anodes, this loss will form but a relatively small proportion of the total amount of energy in the output circuit.

It is desirable that the rise of static potential of the grid becoming negative, should be rapid so as to shut off the flow of electron current completely to its corresponding anode. This result can be effected by making the alternating source 39 of high potential but this also increases the positive charge on the companion grid. A high positive grid potential increases the absorption of energy by the grid. By including a battery 75 or other source of potential in the conductor 40 connected to the cathode and an intermediate point of the secondary of the transformer 39, with its negative terminal connected to the transformer, the potential on the grid negatively charged is increased, and the potential on the grid positively charged is diminished, providing, of course, that the potential of the source 75 does not exceed the potential of the source 39. If desired resistances 77, 78, may be included in the grid circuits 37, 38, or these resistances may be replaced by a single resistance in conductor 40 to reduce current flow therein without reducing the potential. In some cases such resistances may make a separate superimposed negative potential unnecessary.

In the system illustrated by Fig. 3, an electron discharge tube is employed to rectify alternating current furnished by the primary of a transformer 42, the terminals of which are connected to the anodes 3 and 4, respectively, by conductors 43 and 44. The conductor 45 of the direct current consumption circuit is connected to the cathode 2 and the conductor 46 of the direct current circuit is connected to a point of intermediate potential upon the secondary of the transformer 42. It will be observed that the electrodes 3 and 4 will be in turn made positive and negative, current passing from the cathode to the positive electrode. Here likewise the electrode which is connected to the opposite terminal of the source, and hence is negative, would act to cut down the current passing from the cathode to the positive electrode. This effect, however, is prevented by the positively charged grid 6. In the case of a rectifier having a plurality of electrodes functioning as anodes, the current-reducing effect of the electrodes when negatively charged is especially marked as the drop of potential in the direct current load will reduce the potential of the positive electrode which is taking current. As no current is flowing to a negative electrode, it will have the full potential of the source. For this reason also the mechanical distortion of the cathode located in the unsymmetrical field would be serious were the positive grid 6 not present, whereby the cathode is screened and protected.

The positively charged body need not necessarily be grid-shaped. Fig. 4 illustrates somewhat diagrammatically a rectifying device in which a plate 47 is located between an electron-emitting cathode 48 and an anode 49. Heating current is supplied the cathode conductor by a battery 50, and a source of energy for example, a transformer 51 is connected between the cathode and the anode. Surrounding the cathode is a concave dished plate 52, which is maintained negatively charged, conveniently by connecting it to the cathode by means of a conductor 53. This ring serves to modify the static field so as to focus the electrons into a fairly well-defined stream which passes through an aperture in the plate 47 to the anode.

By maintaining the plate 47 positively charged, for example, by means of a battery 54, the passage of the electrons from the cathode to the anode is assisted. The potential of the battery 54 and hence the charge on the plate 47, may be only a fraction of the potential between supply conductors 55, 56. The electrons will be attracted to the plate 47 but will largely pass through the aperture in the same as this represents the center of static attraction. By making the potential of the plate 47 relatively low the loss of energy by the absorption of electrons on the part of the plate 47 will be relatively small, and will be more than compensated by the increase in discharge current. The rectified current may be utilized by load devices 57. If it is desired to utilize both half waves of the alternating current, two sets of the devices illustrated are used in any well-known manner, such, for example, as that disclosed in Arsem Patent #920,371, or Alexanderson Patent #998,445.

As indicated in Fig. 5 the positively charged conductor may be used to advantage in a device for amplifying or repeating weak variable currents, such as signals in radio-telegraphy, or telephony. The repeater or electron discharge tube 58 is provided with a local source of energy, for example a battery 59, which may be of very low voltage, and is connected between the cathode 60 and the anode 61. The grid 62 and the cathode 60 are connected to the secondary of a transformer 63, the primary of which is included in the antenna circuit. The latter has as usual an aerial antenna 64, and a grounded condenser 65. The grid 62 may be maintained at a definite potential by a battery 66. The cathode is surrounded by a grid 67, maintained at a perdetermined positive potential with respect to the cathode by a battery 68. When the cathode is heated by a local source of energy 69, a current will tend to flow from the cathode to the anode but this current is either prevented from flowing or is greatly reduced when the field of the grid 62 is negative. As the electrons are drawn away from the cathode 60 by the positive field furnished by the grid 67, a very low voltage may be used in the plate circuit, in fact, I prefer in some cases to use but a single cell for the battery 59, as indicated. A negative potential on the grid 62 on the other hand may be made relatively high. The current variations in the electrode circuit 72 due to the signal impulses impressed upon the grid circuit, are correspondingly great. The signals may be received by a telephone 70, or other suitable receiver, connected in shunt with a condenser 71.

The sensitiveness of this arrangement is especially marked as the electrons leave the grid 67 at substantially uniform velocity and hence are all affected to an equal extent by the variations in the negative charge of the grid 62.

What I claim as new and desire to secure by Letters Patent of the United States is:—

1. A discharge apparatus operating with an electron discharge comprising a highly evacuated envelope, an electron-emitting cathode, an anode, a conductor therein located near the cathode, means for maintaining said conductor at a substantially uniform positive potential with respect to said cathode, and separate means within said envelope for varying the electron discharge between said cathode and anode.

2. An electrical discharge apparatus comprising an electron-emitting cathode, an anode, an envelope therefor, said electrodes and the space in said envelope being freed from gas to a degree permitting a substantially pure electron-discharge to take place therein without gas ionization, a conducting body in said envelope located near the cathode, and a source of potential having its positive terminal connected to said body and its negative terminal directly to the cathode.

3. An electron discharge device comprising a highly evacuated container, a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a conductor located in part at least between said cathode and anode, means for maintaining said conductor at a uniform positive potential with respect to the cathode, and independent means for establishing an electrostatic field to control an electron discharge between cathode and anode.

4. An electrical discharge apparatus comprising an evacuated container, an electron-emitting cathode, a cooperating anode and a conductor in part surrounding the cathode, means for maintaining said conductor at a uniform positive polarity with respect to the cathode, and means for producing a negative charge in the vicinity of said cathode.

5. The combination of an electron discharge device comprising an evacuated container, an electron-emitting cathode, an anode, a conductor coiled about said cathode but spaced apart therefrom, and a source of potential having its positive terminal connected to the said conductor and its negative terminal connected directly to the cathode.

6. The combination of an electron-discharge apparatus comprising a cathode, means for heating said cathode, cooperating anodes located on opposite sides of said cathode, a grid surrounding the cathode but spaced apart therefrom, a source of potential having its positive terminal connected to said grid, grids located respectively between said surrounding grid and the anodes, and a source of alternating potential connected to said intermediate grids.

7. The combination of a discharge device comprising an envelope, an electron-emitting cathode and an anode, a conductor located near said cathode, means for maintaining said conductor at a positive potential with respect to said cathode, a second conductor located near said cathode, and means for maintaining said second conductor at a negative potential with respect to said cathode.

8. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor surrounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said transformer primary, charge-controlling conductors located between said cathode and said anode, and means for charging said conductors alternately negative and positive.

9. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor

surrounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said tranformer primary, charge-controlling conductors located between said cathode and said anodes, a source of alternating current connected to said charge-controlling conductors and a source of direct current connected at the positive terminal to said cathode and at the negative terminal to a point of intermediate potential on said alternating current source.

10. The combination with an electron discharge device comprising a cathode and a pair of input electrodes enclosed in an evacuated envelope, a transformer secondary having its terminals connected to said input electrodes, a source of direct current having its positive terminal connected to said cathode and its negative terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

11. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence and a pair of input electrodes enclosed in an evacuated envelope of a transformer secondary having its terminals connected to said input electrodes, a source of direct current having one terminal connected to said cathode and its other terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

12. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence, a pair of anodes and a pair of input electrodes enclosed in an evacuated receptacle, said input electrodes being located between said cathode and said anodes, means for maintaining both of said input electrodes normally at a definite potential with respect to said cathode which is different than that of the cathode, and means for charging said input electrodes alternately negative and positive.

13. An electron-discharge device comprising an evacuated vessel containing a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a discharge controlling electrode and a fourth electrode near said cathode, means for producing a current between said cathode and said anode, and means for maintaining said fourth electrode at a definite potential with respect to said cathode.

14. A device of the audion type comprising a thermionic cathode, an anode and an auxiliary electrode, means for supporting said auxiliary electrode, said cathode being filamentary in form, and a planary supporting frame therefor parallel to one of said electrodes and comprising spaced parallel members.

15. Parallel supporting members, and a filamentary thermionic cathode insulatingly supported at a plurality of points thereby, a grid frame at each side of said cathode, and an arbor for supporting said members and said frames.

16. A device of the audion type comprising parallel grids, a support therebetween comprising spaced parallel members, and a cathode extending between said members and supported thereby.

17. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

18. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a positive potential with respect to the cathode, means for maintaining the grid nearest the anode at a negative potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

19. The combination of an electron discharge device comprising an electron emitting cathode, an anode, and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, means for varying the potential of the grid nearest the anode with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that impressed upon the grid nearest the cathode.

20. The combination of an electron discharge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, and means for varying the potential of the other grid with respect to the cathode.

21. The combination of an electron dis-

charge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, means for varying the potential of the other grid with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that at which the first of said grids is maintained.

22. An evacuated vessel containing a filament electrode and a cold electrode, a second cold electrode located between the filament and the first cold electrode, and a third cold electrode located between the filament and second cold electrode.

23. An evacuated vessel containing a filament electrode and a plate electrode, a grid electrode interposed between the filament and the plate electrode, and a second grid electrode interposed between the first grid electrode and the filament.

24. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode surrounding said cathode and a second grid electrode outside of said first grid electrode, a stem through which leading-in conductors for at least two of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

25. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

26. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, and a support of insulating material within said vessel for supporting all of said electrodes.

27. An electron discharge device comprising an electron emitting cathode, an anode, a pair of grid electrodes located in different planes between said cathode and said anode, an evacuated vessel, and a support of insulating material for supporting the cathode and grid electrodes in desired spaced relation within said vessel.

28. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids located in different planes and successively passed by the electron stream.

29. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids which are successively passed by the electron stream.

30. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container, and supporting means for supporting all of said electrodes from a single point in said container.

31. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container and supporting means for supporting all of said electrodes from a single point in said container, said supporting means being arranged to insulate all of said electrodes from one another.

32. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting a plurality of said electrodes from said stem.

33. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting all of said electrodes from said stem.

In witness whereof, I have hereunto set my hand this 27th day of October 1918.

IRVING LANGMUIR.

PLAINTIFF'S EXHIBIT No. 216.

Nicolson Note Book.

(Not printed in full.)

PLAINTIFF'S EXHIBIT No. 216-A.
Certain Pages of Nicolson Note Book.

55

N4.
Test. 2a.

Fil. heat A. 0.72 @ 12.5 Job

Relative distance at 42 Volts (Saturation)

Filament No 1 to Grid 1/4"(+) #2 1260
— — to Fil. No 3 (broken) 0
to Fil. No 2 (cool) 500
to Grid No 3 (1/2") 1320
to plate Anode 1300
to Fila. No 2. (incand) 1000
but this is due to say 10 volts in incandescent circuit
to Fila No 2 (cool) +10 V (B) = say 900

∴ incandescent no advantage

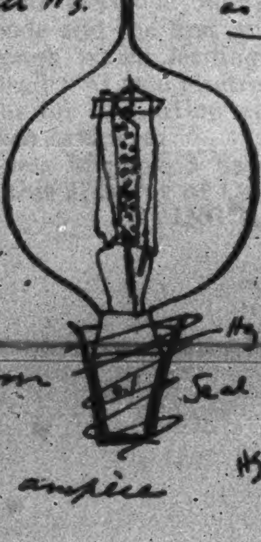
"N 4"
Test 3

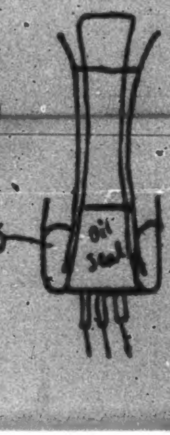
Using both filaments with varying anodes (grid):—
Grid No 3 (1/2") gave a greater deflection than to anode
(The filament No 1 broke several times — after leaving its support)

N5. same as tube N3.

Same anode as in N.3.

Platinum Strip Filaments (Two)
65 mm. × 0·3 mm. × 0·05 mm
covered with the
Ca O Cream #4 (?)
as made by Mr. Hull.
evacuated to highest vacuum
by Molecular pump at
9 a.m. flashed to 2·35 ampere

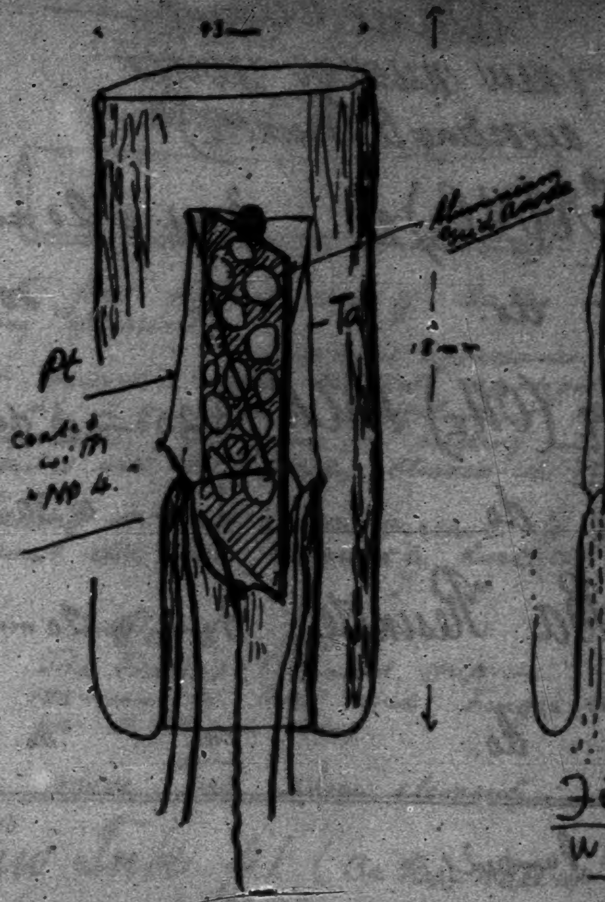


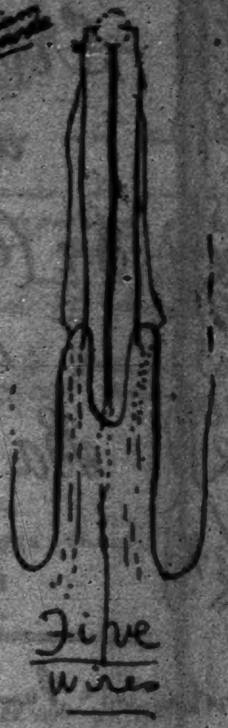


May 7th 1913

N 6.

Comparison of Ta. & Pt. (coated with #4) Filaments


13 mm
Aluminium Grid Anode
Ta
18 mm
Pt
coated with No 4.



Dimensions

Anode (perforated) } – Aluminium – 62 mm × 30 mm × 8 mm
– Ten perforations ca. 0·9 cm diameter.

Cathodes Ta . . . 10.3 80 mm × mm

Pt (coated)* . . . 1.04 78 mm × 0·3 mm × 0·05 mm

Distance betw: do: Minimum from Grid (anode) Ta: 7 mm
Pt: 9.3 mm

Vacuum: Molecular Pump. Highly evacuated

* Wehnelt coating: No. 4. is a creamy paste of CaO

Flashing { Pt: 1·5 amp.; run at 15–19 Volt:
Ta: 30 Volt; " " $1\frac{1}{2}$ – 2·4 Amps.

See Page 65

Aug. 5. 1913

New Tubes

– Three Element –

(new number series according to Trimble)

			Mr. Trimble:
N26 #~~19~~	$Sr(NO_3)_2$	3 amp. @ 20 min	Flashed
N27 #~~20~~	do.	do. do.	@
N28 #~~21~~	$Sr(OH_2) + KOH$	3.25 amp @ do.	
N29 # [illegible]	do.	3 amp @ 30 min	2 amps
N30 #~~22~~	Ba Resinate	3 amp @ 20 min	in
N31 #~~23~~ X	do.	do. do.	Medium Vacuum

#31 Broken in Pumping.

(Note Plain numbers are Mr. Trimble's)

N26 (19)	1	Ba Res.	3 Amps. 20 min.
N30 (22)	1	Ba Res	(see p. 129)
N31 (23)	1	$Sr(NO_3)_2$	do. } developed as resistance on Evacuation

(some of NO_3 got into Pt joint)

See Note page 135

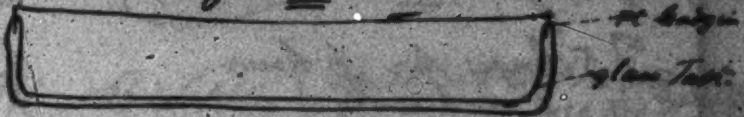
October 4th. 1913

Commencement of Construction of Filament A & B & C 136 Ω

Manufacture of 15" Length Pt. Coated Ba Res. Filament

0·3 mm × 0·05 mm

Length "A"



Covered with five separate coats of Ba Res. in the heating and cooling operations.

Filament appearance is uniformly black and smooth; after a total operation of about one hour at 2·4 amperes the filament was placed in a desiccator, put away for cutting into 4 lengths. Tested with HCl, duly cleaned the Pt. bright.

Turning on and off the current in filament several times did not apparently hurt the coating.

Oct 6. 1913

The Finished Filament Strip:–

Exposed 100 mm to Air and Finger touch for 2 hours (ca.) and made into three element:–

* New Tube 41 (Ba Res "made up") 3 elements (Bk. 36 / 47)

Burned on flashing @ 1·9 amps ⊤

* New Tube 42 (90. & covered with KOH) ⊤ see page 137 and heated to 2 amps for 5 minutes.

(KOH, because the clamping ends have to be cleaned of oxide by HCl acid and alkali is required to remove acid; it is then thoroughly washed & dried in blotting paper, washed again).

* New Tube ~~A~~ 381 (straight from Desiccator) and heated at 2 amps in air for 5 minutes. 3 elements (Bk 36. 56)

Above Lamps "flashed" in vacuo at 1·9 amps

5
9 ~~August~~ October 1913

Exp. 4.

Nickel Filament

Made-up Length (F). 15° Coat 9:- { Ni - BaRe well coated

2.5 Amps for ½ hour.

[New Filaments C, D, F see page 138]

New Tubes & Pt Filaments C, D, F

Bk 20. 195

# 43 Tantalum Pt - $Sr(OH)_2$ (Length C) } with #42 see p. 137 } { 1.5 Amp: for 20 min. on Molecular Pump

# 44 Bk. 20. 195 do do

# 45 ditto do do } 1.75 amps for 20 minutes

# 46 do do do } SEE Book 36 - P 62 64

# 47 do do do

# 48 Pt - { BaRes $Ba(NO_3)_2$ } Length D } ditto amps See Book 36 - Page 60 (weak spot)

# ~~49~~ do do } do (Broken point in) Filament do do

# ~~50~~ do do

# 51 SEE Book 36 P 61 do do } Bk 36 p 61. Flashed ~~at high temp~~ Phosph not used

# ~~52~~ do do } Broke Fil. (Phosph)

# 53 Ni - BaRes. F2 Bk 36 p 65 } 1.7 amps & sealed off without Phosph.

11 Oct 1913
140

New Tubes & Filaments

E, G, Burned @ 1·75 Amp for

#54 Pt-Ba ~~(NO3)~~ Res + KOH } Bk 36 p. 67 Length (E.)

#55 do Bk 36 p. 67 do

#56 Burned out Oct. 21 13 WNT do Bk 36 p. 66 do

#57 ✓ Bk 36 p. 66 Pt - Ba$(NO_3)_2$ } with Cu & #61. 1·8 Amp @ 60 Volts, no B.H. Tried Res P., did no good.

~~#58~~ do } Length (G)

~~#59~~ do } with #65 Burned out at 1·8 Am. No B.H.

Exp V
Length (H) 1, 2, 3.

Saturday - Monday

Pt-Ba Res
(H1) 70 mm dipped in HCl, washed in KOH & H_2O
(H2) 70 " Left in KOH (#60)
(H3) 70 " Left in H_2O → (#61)

13th Oct.

(H₂) was not apparently affected
(H₃) " " " but H_2O contained a whitish sediment.

#60 ✓ Pt-Ba Res Washed off with HCl (see H1) Bk 36 p. 66 } 0.9 Amp

~~#61~~ do after 48 hours in H_2O (see H3) (?damaged filament?) @ 1·75 amp } Length H.

~~#62~~ do untouched

#63 Pt. Ba Res for Peirce (with #48)

{ on Pump, on Gauge, on 100 Volts, @ 1·75 } Blue Haze cleared out ~~after~~ for 20 min.

Retubulated & evacuated at with Gaede & Liquid Air

Bk 20 p. 197

PLAINTIFF'S EXHIBIT No. 217.

L. DE FOREST.
OSCILLATION GENERATOR.
APPLICATION FILED DEC. 28, 1915.

1,201,273. Patented Oct. 17, 1916.

Fig. 1.

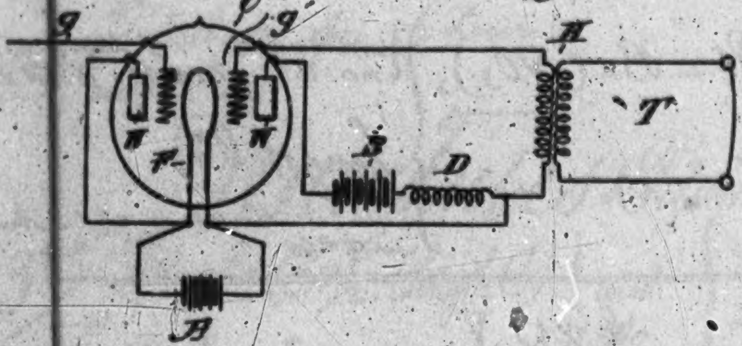
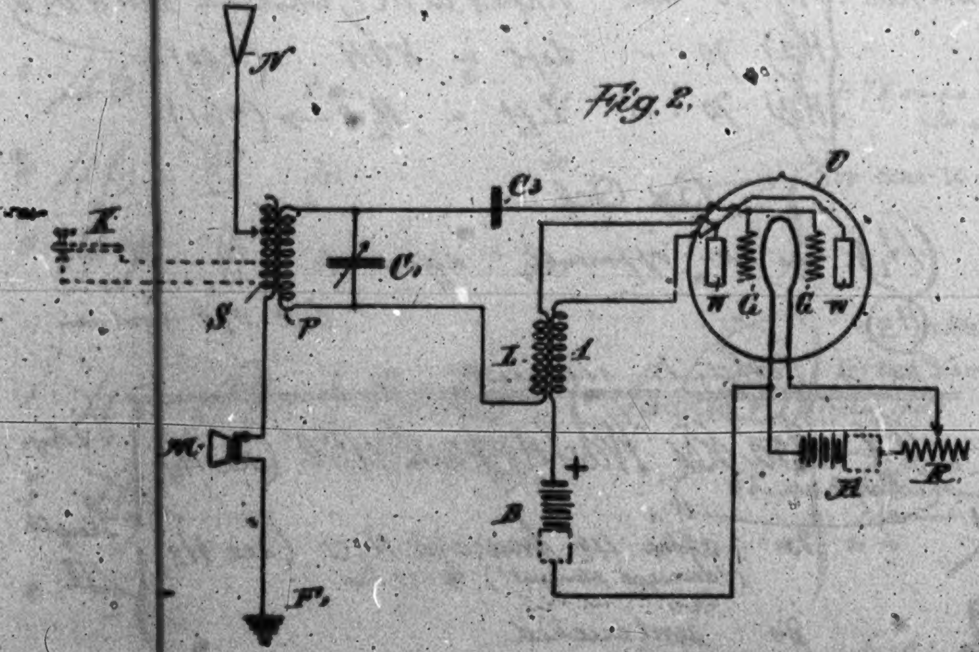

g
V'
g'
H
T
W
F
W
B
D
B

Fig. 2.


N
K
C3
C1
S
P
V
L
I
W
G
G
W
M
+
B
A
R
F'

Lee de Forest Inventor
By his Attorney Samuel E. Darby

UNITED STATES PATENT OFFICE.

LEE DE FOREST, OF NEW YORK, N. Y., ASSIGNOR TO DE FOREST RADIO TELEPHONE AND TELEGRAPH COMPANY, OF NEW YORK, N. Y., A CORPORATION OF DELAWARE.

OSCILLATION-GENERATOR.

1,201,273. Specification of Letters Patent. Patented Oct. 17, 1916.

Original application filed May 13, 1915, Serial No. 27,771. Divided and this application filed December 28, 1915. Serial No. 68,967.

To all whom it may concern:

Be it known that I, LEE DE FOREST, a citizen of the United States, residing at New York city, county of Bronx, State of New York, have made a certain new and useful Invention in Oscillation-Generators, of which the following is a specification.

This invention relates to generators of oscillating, or pulsating currents and embodies subject matter divided from my application Serial No. 27,771, filed May 13, 1915.

The object of the invention is to provide a generator of oscillating, alternating or pulsating electric currents which is simple and efficient.

A further object is to provide an oscillation generator of the character referred to capable of generating oscillating, alternating or pulsating electric currents of substantially uniform amplitude.

Other objects of the invention will appear more fully hereinafter.

The invention consists substantially in the construction, combination, location and relative arrangement of parts, all as will be more fully hereinafter set forth, as shown in the accompanying drawing and finally pointed out in the appended claims.

Referring to the drawing: Figure 1 is a circuit diagram showing an arrangement of generator of continuous, oscillating, alternating or pulsating currents embodying my invention. Fig. 2 is a similar view showing a modified arrangement of oscillating generator embodying my invention as applied for use in connection with radio systems.

In carrying out my invention I employ a closed and preferably, evacuated vessel or bulb in which are located cold and hot electrodes, and I provide suitable circuit connections and current supply source to said electrodes, and where the generator is employed in connection with radio systems I associate the generator with a suitable radiating system having means connected thereto or associated therewith for altering or modifying the radiations from the system either manually, as through a telegraph key, or otherwise, as for instance, a telephone transmitter, in accordance with signal code or sound waves.

Referring to Fig. 1, U designates the evacuated vessel or bulb. Located within this vessel or bulb is a hot electrode F, which, in the form shown, is a filament and also located within the evacuated vessel U are the cold electrodes *g* and W. To the filament or glower electrode F current is supplied from any convenient source as indicated at X, which source may be a battery or a direct current generator. Where an alternating current generator is employed the frequency thereof for wireless telephone operation, should be above that of the essential frequencies of voice sounds, say for instance, fifteen hundred cycles per second, or higher. For wireless telegraph work the frequency of the generator may be very much lower, say, for example, five hundred cycles per second.

In the particular form shown but to which my invention is not to be limited or restricted, I employ two cold electrodes W in the form of plates or wings, and one cold electrode *g* in the form of a grid and I have shown the grid electrode *g* positioned between the hot electrode F and one of the cold plate or wing elements W. A circuit has one of its terminals connected to the cold grid electrode W. This connection including a source of current B to an inductance coil D. This circuit connection of electrodes *g* and W is also connected to one side or terminal of hot electrode F. The other cold plate or wing electrode W is shown connected to the other side or terminal of the hot electrode F. If desired, the circuit connection between the cold electrodes *g* and W may be suitably associated with a telephone indicated at T. This association may be accomplished through a transformer H or other suitable form of coupling.

Referring to Fig. 2, I have shown the

evacuated vessel or bulb U having two cold plate or wing electrodes A, in electrical connection with each other and two cold grid electrodes G in electrical connection with each other. The two cold plate or wing electrodes having a circuit connection to one side or terminal of the hot electrode F, which circuit connection includes an inductance coil *l*, and a source of current supply indicated at B, the positive side of which is connected to the cold plate or wing electrodes W and the negative side to one terminal of the hot electrode F. In this instance the circuit connection between the cold grid electrodes G, and the cold plate or wing electrodes W, includes a blocking condenser, indicated at C_2. Connected across this circuit is a variable capacity C_1, and included in said circuit is an inductance coil P, which constitutes, in the form shown, a coupling member in association with a coil S, in the antenna earth system N, E, the coupling being preferably a loose coupling. Where the apparatus is to be used for telephoning purposes the antenna has associated therewith or includes therein a microphone transmitter M. Where the apparatus is to be used for telegraphic communication a Morse telegraph key K is bridged across a portion of the inductance S. If desired the grid and plate circuit may be inductively associated with the plate and filament circuit through inductance L as shown. It is obvious that the current supply to the hot electrode F, or to the circuit connection of cold plate or wing electrodes W, may be controlled in any suitable or convenient manner, as for instance, by the adjustable resistance R.

By reason of the arrangements above described and the ionizing of the gas in the evacuated vessel or bulb U due to the presence within said vessel of the hot or glower electrode F, and by impressing an electromotive force within the space between the cold plate or wing electrodes W and the hot electrode from the current source B, the device U, with its electrodes and their associated circuits and circuit connections as described becomes a generator of oscillating, alternating or pulsating electric currents which are impressed upon the circuit which connects the grid and plate electrodes, the frequency of which depends upon the condition of the gas within the vessel U, the spatial relation of the electrode member contained therein, the value of the electromotive force impressed across the electrodes, and the amount of inductance and capacity in or associated with the circuit connection between the cold electrodes. This frequency may be varied by adjusting the capacity or inductance in said circuit connection.

By reason of the association of the oscillating circuit connecting the cold electrodes with the antenna earth system N E the oscillating, alternating or pulsating currents in said circuit connection are impressed upon said antenna earth system and with a natural period of oscillation in said circuit, the same as that in said oscillating circuit. The emission of wave trains from the antenna earth system may be controlled in accordance with the telegraphic code through the telegraph key K, which acts to short circuit a portion of the inductance S. Or, if desired, the amplitude of the oscillations induced in the antenna earth system may be varied by and in accordance with sound waves falling upon the microphone transmitter M in the usual manner. It is obvious that the wave length of the emitted wave trains may be altered in a manner well understood in the art.

I am unable at the present time to give a wholly satisfactory explanation of the theory of the generator action of the apparatus. I have discovered, however, as hereinbefore stated that a system constructed as shown and described and energized from a suitable current source becomes the seat of continuous oscillations and it is my opinion that the phenomenon depends upon the inductive effect of successively applied charges or surges of potential upon the grid and plate electrodes which charges or surges have the power to affect momentarily the conductivity of the surrounding or inter-connecting gas medium within the vessel in such manner that the action, when set up, is self perpetuating.

From the foregoing description it will be observed that in its broad scope my invention lies in the discovery that when suitably connected and associated an audion becomes a generator of oscillating, alternating, or pulsating electric currents which may be utilized for any purpose for which such currents are desired, and I have succeeded in securing remarkable results in the practical use and operation of an oscillation generator of this character particularly when applied to the generator of high frequency oscillations.

It is obvious that the principles of my invention may be embodied in various arrangements and circuit connections without departure from the spirit and scope of my invention as defined in the claims, but

Having now set forth the objects and nature of my invention and circuit arrangements embodying the principles thereof, what I claim as new and useful and of my own invention, and desire to secure by Letters Patent, is—

1. The combination with an evacuated vessel, of a plurality of wing elements; a

plurality of grid elements, and a hot electrode arranged therein, a grid element being arranged between each wing element and the hot electrode.

2. An audion having a plurality of grid electrodes, a plurality of wing electrodes, and a hot electrode.

3. An audion having a plurality of grid electrodes, a plurality of wing electrodes, and a hot electrode, a grid electrode being interposed between each wing electrode and the hot electrode.

In testimony whereof I have hereunto set my hand in the presence of the subscribing witnesses, on this 21st day of December, A. D., 1915.

LEE DE FOREST.

PLAINTIFF'S EXHIBIT No. 215.

Certain Pages of Book of O. W. Richardson, entitled "The Emission of Electricity from Hot Bodies."

welded or hard soldered to platinum wires sealed into the glass bulb D. A lies on the axis of a cylindrical electrode E of metal foil, or, preferably, gauze supported by the sealed-in lead F. The tube H enables the bulb to be exhausted and sealed off or connected to the apparatus for supplying various gases, measuring the pressure, etc. The precise construction of such a bulb depends on the nature of the substance A experimented with. If A is a platinum wire then all the metal parts inside the bulb are best made entirely of platinum. The whole apparatus can then be thoroughly cleaned with boiling nitric acid and distilled water. Tungsten filaments require to be electrically welded, in an atmosphere of hydrogen, to the stout leads which may be of iron or copper. Carbon filaments have to be joined with paste as in constructing incandescent lamps. Most other materials are to be welded to the supports if possible, otherwise hard soldering may be employed. In experiments of this character it is often of the utmost importance not merely to secure the chemical purity of the materials used, but to make sure that not even the smallest traces of gases are liberated in the bulb during the course of the experiments. The best way of accomplishing this is to heat the tube D to a high temperature whilst it is exhausted by a Gaede pump, assisted by a liquid air and charcoal condenser. Meanwhile the wire A is glowed out electrically, and, in order to drive every trace of gas out of the cylindrical electrode E, it is desirable that this should be heavily bombarded by cathode rays, obtained by applying a high negative potential to A. To maintain the tube D at a high temperature without its collapsing under the external pressure during the exhaustion, it should be heated in a vacuum furnace. A suitable form of furnace may be constructed with a heavy water jacketed brass base provided with holes for the tube H and the leads B, C, and F. The holes can be made airtight with glass and seal-

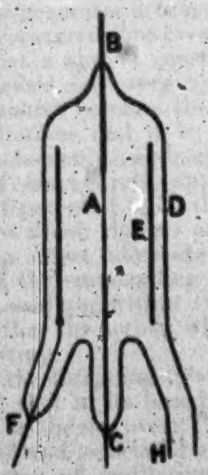


Fig. 1.

ing-wax, and an additional hole for the insertion of a platinum thermometer or thermocouple is desirable. On the base rests a large cylindrical brass bell jar, the line of contact being made airtight with a rubber gasket. The brass cylinder is balanced by weights attached to ropes passing over pulleys so that it can easily be moved up and down. The furnace itself is inside the brass cylinder, and rigidly attached to it. It consists, starting from the inside, of a vertical cylinder of some non-oxidizable metal such as monel metal or nickel; this is insulated by a layer of mica, over which is a winding of nichrome strip having a suitable resistance and current-carrying capacity. Between the nichrome winding and the outer brass cylinder is a thick packing of fireclay and asbestos. The leads to the nichrome strip and the exhaust can be let in through the cover of the brass cylinder. This, as well as the brass base, should be water cooled. With such an arrangement, with the furnace exhausted to a pressure of about 1 cm., the experimental bulbs can be exhausted for several days at a temperature of about 570° C. without collapsing. A vacuum furnace of this type in actual operation is shown in Fig. 2.

Many experiments can be made without taking these elaborate precautions, but we shall see later[1] that if we wish to be sure of obtaining the effects which are characteristic of the pure metals in the absence of a gaseous atmosphere we cannot afford to dispense with the manipulation just described.

Almost all the phenomena under consideration are very sensitive to small changes in temperature; so that even when it is not necessary to know the actual temperature of the filament A it is essential that it should not vary. A very sensitive temperature control is provided by a method which involves the measurement of the resistance of the filament. For this purpose, in carrying out the experiments, the filament is made to form one arm of a Wheatstone's bridge which is actuated by the battery supplying the heating current. The arrangement of apparatus for measuring the thermionic current which flows from the filament A to the cylinder E is shown diagrammatically in Fig. 3. K, L, and M are the three other resistances which form the arms of the Wheatstone's bridge,

---

[1] See chaps. III. and IV.

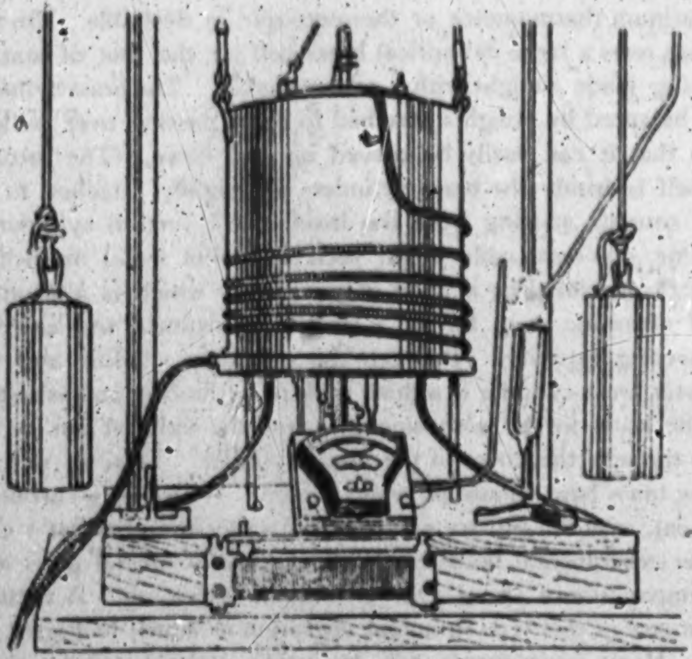


FIG. 2.

the bridge galvanometer G being provided with the key N.

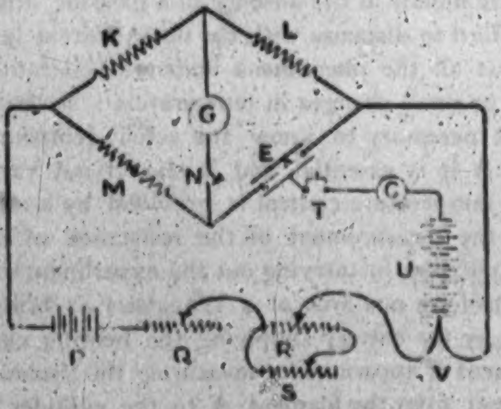


FIG. 3.

The main heating current is supplied by the battery P and to eliminate traces of gas from apparatus containing ground glass joints; so that this type of apparatus is useful only when the effects of such traces of gas are relatively unimportant.

A convenient arrangement for making rapid qualitative tests of the sign of the ions emitted by hot wires has recently been described by Hopwood.[1] This consists in bringing an electrically-charged rod near a long loop of the electrically-heated wire which is connected to earth. The loop will only be deflected provided it does not emit ions of the sign opposite to the charge on the rod.

RELATION BETWEEN THE CURRENTS AND ELECTRO-MOTIVE FORCE AND GAS PRESSURE.

The first experimental investigation of this question was made by McClelland[2] with an arrangement similar to Fig. 1 in its main features. In all these experiments the temperature of the filament is kept constant and the general character of the results to be described is independent of the nature of the material used, provided that the filaments have been heated for a considerable length of time (see pp. 60 and 182). At pressures comparable with atmospheric the relation between the current and the difference of potential maintained between the filament and the cylinder is similar to the left-hand half of the curve shown in Fig. 4, although this figure actually refers to another case. With low voltages the current is proportional to the applied potential difference, but as the potential difference increases, the rate of increase of the current gradually falls off until finally saturation is attained. There is thus a definite limit to the number of ions liberated by the glowing filament in unit time. In air at low temperatures this description applies only when the filament is positively charged; there is no appreciable current when the wire is charged negatively. At higher temperatures similar results are obtained whether the filament is charged positively or negatively, the ratio between the saturation current with the wire negative and that with the wire positive increasing continuously with rising temperature. In these respects the observations agree with the earlier experiments described on page 3.

---

[1] "Phil. Mag.," Vol. XXIX, p. 362 (1915).

[2] "Camb. Phil. Proc.," Vol. XVI, p. 296 (1901).

With pressures of the order of 1 millimetre of mercury the current-E.M.F. curves were found to be entirely different. With the filament negatively charged there was no indication of saturation. The current in general increased more rapidly than the first power of the potential difference. The effects observed with a *positively* charged wire at these pressures are exhibited in Fig. 4. which actually refers to this case. At intermediate voltages there is evidence of saturation, but this stage is succeeded by a stage in which the current again increases with rising potential difference.

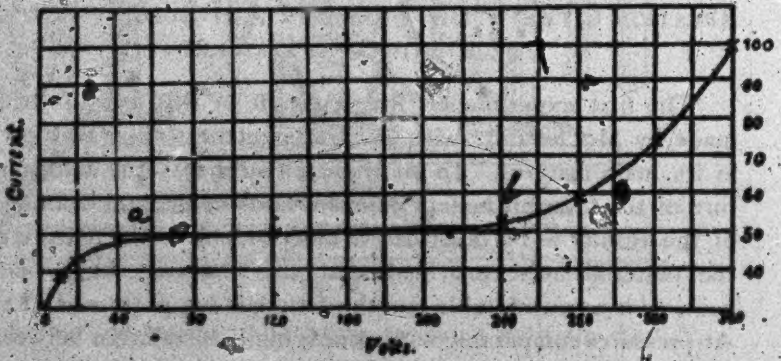


Fig. 4.

McClelland showed that these phenomena could be explained in a general way on the hypothesis that the ions liberated at or near the surface of the filament were able, under the accelerating influence of the electric field, to produce new ions by impact with the neutral molecules with which they collided. In the case of the positive ions this increase in the current due to ionization by impact did not begin to make itself felt, in the example shown in Fig. 4, until there was a difference of potential of over 200 volts between the electrodes. The existence of saturation with lower potentials showed that all the ions initially liberated were being collected by the cylinder, and, as the current was independent of the electromotive force in this region, there was no additional current depending on the energy of the impacts. The absence of saturation with the currents from the negatively charged wire makes it necessary to suppose that ionization by collision sets in before the stage at which saturation is reached. Thus the part *a*, *b* of the curve in Fig. 4 is missing when the wires are charged negatively. Another consequence of this interpretation is that ionization by impact is effective with a smaller fall of potential for negative than for positive ions. The hypothesis of ionization by impact had previously been put forward by Townsend and J. J. Thomson to account for somewhat similar phenomena exhibited by other sources of ionization. McClelland's experiments seem, however, to have first indicated definitely that positive ions could give rise to new ions by collision.

A more detailed examination of the relation between current, pressure, and electromotive force with negatively charged wires has been made by H. A. Wilson.[1] Some of the results obtained by Wilson at pressures ranging from 0·0036 mm. to 760 mm. are shown in Figs. 5 and 6. If the increase of current beyond the horizontal line corresponding to the lowest pressure (0·0036 mm.) is due to ionization by collision, Wilson showed that, according to Townsend's theory,

$$\log n_b/n_a = \frac{V}{E \log b/a}\left\{e^{-(NEpa/V)\log b/a} - e^{-(NEpb/V)\log b/a}\right\} \qquad (7)$$

provided $V/pa \log b/a$ is greater than 200. In this equation n_b is the number of negative ions which reach the cylinder in unit time, n_a is the number emitted by the hot wire (of circular section) in the same time, V is the applied potential difference, p the gas pressure, b the radius of the cylinder, a that of the wire, N the number of ionizing impacts per moving ion per cm., and E the potential fall necessary to acquire the ionizing energy (ionizing potential). This formula was found to represent the experimental results satisfactorily, with N = 3·04 and E = 17·7 (volts). The values of the constants are in satisfactory agreement with those deduced by Townsend from experiments with ionized air at ordinary temperatures, when allowance is made for the difference in the number of molecules in unit volume of a gas at a definite pressure due to change in temperature. The results point to the rather important conclusion that ionization by impact depends solely on the nature of the molecules, and their distance apart, and has nothing directly to do with the temperature of the gas.

---

[1] "Phil. Trans., A.," Vol. CCII, p. 243 (1903).

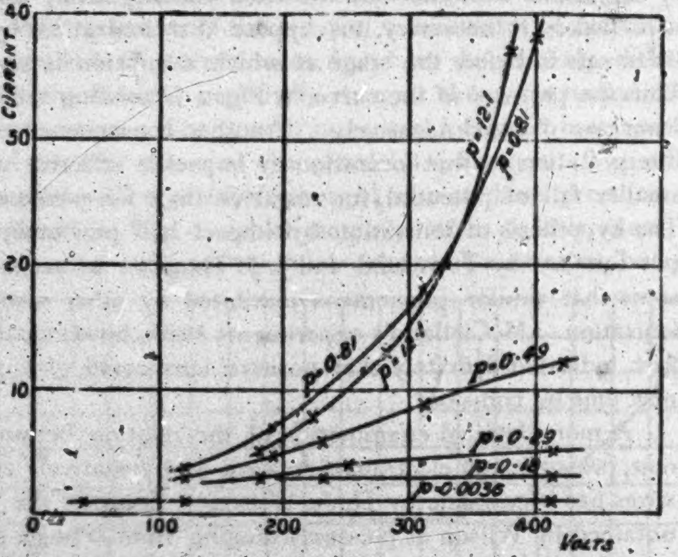


FIG. 5.

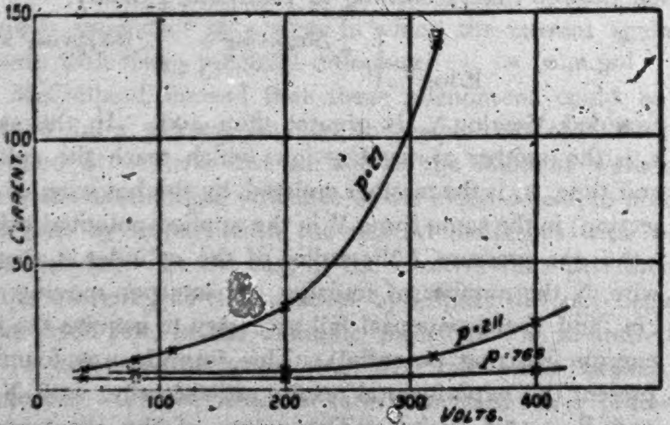


FIG. 6.

In this experiment the temperature must have been about the same as in the case to which Fig. 10 refers. The pressure is given as less than 0·001 mm. It will be seen that there is here no perceptible increase in the current between 25 and 180 volts.

It is only when the thermionic current densities are comparatively small that saturation is attainable with potential differences of 20 volts or under. With the large emissions which occur at very high temperatures the potential difference required for saturation may be very much higher owing to the mutual repulsion of the emitted electrons. This leads to an interesting effect which was discovered and explained by Langmuir.[1] In examining the thermionic current between two hairpin-shaped tungsten filaments, under fixed differences of potential, at various temperatures, the results exhibited in Fig. 11 were obtained. The experimental values lie along the broken curves, the continuous curve representing the saturation current at different temperatures. It will be noticed that the broken curves coincide with the continuous curve up to a certain temperature which is lower the smaller the applied potential difference. Beyond this point the currents are below the saturation value, but they still increase with increasing temperatures of the filament. At still higher temperatures the broken curves bend round, and the current under a given potential difference becomes entirely independent of the temperature of the hot filament. Owing to the mutual repulsion of the electrons a given difference of potential applied over given boundaries is only capable of forcing a definite number of electrons across the intervening space in unit time, no matter how many may be available.

In order more clearly to see how this comes about let us consider the simplest possible case, that of an emitting plane opposite a parallel conducting plane which represents the receiving electrode. Take the axis of x perpendicular to the planes and let V be the electrostatic potential at any point. Then the value of V is governed by Poisson's equation which reduces to

$$\frac{d^2V}{dx^2} = -4\pi\rho \qquad (7)$$

---

[1] "Phys. Rev.," Vol. II, p. 453 (1913).

ρ being the volume density of electricity at any point:

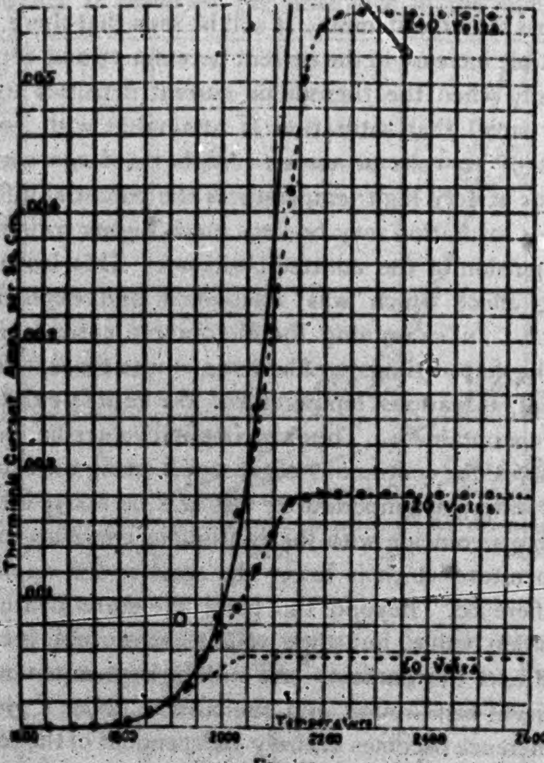


Fig. 11.

When there are no electrons emitted ρ is zero at every point;

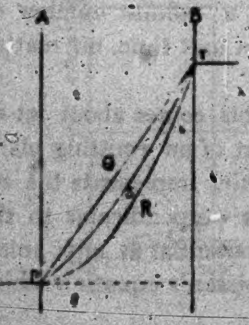


Fig. 12.

so that $\frac{dV}{dx}$ is constant and may be represented by the straight line PQT in Fig. 12. When the plate is emitting electrons these will give rise to a negative value of ρ in the space as they cross it, and if the number is small, the value of ρ thus arising will be approximately independent of x; so that the right-hand side of (7) will be a positive constant and the graph of V will be approximately parabolic and similar to PST. As he current and $-\rho$ increase this curve will sink below PQT until the stage PRT is reached, where the tangent at P is horizontal. Any further increase in the supply of electrons will now have no effect on the distribution of potential between the plates because there is nothing to drag them away from AP. We here assume that the emission velocities of the electrons are small compared with those which they acquire under the influence of the field; so that the results will only be true for fairly large potential differences (see Chapter V).

Now let us see how the current will depend on the applied potential when the condition that $\frac{dV}{dx}$ vanishes at the hot plate is satisfied. Let $+ e_1$ denote the numerical value of the negative charge of an electron and $+ \rho_1$ the numerical value of the negative density of charge at any point. An electron at a point when the potential is V (if $V = 0$ at the hot plate) will have acquired an amount of kinetic energy given by the equation

$$\tfrac{1}{2} mv^2 = Ve_1 \quad . \quad . \quad . \quad . \quad (8)$$

The current per unit area carried by the electrons at that point will be

$$i = v\rho_1 \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and equation (7) may be written

$$\frac{d^2V}{dx^2} = 4\pi\rho_1 \quad . \quad . \quad . \quad . \quad . \quad (10)$$

By elimination of ρ and v from (8), (9), and (10)

$$\frac{d^2V}{dx^2} = 2\pi i\sqrt{\frac{2m}{e_1 V}}$$

and integrating, subject to $\frac{dV}{dx} = 0$ when $V = 0$,

$$\left(\frac{dV}{dx}\right)^2 = 8\pi i\sqrt{\frac{2mV}{e_1}} \quad . \quad . \quad . \quad . \quad (11)$$

By integrating again, subject to $V = 0$ when $x = 0$, and solving for i we find

$$i = \frac{\sqrt{2}}{9\pi}\sqrt{\frac{e_1}{m}}\,\frac{V^{3/2}}{x^2} \quad . \quad . \quad . \quad (12)$$

The same general method of treatment with the appropriate modification of Poisson's equation can be applied to the case of a circular wire surrounded by a coaxial cylinder, giving

$$i = \frac{2\sqrt{2}}{9}\sqrt{\frac{e_1}{m}}\frac{V^{3/2}}{r\beta^2} \quad . \quad . \quad (13)$$

when r is the radius of the cylinder, and

$$\beta = \log\frac{r}{a} - \frac{2}{3}\left(\log\frac{r}{a}\right)^2 + \frac{11}{120}\left(\log\frac{r}{a}\right)^3$$

$$- \frac{47}{3300}\left(\log\frac{r}{a}\right)^4 + \ldots,$$

a being the radius of the wire. In fact Langmuir[1] has shown from a consideration of the dimensions of the equations that, whatever may be the geometrical relation between the emitting and receiving electrode, the current under these circumstances will be equal to $V^{3/2}$ multiplied by a factor depending on e_1/m and the geometry of the system.

It appears then that over the flat part of the broken curves in Fig. 11 the current should be proportional to $V^{3/2}$. This requirement is found to be borne out by the experimental results; so that there can be no doubt of the adequacy of the foregoing explanation. Langmuir has suggested that experiments with concentric cylinders using equation (13) could be made so as to determine the value of e_1/m with great precision.

The effect of the mutual repulsion of the electrons in preventing the attainment of saturation will be important only when the saturation currents are of considerable magnitude; with sufficiently small currents this effect will vanish. We shall see in Chapter V that the electrons are emitted, not with zero velocity, but with a distribution of velocities whose mean square is proportional to the absolute temperature of the hot body. At 2000° K. this mean velocity is comparable with that which an electron would acquire by falling through a potential difference of about 0·25 volt. At relatively low temperatures when the emission is comparatively small, if the hot body is surrounded by the receiving electrode, we should expect saturation to be attained without the application of any potential difference; since all the electrons are emitted with some velocity, and any velocity, however small, will be sufficient to carry them across to the electrode ultimately. This supposition does not accord with the facts as observed in experiments with electrically heated wires surrounded by coaxial cylindrical electrodes. Under these conditions it is the writer's experience that potential differences comparable with two or three volts are required to cause saturation even when dealing with the smallest currents which are convenient to measure. There can be very little doubt that in these cases one cause operating against the attainment of saturation is the effect of the magnetic field, due to the heating current, on the motion of the electrons.

---

[1] Loc. cit.

To see how this comes about consider the case of a hot wire, of circular section and radius *a*, surrounded by a coaxial cylindrical electrode of radius *b*. Let V_1 be the potential difference in volts between the wire and the cylinder. The electric intensity R is everywhere radial and at distance *r* from the axis is given in electro-magnetic units by

$$R = V_1 \times 10^8/r \log b/a = A/r \quad . \quad . \quad (14)$$

The magnetic intensity H lies in circles about the axis of the wire, and, if *j* is the current in amperes, its value at distance *r* is

$$H = 2j/10r = B/r \quad . \quad . \quad . \quad . \quad (15)$$

On account of its direction the magnetic field will not affect the angular velocity of the electrons about the axis. Disregarding this rotation, the paths of the electrons are periodic curves, in the plane containing the axis, which keep intersecting the surface of the emitting cylinder. The effect of the neglected rotation is simply to convert these plane curves into spirals about the axis. There is a certain maximum distance, under given conditions, which an electron is able to travel from the axis, and unless this is equal to or greater than the radius of the outer cylinder the electrons will return to the surface of emission and will contribute nothing to the thermionic current.

If r is the perpendicular distance of an electron from the axis, z its distance from a fixed plane perpendicular to the axis, and θ the angle the plane containing the axis and the electron makes with a fixed plane through the axis, the equations of motion of the electron are:—

$$m\frac{\partial^2 r}{\partial t^2} - mr\left(\frac{\partial \theta}{\partial t}\right)^2 = \mathrm{R}e - \mathrm{H}e\frac{\partial z}{\partial t} = \frac{\mathrm{A}e}{r} - \frac{\mathrm{B}e}{r}\frac{\partial z}{\partial t} \quad . \quad (16)$$

$$m\frac{\partial^2 z}{\partial t^2} = \mathrm{H}e\frac{\partial r}{\partial t} = \frac{\mathrm{B}e}{r}\frac{\partial r}{\partial t} \quad . \quad (17)$$

$$\frac{\partial}{\partial t}\left(r^2\frac{\partial \theta}{\partial t}\right) = 0 \quad . \quad . \quad . \quad . \quad . \quad (18)$$

From (18)

$$\frac{\partial \theta}{\partial t} = \frac{a^2}{r^2}\dot{\theta}_0, \quad . \quad . \quad . \quad (19)$$

if $\frac{\partial \theta}{\partial t} = \dot{\theta}_0$ when $r = a$.

From (17)

$$\frac{\partial z}{\partial t} = \dot{z}_0 + \frac{\mathrm{B}e}{m}\log\frac{r}{a} \quad . \quad . \quad . \quad (20)$$

if $\frac{\partial z}{\partial t} = \dot{z}_0$ when $r = a$.

Substituting these values of $\frac{\partial \theta}{\partial t}$ and $\frac{\partial z}{\partial t}$ in (16) and integrating subject to

$$\frac{\partial r}{\partial t} = \dot{r}_0 \text{ when } r = a,$$

$$\frac{\partial r}{\partial t} = \left[\dot{r}_0^2 + a^2\dot{\theta}_0^2\left(1 - \frac{a^2}{r^2}\right) - \frac{\mathrm{B}^2e^2}{m^2}\left(\log\frac{r}{a}\right)^2 + \frac{2(\mathrm{A}e - \mathrm{B}e\dot{z}_0)}{m}\log\frac{r}{a}\right]^{1/2} \quad . \quad . \quad (21)$$

The maximum value r_m of r is given by $\frac{\partial r}{\partial t} = 0$ or from (21), after substituting the values of A and B in terms of V_1 and i, by

$$V_1 = 10^{-8} \log \frac{b}{a}\left[\frac{j^2e}{50m} \log \frac{r_m}{a} + \frac{j}{5}\dot{z}_0 - \frac{m\dot{r}_0^2 + ma^2\dot{\theta}_0^2\left(1 - \frac{a^2}{r_m^2}\right)}{2e \log {}^{r_m}\!/_a}\right] \quad . \quad . \quad (22)$$

Thus if r_m is to be just equal to the radius b of the outer cylinder,

$$V_1 = 10^{-8} \log \frac{b}{a}\left\{\frac{j^2e}{50m} \log \frac{b}{a} + \frac{j}{5}\dot{z}_0 - \frac{m\dot{r}_0^2 + ma\dot{\theta}^2{}_0{}^2\left(1 - \frac{a^2}{b^2}\right)}{2e \log b/a}\right\} \quad . \quad . \quad (23)$$

If V_1 has a value equal to or greater than this the electrons will reach the electrode and form part of the current, otherwise they will not do so. If j is very small the right-hand side of (23) is negative, indicating that the current will be able to flow against an opposing potential owing to the initial emission velocities. The point of immediate interest, however, is the first term, on the right-hand side of (23), which is always positive and is independent of the emission velocities. This shows that owing to the action of the magnetic field due to the heating current, a definite potential is necessary in order to drag the electrons across to the electrode. With thin wires, which require only a small current to heat them, this potential difference is unimportant. Thus if $b/a = 200$ and $j = 1$ ampere, V_1 is only about 0·2 volt. On the other hand, with thick wires, which require large heating currents, the necessary values of V_1 may be quite large.

Another important factor which has to be taken into account, especially with thin wires, is the drop of potential along the wire due to the flow of the heating current. This is usually comparable with 1 volt per cm. In order to ensure that no part of the wire is at a positive potential compared with the cylinder, it is necessary that the *positive* end of the wire should be at a potential at least as low as that of the cylinder. If the potentials are applied at the negative end of the wire, it will appear from this cause alone that an additional negative potential equal to the fall along the hot wire has to be applied in order to ensure complete saturation.

That the mutual repulsion of the electrons, the magnetic field due to the heating current, and the drop of potential along the wire, also due to the last-named cause, are the chief general factors which prevent the attainment of saturation is strikingly shown by some recent experiments by Schottky.[1] Using concentric cylinders the thermionic currents with small differences of potential, both accelerating and retarding, were measured under conditions such that the heating current was cut out at the instant of measurement. By means of a suitable in-and-out switch, operating continuously, matters were arranged so that no appreciable variation in the temperature of the wire ensued thereby. Under these conditions the drop of potential along the filament and the magnetic field due to the heating current are eliminated, and it was found that the current saturated at zero potential difference; except for an effect, which was smaller the lower the temperature and smaller the current, arising from the mutual repulsion of the emitted electrons. In determining the actual difference of potential between the wire and the electrode, it was found necessary to add to the apparent applied potential difference registered by the voltmeter, a difference of potential equal to the contact potential between the two metals used. Thus experiments of this kind can be used to measure contact differences of potential under good vacuum conditions without displacing the surfaces subject to test.

Schlichter,[2] by using methods of heating the electrode which do not involve the passage of an electric current through it, has been able to show that the electron current with 220 volts driving potential is only about 10-20 per cent greater than that under zero potential difference, when the hot metal has been thoroughly glowed out. The special conditions which affect the attainment of saturation in the case of freshly heated metals will be referred to again on page 182, Chap. VI.

---

[1] "Ann. der Phys.," Vol. XLIV, p. 1011 (1914).

[2] *Ibid.*, Vol. XLVII, p. 573 (1915).

causes which might give rise to the observed effects. No doubt these are partly caused by electrons and ions emitted by the hot surfaces on account of the high temperature, but they may also be due partly to ions emitted by chemical action. The actions are also greatly complicated by the presence of the hot vapours which must have properties similar to those of flames.

THE RELATIVE IMPORTANCE OF VARIOUS FACTORS IN CAUSING THE EMISSION OF ELECTRONS FROM HOT BODIES.

We have already considered three possible causes of electronic emission, namely: the escape of the electrons owing to the purely thermal increase of their kinetic energy (p. 27), the liberation of electrons as one of the products of chemical action (p. 49), and the complete photoelectric emission (p. 95). We have seen (p. 100) that the available photoelectric data indicate that the last of these is too small to account for the emissions which have been observed from hot bodies; so that unless and until fresh observations are made which tend to conflict with this conclusion, it does not appear necessary to consider this particular question further.

It remains to deal with the relative claims of the purely thermal effect and of chemical action. In the last few years a number of writers have advocated the view that all the observed effects are attributable to chemical action. The case for this position is, briefly, as follows:—

We have seen in Chapter II that any electronic emission arising from chemical action would be likely to follow a law of temperature variation practically identical with that required by the purely thermal effect; so that the fact that the theoretical law is satisfied by the experimental results offers no criterion for distinguishing between the two views. In certain cases there is some evidence that electrons are liberated as a direct result of chemical action between solids and gases. The experiments of Haber and Just[1] have shown that when the alkali metals, their alloys, or amalgams, are attacked by oxygen, hydrochloric acid gas, phosgene gas, water vapour, and certain other chemically active gases or vapours, electrons are liberated in considerable quantity. It may be urged (cf. Chapter IX, p. 290) that in reality this also is a thermal emission, caused by a local increase of temperature in the surface layer arising from the heating caused by the chemical action. Most of Haber and Just's experiments were made with drops of various amalgams and with the liquid alloy of sodium and potassium. From a determination of the amount of chemical action occurring they calculate that in a particular experiment the heat generated by the chemical action was not sufficient to raise the temperature of the whole of a drop more than 2° C. But it is clear that the temperature of the surface layers must have been raised to a very much greater extent, and as it is only the temperature of the surface layer which is of any account if the effect is a purely thermal one, it cannot be said that the experiments so far made by these authors prove that the emission is a direct consequence of chemical action. Similar conclusions to those of Haber and Just have been reached by Fredenhagen,[1] who has shown that the emission ordinarily observed when the alkali metals are heated can be reduced to very much smaller values by the careful elimination of gases. The smallest currents recorded by Fredenhagen are, however, not smaller than those calculated [2] by an application of the considerations on p. 40 to the known emission from platinum or tungsten, in spite of the strong electropositive character of the alkali metals. The large values are restored, at least partially, when small quantities of gases, and especially of oxygen, are allowed to come in contact with the metal. But when one remembers the extraordinary sensitiveness of the emission to changes of temperature and that, in any event, the effect is a purely superficial one, it is questionable whether the observed enhancement of the emission may not be due to the local increase of temperature caused indirectly by the chemical action. It is, of course, abundantly proved that an emission is caused by chemical action in these cases, but it is extremely difficult to be sure that the effect is the direct result of the chemical action and is not caused indirectly by the heat generated at the surface. (See, however, p. 296.)

---

[1] "Ann. der Physik," Vol. XXXVI, p. 308 (1911).

---

[1] "Verh. der Deut[illegible] Physik. Ges.," Jahrg. 14, p. 386 (1912).

[2] Cf. O. W. Richardson, "Phil. Mag.," Vol. XXIV, p. 742 (1912).

The remaining cases which have been cited as examples of the emission of electrons by chemical action are the oxidation of calcium and the emission from incandescent carbon. Fredenhagen[1] has put forward the view that the activity of the lime-covered cathode is caused by the recombination of the calcium and oxygen which are separated by electrolysis during the passage of the current. The arguments in favour of this view have already been dealt with on p. 85 where they were not found to resist a critical examination successfully. We have already seen (p. 86) that Horton, who made a direct test of the question, was unable to detect any emission from calcium arising directly from oxidation. Wehnelt,[2] who has devoted much attention to the lime-covered cathode, has recently expressed the opinion that in the case of this material there is no evidence which would favour a chemical rather than a purely thermal cause for the origin of the emission. Finally, Germershausen[3] has shown that the emission from lime is increased by the removal of every trace of gas from its surroundings. Under these conditions the discharge becomes very similar to that from tungsten as observed by the writer and by Langmuir.

The emission from carbon has been attributed to chemical action between the carbon and traces of gaseous contamination by Pring and Parker,[4] and by Pring.[5] Using comparatively large rods of carefully purified carbon they found that the negative discharge to a small electrode in the neighbourhood of the rod diminished progressively as the gases were removed from the rod by continuous heating. The currents finally obtained at the highest temperatures were very much smaller than those recorded by other observers with carbon (see pp. 69 and 75). An application[1] of the considerations developed on p. 65, however, shows that the magnitude of the heating currents and the geometrical arrangement of the apparatus used by these authors were such that no electrons at all would be able to reach the electrode at the higher temperatures. Thus there is no difficulty in accounting for the smallness of the observed currents on the purely thermal theory of the emission. The only difficulty, which is present on any theory of the origin of the electrons, is to explain why the observed currents were not actually zero. The small currents can be accounted for[2] if it is supposed either that traces of gas present interfere with the motion of the electrons or that some of the electrons combine with uncharged molecules or atoms of the gas to form negative ions whose motion is almost unaffected by the magnetic field. Either of these assumptions would explain the fact that the observed currents are increased by the admission of traces of various gases. The relatively large effects produced by very small amounts of gas are in favour of the second hypothesis, which also explains the relative efficiency in this respect of the various gases tested. Another factor which would tend to make the currents observed in these experiments too small is the effect of the mutual repulsion of the electrons considered by Langmuir (see p. 61). Moreover, the results of the experiments are in complete disagreement with the results of experiments made with well-glowed-out carbon filaments by Deininger[3] in 1908, and of the more recent experiments of the writer and of Langmuir. In the last two cases the precautions described on p. 14 were taken in preparing the bulbs, and although it is not claimed that every trace of gas was got out of this very difficult substance, the conditions were much better in this respect than in the experiments of Pring and of Pring and Parker. The same claim can almost certainly be made for Deininger's work. In fact, it is quite impossible to attain good vacuum conditions with the large quantities of hot material used by Pring. Taking all the facts into consideration they appear to the writer to afford no support to the contention that the emission from carbon has anything whatever to do with chemical action. It may be that such a chemical effect exists, but its existence is not demonstrable, or even rendered probable, by the evidence which has been submitted.

---

[1] "Leipziger Ber.," Vol. LXV, p. 42 (1913).

[2] "Physik. Zeits.," Jahrg. 15, p. 558 (1914).

[3] *Ibid.*, Jahrg. 16, p. 104 (1915).

[4] "Phil. Mag.," Vol. XXIII, p. 192 (1912).

[5] "Roy. Soc. Proc., A.," Vol. LXXXIX, p. 344 (1913).

---

[1] O. W. Richardson, "Roy. Soc. Proc., A.," Vol. XC, p. 174 (1914).

[2] Loc. cit.

[3] "Ann. der Physik," Vol. XXV, p. 285 (1908).

Thus there is no case in which it has been established with certainty that chemical action is the direct and immediate cause of an emission of *electrons*. The majority of chemical actions between solids and gases certainly do not give rise to electrical effects of this kind to any appreciable extent (see Chap. IX). The only case in which the evidence renders the occurrence of electron emission as a chemical effect probable is that of the alkali metals. The experiments of Haber and Just and of Fredenhagen do, on the whole, indicate a balance of probability in favour of a direct chemical effect in this case, although, in the judgment of the writer, they cannot be held to establish it with certainty.

The advocates of the chemical point of view have held that the emissions usually observed are due to actions between the hot metal and minute traces of residual gas and not to chemical actions on any considerable scale. In support of this it may be urged that, as the effect is a *purely* superficial one, a small quantity of gas will exert as large an effect as a greater amount, down to a certain limit. On the other hand, it cannot be said that a comparison of the specific effects of different gases lends any support to the chemical theories. In the case of platinum, the only gas which causes any considerable increase in the emission is hydrogen, and although there is probably some chemical combination in this case it certainly is not of a violent character. In the case of tungsten all gases which act chemically on the metal have been found to reduce the emission and not to increase it.

The difficulty, discussed on pp. 71 *et seq.*, of determining the precise values of the constants A and *b*, and the dependence generally of the emission on factors which are difficult to control and to specify, has been held to favour the view that these effects are caused by the interaction between the hot bodies and traces of gaseous contamination of uncertain composition. It would, however, seem more reasonable to attribute these features of the phenomenon to the fact that it is of an entirely superficial character and is very sensitive to changes in the nature or composition of the surfaces. For example, the admission of oxygen will coat the hot metal with a layer of oxide. If, as appears to be the case with calcium, the oxide is more active thermionically than the metal, the emission in presence of oxygen will exceed the normal value. If the oxide is inactive its presence will tend to prevent the electrons escaping from the metal and will thus reduce the emission. The effect of oxygen on tungsten is probably of this nature. Minute traces of gas would be sufficient to produce effects of this kind, and if the composition of the gas were uncertain and variable the effects would be correspondingly so. A similar difficulty arises in other superficial phenomena, such as the photoelectric effect, surface tension, and optical reflexion, although, as a rule, it is not so marked. This is on account of the extreme sensitiveness of the thermionic emission to small changes in the work required for an electron to escape. There is, in fact, no comprehensive body of evidence supporting the view that interaction with gases is an invariable and direct cause of thermionic emission; the evidence that gases act indirectly by modifying the quantity of the emission quite generally is of a much stronger character. In this connexion the close relationship between electron emission and contact potential difference, which is required on theoretical grounds, and the sensitiveness of both these phenomena to superficial contamination, should also be kept in mind.

Experiments made by the writer[1] have shown that the emission from tungsten in a good vacuum is a property of the element itself, and cannot be attributed to chemical or other secondary actions between the tungsten and traces of other contaminating material. The advantages of tungsten in investigations of this character have been alluded to already (p. 127). The tests were made with experimental tungsten lamps carrying a vertical filament of ductile tungsten which passed axially down a concentric cylindrical electrode of copper gauze or foil. The tungsten filaments were welded electrically in a hydrogen atmosphere to stout metal leads. These in turn were silver-soldered to platinum wires sealed into the glass container. The lead to the copper electrodes was sealed into the glass in the same way. The lamps were exhausted with a Gaede pump for several hours. During this time they were maintained at 550° to 570° C. by means of the vacuum furnace described in Chapter I. The duration of this exhaustion varied from 8 to 24 hours with different bulbs. It was continued until the apparent evolution of gas was very small and practically constant. This small final development of gas, which appeared to persist indefinitely, is believed to be due to the dissociation of the glass walls of the tube and to the diffusion through them of gases from the vacuum furnace which could only be exhausted to about 1 cm. pressure. The exhaustion was completed by means of liquid air and charcoal, the tungsten filament meanwhile being glowed out by means of an electric current at over 2200° C. Most of the tests were made after the furnace had been opened up and the lamps allowed to cool off. This treatment has been found completely to stop the emission, under the relatively slight heating caused by the radiation from the hot filament, of gases from the walls of the tubes and from the cold electrodes which had previously formed such a persistent source of difficulty in experiments with hot wires.

---

[1] "Phil. Mag.," Vol. XXVI, p. 345 (1913).

Although the filaments used were quite thin (about 0·007 cm. diameter), these lamps were found capable of being run so as to give thermionic currents of about 0·1 ampere for hours. Tests were made covering the following alternative possible causes of the emission :—

(1). That the emission is caused by the evolution of gas from the filaments.

In one experiment the tube was shut off by a mercury trap and the gases allowed to accumulate. The filament gave an electronic current of 0·50 ampere continuously for 30 minutes. The pressure of the gas which had accumulated was less than

10^{-7} mm. and was too small to measure. Taking into account the volume of the bulb, these figures show that for every molecule of gas evolved $2{\cdot}6 \times 10^8$ electrons were emitted. No conceivable process could cause so many electrons to arise from each gas molecule.

(2) That the emission is caused by chemical action or some other cause depending on impacts between the gas molecules and the filaments.

If for purposes of computation we consider the gas to be hydrogen, which is the most unfavourable assumption, since this gas makes most collisions, the data of the last experiment show that 15,000 electrons would have to arise every time a molecule impinged on the filament. This number is of course quite prohibitive. Moreover, in certain other experiments quite appreciable changes in the gas pressure caused no change in the emission.

(3) That the emission is a result of some process involving consumption of the tungsten.

In these experiments there is a loss of tungsten from the filament which is believed to be due to evaporation. The loss was determined by measuring the change in the resistance of the filament. At the same time the thermionic current was measured, giving the number of electrons emitted. In one experiment it was found that for each atom of tungsten lost 984,000 electrons were emitted. In this case the mass of the electrons emitted was *three times* the mass of tungsten lost. This experiment and others similar to it show conclusively that the emitted electrons must have flowed into the tungsten from outside points of the circuit.

(4) That the emission is caused by interaction with some condensible vapour which does not affect the McLeod gauge.

This explanation is cut out by the fact that the currents are not affected when the tube is cut off from the liquid air and charcoal and the hypothetical vapours allowed to accumulate.

These experiments have not been accepted as conclusive by Fredenhagen[1] and by Horton[2] on the ground that they still leave open the possibility that the emission is due to interaction with the tungsten of some substance present in the filaments. In regard to this suggestion it is to be remembered that the assumption of the presence of foreign substances in the filament is a pure hypothesis. It is very unlikely that any gaseous substance, and most substances are gaseous under these conditions, could remain in a thin filament kept at over 2200° C. in a vacuum of 10^{-6} mm. pressure for a long time. The behaviour of the filaments during the experiments is distinctly opposed to this suggestion. When they are first glowed out there is a considerable evolution of gas lasting for a few seconds, and after that nothing. When the filaments are sealed in a small closed tube and allowed to disintegrate through overrunning no gas is evolved. There is good evidence that the small quantities of gas which occasionally appear in experiments of this kind come from the walls of the tube and the relatively heavy parts of the metal electrodes owing to inadequate preliminary treatment. The only impurities which would seem to have any chance of remaining in the filaments during these experiments are the highly refractory elements such as molybdenum, tantalum, carbon, thorium, etc. Even these would be expected gradually to disappear, and *there is no evidence of any progressive change in the emission at constant temperature* with properly prepared tubes. In any event it is questionable whether their presence would help the chemical theory, which would then be reduced to the position of admitting the existence of an emission from alloys but not from the pure metals. That the emission cannot be attributed to the commoner gases is also shown conclusively by the experiments (see p. 125) of Langmuir, who found that they all reduced the emission, except the inert gases which left it unaltered.

---

[1] "Phys. Zeits.," Jahrg. 15, p. 19 (1914).

[2] "Phil. Trans., A.," Vol. CCXIV, p. 278 (1914).

These experiments with tungsten definitely exclude chemical action as the cause of the emission from this substance. Such, at least, is the considered judgment of the writer. Although equally searching tests have not been made with other materials, a general survey of the phenomena does not indicate any definite connexion with chemical action, certainly n the case of the refractory elements. This is supported by he results of Langmuir,[1] who finds that with tantalum, olybdenum, carbon, and platinum as well as tungsten, the mission is increased with progressive elimination of gaseous ontamination and corresponding freedom from liability to hemical action. There is, of course, no compelling reason o expect a purely thermal origin for the effects in all cases. t may be that in the case of the alkali metals such effects as ave been observed are due entirely or chiefly to chemical ction; but this has not yet been proved, certainly not with nything like the thoroughness of proof of the contrary proposition in the case of tungsten. If the emission is ever aused by chemical action we should expect this type of ffect to be exhibited by the alkali metals, where the reactions e much more vigorous than with the refractory elements, as shown by the very much greater heat liberation per gram quivalent.

There is another argument, to which great weight should e attached, which is definitely against a chemical origin of he effects exhibited by the refractory elements. We have een that the variation of the emission with temperature enables us to form an estimate of the energy change associated ith the liberation of one electron. We shall see in the next hapter that more direct methods are available for determining this quantity, both from the absorption of heat when electrons are emitted, and from the liberation of heat when electrons re absorbed. All three methods give consistent results, and how that the quantity in question is very considerable.

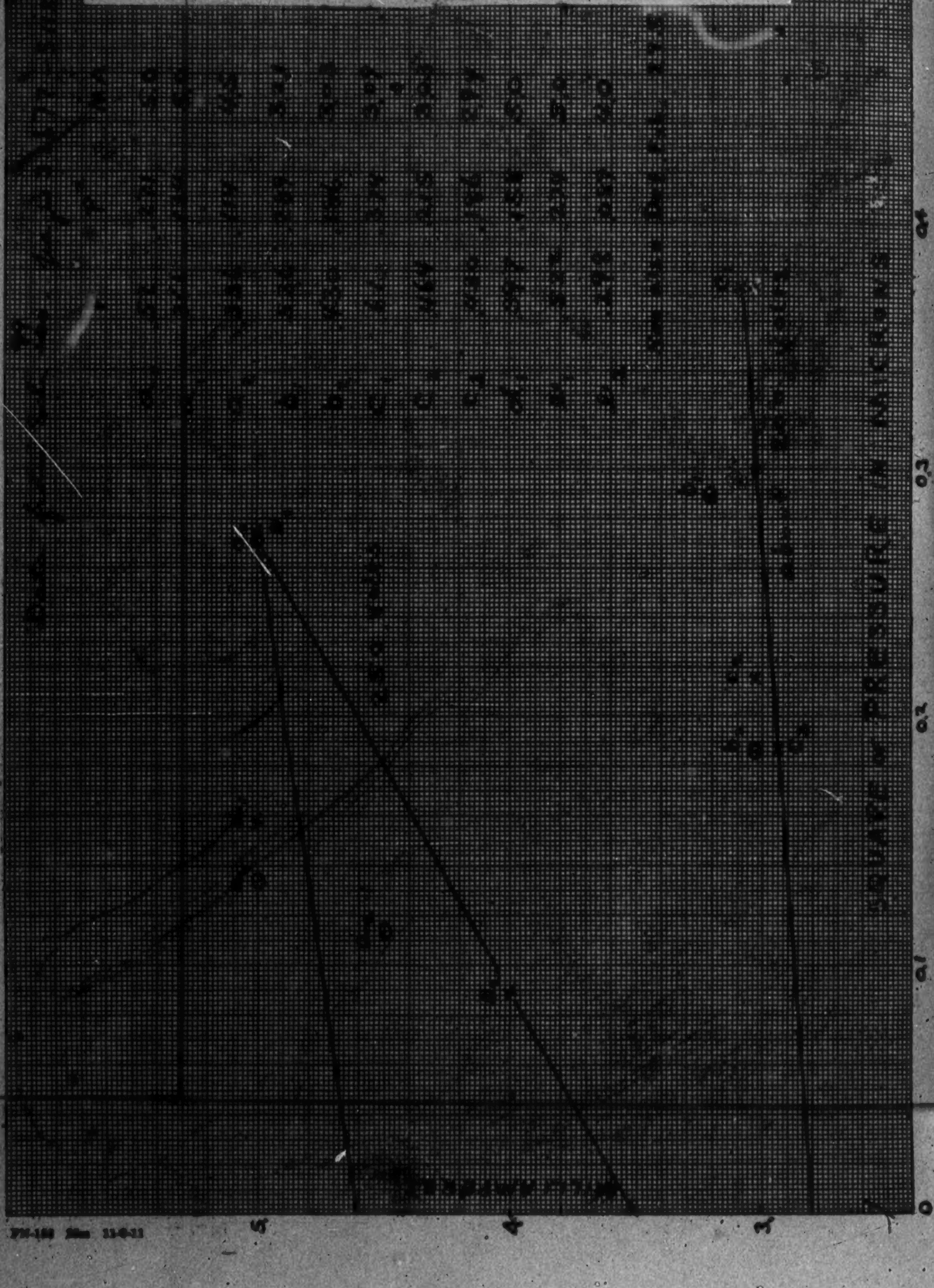
If we compare this heat change per gram equivalent of ectrons, with the heat liberated per gram equivalent in various chemical reactions, we find, in the case of tungsten or atinum, that it is about equal to the corresponding quantity r the most vigorous chemical actions known, such as the mbination of the alkali metals with the haloids, and is far reater than the heat of any known reaction of the elements nder consideration. Thus the rate of variation of the emission with temperature is right for the physical theory of the phenomena, but is wrong, so far as we can judge, for the chemical theory. It is desirable at present to restrict this argument to the more refractory elements which are less active chemically, as the thermionic data for the more electropositive elements cannot be considered to be known with sufficient definiteness.

---

[1] "Phys. Rev.," Vol. II, p. 484 (1913).

PLAINTIFF'S EXHIBIT No. 219-A.

A Replot of Data Taken from Defendant's Exhibit No. 295.



219-B

PLAINTIFF'S EXHIBIT No. 219-B.

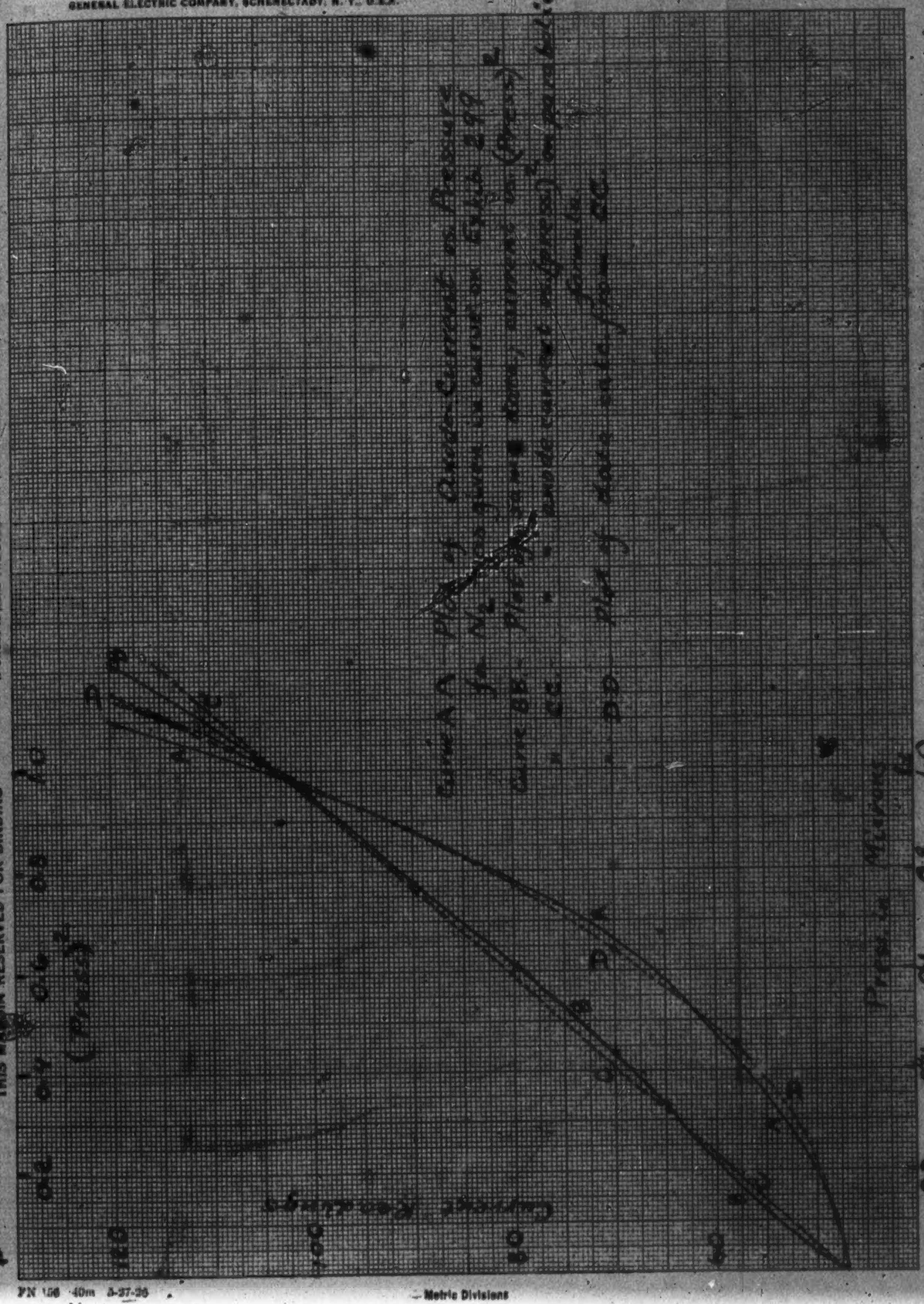
Parabolic Plots of Currents Taken from Defendant's Exhibit No. 299.

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U.S.A.

IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING

B

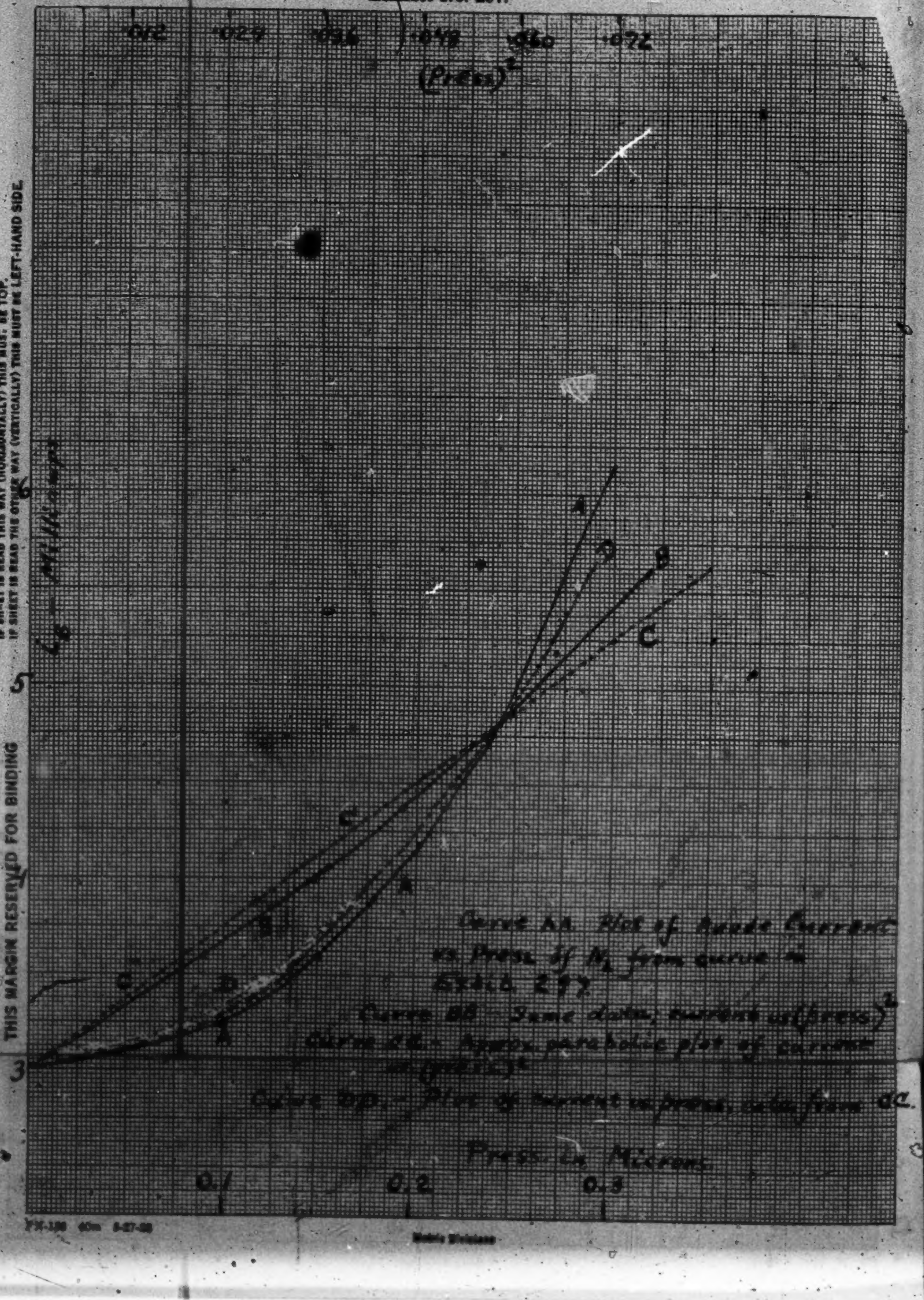


PN 156 40m 3-27-36

Metric Divisions

PLAINTIFF'S EXHIBIT No. 219-C.

Parabolic Plot of Currents Taken from Defendant's Exhibit No. 297.



Curve AA. Plot of Anode Current vs Press. of N_2 from curve in Exhib. 297.

Curve BB – Same data; current vs (press)^2

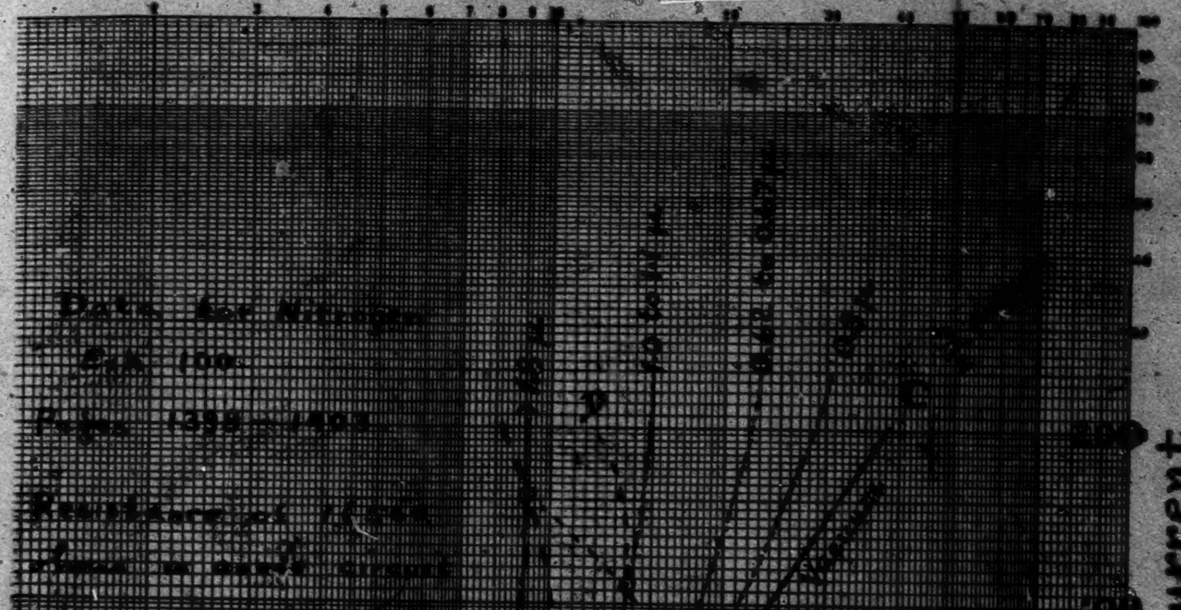
Curve CC – Approx. parabolic plot of current vs (press)^2

Curve DD. – Plot of current vs press, calc. from CC.

ARGI

PLAINTIFF'S EXHIBIT No. 220.

Logarithmic Current Voltage Curve for Different Pressures of Nitrogen.



Pat

136

65867
S.C.

Vol. V

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DeFOREST RADIO COMPANY, PETITIONER,

vs.

GENERAL ELECTRIC COMPANY

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT
COURT OF APPEALS FOR THE THIRD CIRCUIT

PETITION FOR CERTIORARI FILED JANUARY 8, 1931

CERTIORARI GRANTED FEBRUARY 25, 1931

(35,552)

DEFENDANT'S EXHIBITS.

GENERAL INDEX.

	Admitted		Printed	
	Vol.	Page	Vol.	Page
1. Hogan Graph plotted between filament and plate currents (Pltff.'s Ex. 52, Hewlett v. A. T. & T. Co., S. D. of N. Y.)	I	145	V	1
Nature, July 15, 1875, p. 217, "Charcoal Vacua," by James DeWar	I	196	V	3
Physikalische Zeitschrift, Vol. 29, pp. 46-50, 1909, "Tests of the Methods Used for Producing High Vacua," by Scheel & Heuse	I	196	V	8
Annalin der Physik, Vol. 12 (1881) pp. 425-445, "A New Construction of the Mercury Pump of Toepler and Describing Some Experiments Made Therewith," by Bessel-Hagen	I	196	V	16
Edison U. S. Patent No. 411,019, Sept. 17, 1889	I	196	V	37
Malignani U. S. Patent No. 537,693, April 16, 1895	I	196	V	40
Dwyer U. S. Patent No. 596,654, Jan. 4, 1898	I	197	V	42
American Electrician, Vol. VIII, No. 1, May, 1896, "Crookes Tubes and Experiments With Roentgen Rays," by Thomas Duncan	I	197	V	47
Proceedings of the Royal Society, A, Vol. 64, pp. 231-238, "Liquid Hydrogen for the Production of High Vacua," by James DeWar	I	197	V	53
Annalin der Physik, Vol. II (1900), pp. 359-374, "Production of Cathode Rays by Ultra-Violet Light," by P. Lenard	I	197	V	62
A. Annalin der Physik, Vol. VIII, (1902), pp. 149-198, "Photoelectric Action," by P. Lenard	I	197	V	79
Electrical World and Engineer, Vol. III, May 21, 1904, pp. 963-965, "A Resume of Incandescent Electric Lamps Exhausting," by S. E. Doane	I	197	V	122
Recklinghausen U. S. Patent No. 946,068, Jan. 11, 1910	I	197	V	135
Merritt U. S. Patent No. 909,811, Jan. 12, 1909	I	197	V	138

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
14.	Proceedings of the Royal Society, Vol. 74 (1905), pp. 476-487, "Conversion of Electric Oscillations into Continuous Currents by Means of a Vacuum Valve," by J. A. Fleming	I	197	V	142
15.	Fleming U. S. Patent No. 803,684, Nov. 7, 1905	I	197	V	157
16.	Scientific American Supplement, No. 1568, Jan. 20, 196, pp. 25129-25131, "On the Electric Conductivity of a Vacuum," by J. A. Fleming	I	197	V	165
17.	Soddy U. S. Patent No. 859,021, July 2, 1907	I	198	V	181
18.	Nature, Nov. 21, 1907, pp. 53-54, "The Wehnelt Kathode in a High Vacuum," by Frederick Soddy	I	198	V	190
18-A.	Proceedings of the Royal Society (1907), Vol. 78-A, pp. 429-458, "Calcium as an Absorbent of Gases for the Production of High Vacua and Spectroscopic Research," by Frederick Soddy	I	198	V	192
19.	Physikalische Zeitschrift, Vol. 9 (1908), p. 193, Reply to Soddy by Lilienfeld	I	198	V	222
20.	Proceedings of the American Academy of Arts and Sciences, Vol. XIV, No. 1, August, 1909, pp. 1-17, "Friction in Gases at Low Pressures," by J. L. Hogg	I	198	V	225
21.	Annalin der Physik, Vol. 31, (1910), pp. 169-304, "A Contribution to the Knowledge of the Inertia of Moving Electrons," by E. Hupka	I	198	V	241
22.	Physikalische Zeitschrift, Vol. 10, (1909), pp. 168-176, "Concerning Slow Cathode Rays," by O. V. Baeyer	I	198	V	281
23.	Thatcher U. S. Patent No. 1,028,636, June 4, 1912	I	198	V	305
24.	Friedrich U. S. Patent No. 1,083,677, Jan. 6, 1914	I	198	V	309
25.	Annalin der Physik, Vol. 32 (1910), pp. 673-738, "Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	315
25-A.	Leipsiger Berichte, Vol. 63, (1911), pp. 534-539, "The Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	388
26.	Verhandlunger der Deutschen Physikalischen Gesellschaft, Vol. 13, (1911), pp. 601-606, "On a Method of Producing Very Soft Roentgen Rays in the Highest Vacuum," by H. Dember	I	198	V	397

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
27.	Annalin der Physik, Vol. 36 (1911), pp. 995-1026, "Reflection and Secondary Radiation of Photoelectrically Liberated Cathode Rays," by A. Gehrts...	I	199	V	403
28.	Marshall U. S. Patent No. 205,002, Nov. 14, 1916....	I	199	V	433
29.	Physical Review, Vol. 32, (1911), pp. 492-511, "Discharge from Hot CAO," by C. D. Child.....	I	199	V	437
30.	Atti Della Raele Accademia Dei Lincei, Vol. XXI, (1912), pp. 235-239, "On Electromagnetic Wave Indicators Based on the principle of Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	457
30-A.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 274-277, "On a New Type of Indicator of Electromagnetic Waves Based Upon Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	465
31.	Fortschritte uf dem Gebiete der Rontgen Strahlen, Vol. 18 (1912), pp. 256-263, "An X-Ray Tube of an Optional and Instantaneously Attainable Degree of Hardness Independent of Vacuum," by J. E. Lilienfeld and W. J. Rosenthal	I	199	V	472
32.	Physikalische Zeitschrift, Vol. XIII (1912), pp. 594-595, "About the Distribution of Light During the Stratified Discharge in Vapors of Alkali Metals," by Kunz and Kemp	I	199	V	488
33.	American Institute of Electrical Engineers, Proceedings of, June 25, 1912 pp. 1207-1217, "Vacua," by W. R. Whitney	I	199	V	491
34.	Clark U. S. Patent No. 1,121,803, Dec. 22, 1914....	I	199	V	502
35.	Annalin der Physik, Vol. 41 (1913), pp. 1-26, "Concerning the Pressure of Cathode Rays," by Ernst V. Angerer	I	199	V	507
36.	Clough U. S. Patent No. 246,054, Nov. 13, 1917....	I	200	V	539
37.	Mackay U. S. Patent No. 1,208,597, Dec. 12, 1916..	I	200	V	542
38.	Coolidge U. S. Patent No. 1,082,933, Dec. 30, 1913..	I	382	V	545
39.	Langmuir New Zealand Patent No. 35,611, April 8, 1924	I	384	V	556

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
40.	General Electric Co. Australian Patent No. 14,677, Oct. 22, 1914	I	384	V	580
41.	British Thomson-Houston Co., Ltd., British Patent No. 15,788 of 1914	I	387	V	592
42.	White U. S. Patent No. 1,159,307, Nov. 2, 1915	I	387	V	604
43.	Arnold U. S. Patent No. 1,118,172, Nov. 24, 1914	I	494	V	610
44.	Hewitt U. S. Patent No. 1,025,464, May 7, 1912	I	583	V	614
45.	Hewitt U. S. Patent No. 682,699, Sept. 17, 1901	I	583	V	619
46.	Hewitt U. S. Patent No. 682,692, Sept. 17, 1901	I	583	V	622
47.	Kelly's approximate duplicate tube of Arnold priority record Exhibit No. 30	II	816	—	—
48.	Kelly diagram for Arnold Priority Exhibit No. 30	II	826	V	629
49.	Kelly diagram for Western Electric Standard 102-D Vacuum Tube	II	828	V	630
50.	Kelly diagram for tube 201-A	II	828	V	631
51.	Kelly approximate duplicate tube of Arnold Priority Exhibit No. 32	II	833	—	—
52.	Kelly diagram for Arnold Priority Exhibit No. 32 and approximate duplicate tube	II	834	V	633
53.	Kelly diagram for Arnold Priority Exhibit No. 32 and Arnold Audion 9.111	II	836	V	634
54.	Kelly diagram for data of Audion 9.111 in Arnold priority Exhibit No. 34	II	837	VI	635
54-A.	Kelly diagram showing correction of lowermost line of Exhibit No. 54	II	852	VI	636
55.	Circulars of General Electric tubes including tube UV-200	II	840	VI	637
56.	Kelly Helium filled tube	II	845	—	—
57.	Kelly diagram for Helium filled tube	II	845	VI	651
58.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	652
58-A.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	653
58-B.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	654
59.	Kelly diagram of two-way telephone repeater	II	849	VI	655

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
60.	Diagram of Page 591 of Warner Article, Proceedings of Radio Engineers, showing curves for tubes UV-199, 201 and 201-A	II	854	VI	656
61.	Kelly diagram for Arnold priority Exhibit No. 32 and approximate duplicate tube, plotted for exponent 3/2 or its inverse	II	856	VI	657
62.	File wrapper and contents, Langmuir U. S. Patent No. 1,558,436	II	912	VI	659
63.	File wrapper and contents Langmuir U. S. Patent No. 1,244,216	II	912	VI	786
64.	File wrapper and contents Langmuir U. S. Patent No. 1,244,217	II	912	VI	824
65.	File wrapper and contents Langmuir U. S. Patent No. 1,522,597	II	912	VI	852
66.	Physical Review, December, 1913, "A Powerful Roentgen Ray Tube With a Pure Electron Discharge," by W. D. Coolidge	II	913	VI	919
67.	File wrapper and contents Coolidge U. S. Patent No. 1,203,495	II	913	VI	941
68.	Drawing of pump used by Lamont	II	915	VI	1031
69.	Drawing of pump used by Lamont	II	916	VI	1033
70.	Photograph of Lamont preliminary pump	II	916	VI	1034
71.	Photograph of Lamont mercury pump	II	916	VI	1035
72.	Hewlett pump sketch	II	916	VI	1036
73.	Clark pump sketch	II	916	VI	1037
74.	Lamont account book (cash)	II	917	VI	1038
75.	Lamont account book (order)	II	917	VI	1048
76.	Shop card, amplifiers (3-stage)	II	918	VI	1054
77.	Shop card, amplifier tubes	II	918	VI	1055
78.	Letter, McCandless & Co. to Federal Telegraph Co., May 4, 1912	II	918	VI	1056
78-A.	Letter, McCandless & Co. to Federal Telegraph Co., June 9, 1912	II	918	VI	1057
78-B.	Letter, McCandless & Co. to Federal Telegraph Co., Dec. 23, 1912	II	918	VI	1058
78-C.	Letter, McCandless & Co. to Federal Telegraph Co., Jan. 8, 1913	II	918	VI	1059

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
79.	Letter, Federal Telegraph Co. to McCandless & Co., April 27, 1912	II	919	VI	1060
79-A.	Letter, Federal Telegraph Co. to McCandless & Co., July 26, 1912	II	919	VI	1061
79-B.	Letter, Federal Telegraph Co. to McCandless & Co., August 14, 1912	II	919	VI	1062
79-C.	Letter, Federal Telegraph Co. to G. E. Lamont, Oct. 16, 1912	II	919	VI	1063
80.	Watkin's photograph	II	919	VI	1064
81.	Drawing 88, Federal Telegraph Co.	II	919	VI	1065
82.	Drawing 229, Federal Telegraph Co.	II	919	VI	1067
83.	DeForest Audion structure, California depositions (Exhibit withdrawn)	II	920	—	—
84.	Jahnke Tube, California depositions (Exhibit withdrawn)	II	920	—	—
85.	Letter, Commissioner of Patents to Irving Langmuir, Sept. 8, 1916	II	923	VI	1069
86.	Telegram, Albert G. Davis to Edw. Williams, Sept. 15, 1916	II	923	VI	1070
87.	Supplemental petition of Irving Langmuir that claims be added, Interference No. 40,380	II	924	VI	1071
88.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1075
89.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1076
90.	Memorandum, Albert G. Davis on motion to dissolve and to add counts, Interference No. 40,380, Feb. 2, 1921	II	925	VI	1079
91.	Stipulation between attorneys for Langmuir and Arnold, Interference No. 40,380	II	925	VI	1081
92.	Communication from Law Examiner, Stipulation to amend, Interference No. 40,380, March 18, 1921	II	925	VI	1083
93.	Langmuir U. S. Patent No. 1,280,769, Oct. 8, 1918	II	925	VI	1085
94.	Hull U. S. Patent No. 291,527, Jan. 14, 1919	II	925	VI	1088
95.	Payne U. S. Patent No. 313,112, Aug. 12, 1919	II	925	VI	1095
96.	Hull U. S. Patent No. 1,313,187, Aug. 12, 1919	II	925	VI	1099
97.	Hull U. S. Patent No. 313,188, Aug. 12, 1919	II	926	VI	1104

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
98.	Hull U. S. Patent No. 1,385,873, July 26, 1921	II	925	VI	1108
99.	Hull, U. S. Patent No. 387,984, Aug. 16, 1921	II	925	VI	1117
	[Nos. 100 to 278, incl., Arnold Exhibits in Interference Record and not reprinted. *See Separate Index.*]	II	927	—	—
279.	(No Exhibit.)				
280.	Dushman U. S. Patent No. 172,961, Feb. 22, 1916	II	948	VI	1126
281.	Hawkins U. S. Patent No. 1,172,990, Feb. 22, 1916	II	948	VI	1130
282.	Meikle U. S. Patent No. 1,182,290, May 9, 1916	II	948	VI	1133
283.	Meikle U. S. Patent No. 266,517, May 14, 1918	II	948	VI	1137
284.	Langmuir U. S. Patent No. 1,273,628, July 23, 1918	II	949	VI	1141
285.	Langmuir re-issued Patent No. 15,278, Jan. 31, 1922	II	949	VI	1144
286.	Berg U. S. Patent No. 1,352,242, Sept. 7, 1920	II	949	VI	1150
287.	White U. S. Patent No. 1,365,576, Jan. 11, 1921	II	949	VI	1153
288.	Pratt U. S. Patent No. 1,374,679, April 12, 1921	II	949	VI	1157
289.	Alexanderson U. S. Patent No. 1,477,413, Dec. 11, 1923	II	949	VI	1160
290.	White U. S. Patent No. 1,506,468, Aug. 26, 1924	II	949	VI	1163
291.	Hull U. S. Patent No. 1,523,776, Jan. 20, 1925	II	949	VI	1168
292.	Alexanderson U. S. Patent No. 1,535,082, April 21, 1925	II	949	VI	1178
293.	Alexanderson U. S. Patent No. 1,549,737, Aug. 18, 1925	II	950	VI	1181
294.	Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	II	950	VI	1194
295.	Becker diagram for low current values of Sweetser, August, 1912, notes	III	1799	VI	1202
296.	Becker approximate duplicate Sweetser tube, August 1912	III	1804	—	—
297.	Becker diagram for current pressure relation in tube, Defendant's Exhibit No. 296	III	1804	VI	1204
298.	Becker current temperature diagrams for hydrogen Sweetser notes for Nov. and Dec., 1912	III	1809	VI	1205
299.	Becker diagram for current pressure data of Defendant's Exhibit No. 298 reduced to common voltage	III	1813	VI	1206

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
300.	Petition, specification, oath and drawings, Langmuir U. S. Patent No. 558,437, Oct. 20, 1925	III	1851	VI	1207
301.	Amendment B to application, Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1851	VI	1228
302.	Alexanderson U. S. Patent No. 1,102,628, July 7, 1914	III	1821	VI	1233
303.	White U. S. Patent No. 1,195,632, Aug. 22, 1916	III	1821	VI	1241
304.	Langmuir U. S. Patent No. 1,273,627, July 23, 1918	III	1821	VI	1246
305.	White U. S. Patent No. 1,298,613, March 25, 1919	III	1821	VI	1251
306.	Langmuir U. S. Patent No. 1,301,279, April 22, 1919	III	1821	VI	1257
307.	Alexanderson U. S. Patent No. 313,042, Aug. 12, 1919	III	1821	VI	1263
308.	Langmuir re-issued U. S. Patent No. 15,495, Nov. 21, 1922	III	1822	VI	1267
309.	Goldsmith U. S. Patent No. 1,323,759, Dec. 2, 1919	III	1822	VI	1271
310.	Goldsmith and Weinberger U. S. Patent No. 1,334,087, March 16, 1920	III	1822	VI	1276
311.	Alexanderson U. S. Patent No. 1,340,101, May 11, 1920	III	1822	VI	1280
312.	Alexanderson U. S. Patent No. 1,373,931, April 5, 1921	III	1822	VI	1285
313.	Payne U. S. Patent No. 1,400,235, Dec. 13, 1921	III	1822	VI	1289
314.	Bradbury U. S. Patent No. 1,430,883, Oct. 3, 1922	III	1822	VI	1293
315.	Beverage U. S. Patent No. 1,434,984, Nov. 7, 1922	III	1822	VI	1297
316.	Beverage U. S. Patent No. 1,434,985, Nov. 7, 1922	III	1823	VI	1303
317.	Bradbury U. S. Patent No. 1,443,209, Jan. 23, 1923	III	1823	VI	1314
318.	Becker U. S. Patent No. 1,455,099, May 15, 1923	III	1823	VI	1317
319.	Alexanderson U. S. Patent No. 1,466,263, Aug. 28, 1923	III	1823	VI	1321
320.	Traver U. S. Patent No. 1,470,582, Oct. 9, 1923	III	1823	VI	1325
321.	Alexanderson U. S. Patent No. 1,491,372, April 22, 1924	III	1823	VI	1331
322.	White U. S. Patent No. 1,544,202, June 30, 1925	III	1823	VI	1337
323.	Hull U. S. Patent No. 1,547,153, July 21, 1925	III	1823	VI	1341
324.	Letter, Charles Neave to H. B. Thayer, Oct. 10, 1913, with Memorandum "Cooper-Hewitt Matters" annexed	III	1853	VI	1349

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
325.	Letter, C. E. Scribner to D. C. Tanner, Feb. 10, 1915 with Memorandum from H. D. Arnold to E. H. Colpitts annexed	III	1859	VI	1358
326.	Physical Review, Vol. II, No. 5, Oct. 18, 1913, Abstract of Langmuir paper "The Effect of Space Charge and Residual Gases on the Thermionic Current in High Vacuum"	III	1886	VI	1361
327.	Logarithmic plot of Volt-Ampere characteristics of Type U pliotron (Plaintiff's Exhibit No. 60 with additions)	III	1886	VI	1363
328.	Data sheets furnished to plaintiff by defendant's witness Kelly	III	1887	VI	1364
329.	Tube used by Arnold in demonstration in Court of Blue Glow	III	1893	—	—
330.	DeForest tube as placed on pump	III	1901	—	—
331.	DeForest tube sealed off from pump	III	1901	—	—
332.	DeForest tube prior to volatilization of magnesium	III	1902	—	—
333.	DeForest tube in completed commercial form	III	1903	—	—

DEFENDANT'S EXHIBITS.

CLASSIFIED INDEX.

Diagrams, Drawings and Photographs.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
295.	Becker diagram for low current values of Sweetser August, 1912, notes	III	1799	VI	1202
297.	Becker diagram for current pressure relation in tube, Defendant's Exhibit No. 296	III	1804	VI	1204
298.	Becker current temperature diagrams for hydrogen Sweetser notes for Nov. and Dec., 1912	III	1809	VI	1205
299.	Becker diagram for current pressure data of Defendant's Exhibit No. 298 reduced to common voltage	III	1813	VI	1206
73.	Clark pump sketch	II	916	VI	1037
81.	Federal Telegraph Co., Drawing 88	II	919	VI	1065
82.	Federal Telegraph Co., Drawing 229	II	919	VI	1067
72.	Hewlett pump sketch	II	916	VI	1036
1.	Hogan graph plotted between filament and plate currents (Pltff.'s Ex. 52, Hewlett v. A. T. & T. Co., S. D. of N. Y.)	I	145	V	1
48.	Kelly diagram for Arnold Priority Exhibit No. 30	II	826	V	629
49.	Kelly diagram for Western Electric Standard 102-D Vacuum Tube	II	828	V	630
50.	Kelly diagram for tube 201-A	II	828	V	631
52.	Kelly diagram for Arnold Priority Exhibit No. 32 and approximate duplicate tube	II	834	V	633
53.	Kelly diagram for Arnold Priority Exhibit No. 32 and Arnold Audion 9.111,	II	836	V	634
54.	Kelly diagram for data of Audion 9.111 in Arnold priority Exhibit No. 34	II	837	VI	635
54-A.	Kelly diagram showing correction of lowermost line of Exhibit No. 54	II	852	VI	636
57.	Kelly diagram for Helium filled tube	II	845	VI	651
58.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	652
58-A.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	653

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
58-B.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	654
59.	Kelly diagram of two-way telephone repeater	II	849	VI	655
61.	Kelly diagram for Arnold priority Exhibit No. 32 and approximate duplicate tube, plotted for exponent 3/2 or its inverse	II	856	VI	657
68.	Lamont, Drawing of pump used by	II	915	VI	1031
69.	Lamont, Drawing of pump used by	II	916	VI	1033
70.	Lamont preliminary pump, Photograph of	II	916	VI	1034
71.	Lamont mercury pump, Photograph of	II	916	VI	1035
327.	Logarithmic plot of Volt-Ampere characteristics of Type U pliotron (Plaintiff's Exhibit No. 60 with additions)	III	1886	VI	1363
60.	Warner Article, Diagram on Page 591 of, Proceedings of Radio Engineers, showing curves for tubes UV-199, 201 and 201-A	II	854	VI	656
80.	Watkin's photograph	II	919	VI	1064
	Documentary, Miscellaneous.				
330.	Amendment B to application, Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1851	VI	1228
55.	Circulars of General Electric tubes including tube UV-200	II	840	VI	637
92.	Communication from Law Examiner, Stipulation to amend, Interference No. 40,380, March 18, 1921	II	925	VI	1083
328.	Data sheets furnished to plaintiff by defendant's witness Kelly	III	1887	VI	1364
74.	Lamont account book (cash)	II	917	VI	1038
75.	Lamont account book (order)	II	917	VI	1048
78.	Letter, McCandless & Co. to Federal Telegraph Co., May 4, 1912	II	918	VI	1056
78-A.	Letter, McCandless & Co. to Federal Telegraph Co., June 9, 1912	II	918	VI	1057
78-B.	Letter, McCandless & Co. to Federal Telegraph Co., Dec. 23, 1912	II	918	VI	1058
78-C.	Letter, McCandless & Co. to Federal Telegraph Co., Jan. 8, 1913	II	918	VI	1059

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
79.	Letter, Federal Telegraph Co. to McCandless & Co., April 27, 1912	II	919	VI	1060
79-A.	Letter, Federal Telegraph Co. to McCandless & Co., July 26, 1912	II	919	VI	1061
79-B.	Letter, Federal Telegraph Co. to McCandless & Co., August 14, 1912	II	919	VI	1062
79-C.	Letter, Federal Telegraph Co., to G. E. Lamont, Oct. 16, 1912	II	919	VI	1063
85.	Letter, Commissioner of Patents to Irving Langmuir, Sept. 8, 1916	II	923	VI	1069
88.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1075
89.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1076
324.	Letter, Charles Neave to H. B. Thayer, Oct. 10, 1913, with Memorandum "Cooper-Hewitt Matters" annexed	III	1853	VI	1349
325.	Letter, C. E. Scribner to D. C. Tanner, Feb. 10, 1915 with Memorandum from H. D. Arnold to E. H. Colpitts annexed	III	1859	VI	1358
90	Memorandum, Albert G. Davis on motion to dissolve and to add counts, Interference No. 40,380, Feb. 2, 1921	II	925	VI	1079
76.	Shop card, amplifiers (3-stage)	II	918	VI	1054
77.	Shop card, amplifier tubes	II	918	VI	1055
91.	Stipulation between attorneys for Langmuir and Arnold, Interference No. 40,380	II	925	VI	1081
87.	Supplemental petition of Irving Langmuir that claims be added Interference No. 40,380	II	924	VI	1071
86.	Telegram, Albert G. Davis to Edw. Williams, Sept. 15, 1916	II	923	VI	1070

File Wrappers and Contents.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
67.	File wrapper and contents Coolidge U. S. Patent No. 1,203,495	II.	913	VI	941
62.	File wraper and contents, Langmuir U. S. Patent No. 1,558,436	II	912	VI	659

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
63.	File wrapper and contents Langmuir U. S. Patent No. 1,244,216	II	912	VI	786
64.	File wrapper and contents Langmuir U. S. Patent No. 1,244,217	II	912	VI	824
65.	File wrapper and contents Langmuir U. S. Patent No. 1,522,597	II	912	VI	852
300.	Petition, specification, oath and drawing, Langmuir U. S. Patent No. 558,437, Oct. 20, 1925	III	1851	VI	1207

Patent, Australian.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
40.	General Electric Co., No. 14,677, Oct. 22, 1914	I	384	V	580

Patent, British.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
41.	Thomson-Houston Co., Ltd., British, No. 15,788 of 1914	I	387	V	592

Patent, New Zealand.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
39.	Langmuir, No. 35,611, April 8, 1924	I	384	V	556

Patents, United States.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
289.	Alexanderson, No. 1,477,413, Dec. 11, 1923	II	949	VI	1160
292.	Alexanderson, No. 1,535,082, April 21, 1925	II	949	VI	1178
293.	Alexanderson, No. 1,549,737, Aug. 18, 1925	II	950	VI	1181
302.	Alexanderson, No. 1,102,628, July 7, 1914	III	1821	VI	1233
307.	Alexanderson, No. 313,042, Aug. 12, 1919	III	1821	VI	1263
311.	Alexanderson, No. 1,340,101, May 11, 1920	III	1822	VI	1280
312.	Alexanderson, No. 1,373,931, April 5, 1921	III	1822	VI	1285
319.	Alexanderson, No. 1,466,263, Aug. 28, 1923	III	1823	VI	1321
321.	Alexanderson, No. 1,491,372, April 22, 1924	III	1823	VI	1331
43.	Arnold, No. 1,118,172, Nov. 24, 1914	I	494	V	610
318.	Becker, No. 1,455,099, May 15, 1923	III	1823	VI	1317
286.	Berg, No. 352,242, Sept. 7, 1920	II	949	VI	1150
315.	Beverage, No. 1,434,984, Nov. 7, 1922	III	1822	VI	1297
316.	Beverage, No. 1,434,985, Nov. 7, 1922	III	1823	VI	1303
314.	Bradbury, No. 1,430,883, Oct. 3, 1922	III	1822	VI	1293
317.	Bradbury, No. 1,443,209, Jan. 23, 1923	III	1823	VI	1314

34.	Clark, No. 1,121,803, Dec. 22, 1914	I	199	V	502
36.	Clough, No. 246,054, Nov. 13, 1917	I	200	V	539
38.	Coolidge, No. 1,082,933, Dec. 30, 1913	I	382	V	545
280.	Dushman, No. 172,961, Feb. 22, 1916	II	948	VI	1126
7.	Dwyer, No. 596,654, Jan. 4, 1898	I	197	V	42
5.	Edison, No. 411,019, Sept. 17, 1889	I	196	V	37
15.	Fleming, No. 803,684, Nov. 7, 1905	I	197	V	157
24.	Friedrich, No. 1,083,677, Jan. 6, 1914	I	198	V	309
309.	Goldsmith, No. 1,323,759, Dec. 2, 1919	III	1822	VI	1271
310.	Goldsmith and Weinberger, No. 1,334,087, March 16, 1920	III	1822	VI	1276
281.	Hawkins, No. 1,172,990, Feb. 22, 1916	II	948	VI	1130
44.	Hewitt, No. 1,025,464, May 7, 1912	I	583	V	614
45.	Hewitt, No. 682,699, Sept. 17, 1901	I	583	V	619
46.	Hewitt, No. 682,692, Sept. 17, 1901	I	583	V	622
94.	Hull, No. 291,527, Jan. 14, 1919	II	925	VI	1090
96.	Hull, No. 1,313,187, Aug. 12, 1919	II	925	VI	1099
97.	Hull, No. 313,188, Aug. 12, 1919	II	925	VI	1104
98.	Hull, No. 1,385,873, July 26, 1921	II	925	VI	1108
99.	Hull, No. 387,984, Aug. 16, 1921	II	925	VI	1117
291.	Hull, No. 1,523,776, Jan. 20, 1925	II	949	VI	1168
323.	Hull, No. 1,547,153, July 21, 1925	III	1823	VI	1341
93.	Langmuir, No. 1,280,769, Oct. 8, 1918	II	925	VI	1085
284.	Langmuir, No. 1,273,628, July 23, 1918	II	949	VI	1141
285.	Langmuir, Re-issue, No. 15,278, Jan. 31, 1922	II	949	VI	1144
294.	Langmuir, No. 1,558,437, Oct. 20, 1925	II	950	VI	1194
304.	Langmuir, No. 1,273,627, July 23, 1918	III	1821	VI	1246
306.	Langmuir, No. 1,301,279, April 22, 1919	III	1821	VI	1257
308.	Langmuir, Re-issue, No. 15,495, Nov. 21, 1922	III	1822	VI	1267
37.	Mackay, No. 1,208,597, Dec. 12, 1916	I	200	V	542
6.	Malignani, No. 537,693, April 16, 1895	I	196	V	40
28.	Marshall, No. 205,002, Nov. 14, 1916	I	199	V	433
282.	Meikle, No. 1,182,290, May 9, 1916	II	948	VI	1133
283.	Meikle, No. 266,517, May 14, 1918	II	948	VI	1137
13.	Merritt, No. 909,811, Jan. 12, 1909	I	197	V	138
95.	Payne, No. 313,112, Aug. 12, 1919	II	925	VI	1095
313.	Payne, No. 1,400,235, Dec. 13, 1921	III	1822	VI	1289
288.	Pratt, No. 1,374,679, April 12, 1921	II	949	VI	1157

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
12.	Recklinghausen, No. 946,068, Jan. 11, 1910	I	197	V	135
17.	Soddy, No. 859,021, July 2, 1907	I	198	V	181
23.	Thatcher, No. 1,028,636, June 4, 1912	I	198	V	305
320.	Traver, No. 1,470,582, Oct. 9, 1923	III	1823	VI	1325
42.	White, No. 1,159,307, Nov. 2, 1915	I	387	V	604
287.	White, No. 1,365,576, Jan. 11, 1921	II	949	VI	1153
290.	White, No. 1,506,468, Aug. 26, 1924	II	949	VI	1163
303.	White, No. 1,195,632, Aug. 22, 1916	III	1821	VI	1241
305.	White, No. 1,298,613, March 25, 1919	III	1821	VI	1251
322.	White, No. 1,544,202, June 30, 1925	III	1823	VI	1337

Publications.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
20.	American Academy of Arts and Sciences, Proceedings of the, Vol. XIV, No. 1, August, 1909, pp. 1-17, "Friction in Gases at Low Pressures," by J. L. Hogg	I	198	V	225
8.	American Electrician, Vol. VIII, No. 1, May, 1896, "Crookes Tubes and Experiments with Roentgen Rays," by Thomas Duncan	I	197	V	47
33.	American Institute of Electrical Engineers, Proceedings of, June 25, 1912, pp. 1207-1217, "Vacua," by by W. R. Whitney	I	199	V	491
4.	Annalin der Physik, Vol. 12 (1881), pp. 425-445, "A New Construction of the Mercury Pump of Toepler and Describing Some Experiments Made Therewith," by Bessel-Hagen	I	196	V	16
10.	Annalin der Physik, Vol. II, (1900), pp. 359-374, "Production of Cathode Rays by Ultra-Violet Light," by P. Lenard	I	197	V	62
10-A.	Annalin der Physik, Vol. VIII, (1902), pp. 149-198, "Photoelectric Action," by P. Lenard	I	197	V	79
21.	Annalin der Physik, Vol. 31, (1910), pp. 169-304, "A Contribution to the Knowledge of the Inertia of Moving Electrons," by E. Hupka	I	198	V	241
25.	Annalin der Physik, Vol. 32 (1910), pp. 673-738, "Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	315

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
27.	Annalin der Physik, Vol. 36 (1911), pp. 995-1026, "Reflection and Secondary Radiation of Photo-electrically Liberated Cathode Rays," by A. Gehrts	I	199	V	403
35.	Annalin der Physik, Vol. 41, (1913), pp. 1-26, "Concerning the Pressure of Cathode Rays," by Ernst V. Angerer	I	199	V	507
30.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 235-239, "On Electromagnetic Wave Indicators Based on the Principle of Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	457
30-A.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 274-277, "On a New Type of Indicator of Electromagnetic Waves Based Upon Electronic Emissions From Incandescent Wires," by Quirino Majorana	I	199	V	465
11.	Electrical World and Engineer, Vol. III, May 21, 1904, pp. 963-965, "A Resume of Incandescent Electric Lamps Exhausting," by S. E. Doane	I	197	V	122
31.	Fortschritte uf dem Gebiete der Rontgen Strahlen, Vol. 18 (1912), pp. 256-263, "An X-Ray Tube of An Optional and Instantaneously Attainable Degree of Hardness Independent of Vacuum," by J. E. Lilienfeld and W. J. Rosenthal	I	199	V	472
25-A.	Leipsiger Berichte, Vol. 63, (1911), pp. 534-539, "The Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	388
2.	Nature, July 15, 1875, p. 217, "Charcoal Vacua," by James DeWar	I	196	V	3
18.	Nature, Nov. 21, 1907, pp. 53-54, "The Wehnelt Kathode in a High Vacuum," by Frederick Soddy	I	198	V	190
29.	Physical Review, Vol. 32, (1911), pp. 492-511, "Discharge from Hot CAO," by C. D. Child	I	199	V	437
66.	Physical Review, December, 1913, "A Powerful Roentgen Ray Tube With a Pure Electron Discharge," by W. D. Coolidge	II	913	VI	919

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
326.	Physical Review, Vol. II, No. 5, Oct. 18, 1913, Abstract of Langmuir paper "The Effect of Space Charge and Residual Gases on the Thermionic Current in High Vacuum"	III	1886	VI	1361
3.	Physikalische Zeitschrift, Vol. 29, pp. 46-50, 1909, "Tests of the Methods Used for Producing High Vacua," by Scheel & Heuse	I	196	V	8
19.	Physikalische Zeitschrift, Vol. 9 (1908), p. 193, Reply to Soddy by Lilienfeld	I	198	V	222
22.	Physikalische Zeitschrift, Vol. 10 (1909), pp. 168-176, "Concerning Slow Cathode Rays," by O. v. Baeyer	I	198	V	281
32.	Physikalische Zeitschrift, Vol. XIII (1912), pp. 594-595, "About the Distribution of Light During the Stratified Discharge in Vapors of Alkali Metals," by Kunz and Kemp	I	199	V	488
9.	Royal Society, Proceedings of the, A, Vol. 64, pp. 231-238, "Liquid Hydrogen for the Production of High Vacua," by James DeWar	I	197	V	53
14.	Royal Society, Proceedings of the, Vol. 74 (1905), pp. 476-487, "Conversion of Electric Oscillations Into Continuous Currents by Means of a Vacuum Valve," by J. A. Fleming	I	197	V	142
18-A.	Royal Society, Proceedings of the, (1907), Vol. 78-A, pp. 429-458, "Calcium as an Absorbent of Gases for the Production of High Vacua and Spectroscopic Research," by Frederick Soddy	I	198	V	192
16.	Scientific American Supplement, No. 1568, Jan. 20, 1906, pp. 25129-25131, "On the Electric Conductivity of a Vacuum," by J. A. Fleming	I	197	V	165
26.	Verhandlunger der Deutschen Physikalischen Gesellschaft, Vol. 13, (1911), pp. 601-606, "On a Method of Producing Very Soft Roentgen Rays in the Highest Vacuum," by H. Dember	I	198	V	397
	Physical Exhibits.				
329.	Arnold, tube used by, in demonstration in Court of Blue Glow	III	1893	—	—

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
296.	Becker approximate duplicate Sweetser tube, August, 1912	III	1804	—	—
83.	DeForest Audion structure, (California depositions) [Exhibit withdrawn]	II	920	—	—
330.	DeForest tube as placed on pump	III	1904	—	—
331.	DeForest tube sealed off from pump	III	1901	—	—
332.	DeForest tube prior to volatilization of magnesium	III	1902	—	—
333.	DeForest tube in completed commercial form	III	1903	—	—
84.	Jahnke Tube, (California depositions) [Exhibit withdrawn]	II	920	—	—
47.	Kelly's approximate duplicate tube of Arnold priority record Exhibit No. 30	II	816	—	—
51.	Kelly's approximate duplicate tube of Arnold Priority Exhibit No. 32	II	833	—	—
56.	Kelly Helium filled tube	II	845	—	—

DEFENDANT'S EXHIBIT No. 2.

July 15, 1875] NATURE 217

CHARCOAL VACUA *

(From a Correspondent.)

Prof. Dewar began his discourse by describing the different processes which have been adopted for obtaining very perfect vacua, and referred to a paper regarding this matter, read by Prof. Tait and himself before the Society last year.

By the ordinary air-pump the exhaustion can only be obtained to ⅛ of an inch, *i.e.* 1/240 of the ordinary pressure.

Regnault, in some of his experiments, after exhausting with the air-pump, boiled water, and when the water had evaporated, sealed the vessel, and then broke a flask inside containing sulphuric acid, and so the water vapour was absorbed.

Dr. Andrews' way is a revival of one due to Davy, viz. to fill and exhaust twice with carbonic acid after the pump exhaustion, and then by caustic potash to fix the CO_2 which is left.

Professors Tait and Dewar's method is to take advantage of the power charcoal has of condensing gases; while the exhaustion, by means of a mercury pump, is going on, the charcoal is kept heated; when the exhaustion has been carried as far as possible, the vessel is sealed, and as the charcoal cools, it condenses the very small residue of gas there may be present, and this can again be temporarily driven out by heating the charcoal. The test they have employed to gauge the perfection of their vacuum has been to see if it will allow an electric spark to pass. It is well known that at the ordinary atmospheric density it requires considerable tension for a spark to pass through air, and as the density diminishes, the spark passes more easily; but when a certain point is reached the difficulty again increases, and in a very perfect vacuum no spark passes at all. Two wires, ¼ inch apart, in one of Tait and Dewar's exhausted tubes would not allow a spark to pass, although a powerful coil was employed.

---

* By Professors Tait and Dewar. Paper read by Prof. Dewar before the R.S. of Edinburgh on Monday, July 12.

Prof. Dewar went on to say that the effect of light and heat had been tried by many experimenters, on magnets and delicately suspended bodies, and in the *Edinburgh New Philosophical Journal* for 1828 there is an interesting account of some experiments performed by Mark Watt on the same subject, with apparatus little differing in appearance from that now used by Mr. Crookes.

Recently Mr. Crookes has found some curious results which he seems to think are inexplicable. He found that the action of a beam of light on a delicately suspended glass fibre with a disc at each end was repulsion of the disc when the exhaustion was perfect, but attraction when at ordinary pressures. The discs were light bodies of pith or cork. One side of each was covered with lampblack, the other was white. The first thing to be noticed is that the blackened face is affected much sooner than the white face. Since there was attraction at one density and repulsion at another, it follows that at some intermediate density there is no action at all, and this neutral point depends among other things on the conductivity of the body and the nature of the residual gas.

It will be seen that for delicate action one essential is that the glass of the vessel be thin. The sensibility is also found to increase with the perfection of the vacuum.

The first fact ascertained is that the action follows the law of the inverse square of the distance, that which all radiation obeys. Thus, when the light was 3¾ inches from the beam, the reading was 110, zero 22, deflection 88; at 7½, reading 48, deflection 22, or only about ¼; and when at 11½, reading 33; and as zero changed, reading 33, deflection 9, or only about ⅑.

The next experiment was this. Professor Dewar interposed between the candle and the beam a substance opaque to heat rays. The candle was placed so as to give a large deflection, and then a vessel of ordinary glass was interposed, and the deflection decreased, and on filling the vessel with water, which is almost opaque to heat rays, there was no perceptible deflection left. This shows that when the heat rays are absorbed or prevented from reaching the disc, hardly any action takes place. A layer of water ¼ of an inch thick diminishes the amount of deflection to ⅛ part of the original.

Next a smoked piece of rock-salt was interposed, or a vessel filled with a substance transparent to heat but opaque to light, viz., a solution of iodine in bisulphide of carbon. The deflection was as before, large; on the empty screen being interposed a diminution followed, due to the non-transparency of the glass screen for heat. But when by means of the iodine solution the light rays were cut off there was hardly any further diminution in the deflection. This shows that the light rays may be taken away without any considerable diminution of the action.

Prof. Dewar then proceeded to show that the heating of the disc was the efficient cause of the action.

Two equal discs, one of rock-salt, the other of glass, were attached to the glass fibre. The rock-salt was inactive when the beam was thrown on it; the glass disc was active. The reason is evidently that the rock-salt is not heated, being transparent to heat, whereas the glass is opaque, absorbs the heat and is heated. Unless the shell of the receiver be thin, however, the selective action is very small, as the glass envelope absorbs much of the heat.

The back of the rock-salt disc was then coated with lampblack, and the beam sent through to the blackened side. Yet there would be attraction. The heat and light passes through the rock-salt and is absorbed by the lampblack at the surface of contact. The lampblack is heated up in consequence, but it is so bad a conductor that before this heat can be conducted through the thin coating of lampblack it is conducted through the rock-salt, heats it up, and the action is repulsion. If the lampblack were not so bad a conductor, all the lampblack would be first heated up and there would be repulsion at the other side, or apparent attraction. The subsequent action is due to the giving out heat unequally on the two sides.

The next modification was to substitute for the rock-salt clear sulphur and ordinary sulphur on the other. The peculiarity of clear sulphur is that when acted on by light it resumes the appearance of ordinary sulphur, with a disengagement of heat. A beam was thrown on this, and the effect was, as expected, attraction, the back being heated, and repulsion, there being attraction on the other side. The success of this experiment depends on the way in which the sulphur is transforming.

This suggested to the learned Professors an instrument for detecting the presence of very high violet rays. Have the transparent discs coated with white phosphorus, which is opaque to the ultra-violet rays. There would ensue a chemical action with disengagement of heat, and the result would be a motion of the discs. To show the sensitiveness of the apparatus, it may be stated that an ordinary lucifer-match held at a distance of 4 feet produced instant action, which was observed by means of a telescope. When ether was brought near there was attraction. The disc followed the ether about because there was radiation of heat from the disc. The action is clearly due to the infinitesimal heating of the discs. Reynolds suggested the action was due to the evaporation of some fluid on the surface of the discs. The recoil of the evaporating particles leaving the disc sent it back.

When the action takes place in ordinary pressures it is probably due to convection currents. The air in front of the disc is heated and ascends, there is a vacuum, and hence the disc advances. To understand the action that takes place when the exhaustion is more perfect, we must consider how much gas there is in the vessel. The capacity of the vessel is about a litre or 1000 cubic centimetres. But since we know that the exhaustion has reduced the density to $\frac{1}{4000000}$ of its original, the volume occupied by the residual gas at ordinary pressures would be that of a little bubble $\frac{1}{100}$ of an inch in diameter.

Sir Wm. Thomson, T. Clerk-Maxwell, and Clausius have shown that in a gas, at ordinary pressure, the mean or average path between two collisions is about $\frac{1}{10000}$ of a millimetre. When the pressure is reduced to $\frac{1}{4000000}$ the mean will be 400 millimetres, or about a foot and a half. What takes place is this. The particles of the gas are flying about in all directions, with a velocity which depends on the temperature. When they impinge on the heated disc their velocity is increased, they go off with a greater velocity than those which go off from the colder side, and hence there is a recoil of the disc. When the gas is at all dense the particles get a very short way before they are met by another and sent back, and so the velocity gets a common velocity before any visible action takes place. When the gas is rare the particles may get a long way off before they meet others, and so the action becomes perceptible.

In case of cooling they go away with diminished velocity and a negative recoil.

The author of the paper went on to show that the total mechanical action on a square centimetre of black surface derived from the radiation of a magnesium lamp, at a distance of 150 mill., did not exceed a continuous pressure of $\frac{1}{50}$ part of a milligramme, and that the total work done did not amount to the five-millionth part of the available energy received by the movable surfaces.

DEFENDANT'S EXHIBIT No. 3.

Physikalische Zeitschrift,
Vol. 29 (1909) pp. 46-50.

[Translation.]

TESTING METHODS OF PRODUCING HIGH VACUA.

BY KARL SCHEEL AND WILHELM HEUSE.

(Report from the Physical Technical Society.)

In a previous article we have shown that the vacuum gauge of McLeod may be used in producing the lowest pressure, when following certain precautions. In using this apparatus we have now quantitatively investigated the efficiency of the present-day methods for producing high vacua.

The receiver of the vacuum gauge of McLeod as used held 400 ccm.; its perfectly cylindrical capillaries had a diameter of 0.5 mm. The highest measurable pressure amounted to about 0.07 mm.; the instrument had a measuring range down to 0,00005 mm.

In addition to the vacuum gauge of McLeod, the air pumps to be tested were to evacuate a receiver holding a content of 6 liters. The connecting means between the vacuum gauge, receiver and the respective pump in use consisted of glass tubes having a width of at least 12 mm., and a length of about 1½ m. In front of the vacuum gauge a glass cock provided with a bore of about 3 mm., in width had been installed.

For the purpose of sufficiently drying the gas, vessels containing phosphoric anhydride had been introduced.

1. *Pump of Toepler.*

The receiver of the pump of Toepler, which prior to its use had carefully been cleaned and dried, held a content of 850 ccm. The test had been made in such a manner that one piston stroke was accomplished every four minutes, said stroke lasting about 2 minutes. The remaining 2 minutes were required for the equalization of the pressure.1)

(1) Remarks: According to a report just issued by M. Kundsen and relating to the transpiration of gases at low pressures, a formula supported by tests is given, said formula rendering it possible to calculate the rate of equalization in a tube system. In accordance therewith, for instance, the period of time required in order that a difference of pressure may be equalized to 1/100 of its amount between two tanks, each holding a content of 200 ccm., through a tube having a length of 1 meter, and a width of 6 mm., amounts approximately to 20 seconds. This period of time, as it occurs during our experiments with low pressure is independent of the pressure itself. We already arrived at similar results in connection with our tests relating to the diaphragm manometer as previously described. The continuation of such particular tests, which confirm the result even quantitatively, have become superfluous by the comprehensive observations of Kundsen.

TABLE I.

Pump of Toepler

Period of Time in Minutes.	Pressure in mm.	
0	0,0645	
12	0,0399	0,62
24	0,0254	0,64
36	0,0163	0,64
48	0,0107	0,65
60	0,00719	0,67
72	0,00459	0,64
84	0,00317	0,69
96	0,00210	0,66
108	0,00141	0,67
120	0,00093	0,66
132	0,00063	0,68
144	0,00048	0,76
156	0,00037	0,77
168	0,00025	0,68
180	0,00024	0,94
192	0,00015	0,62
204	0,00011	0,73
216	$0{,}00007_6$	0,71
228	—	
240	$0{,}00005_3$	
252	$0{,}00003_8$	
264	$0{,}00003_2$	0,71
276	$0{,}00002_5$	0,83
288	$0{,}00002_9$	0,77
300	$0{,}00002_2$	
312	$0{,}00002_4$	

After each of three piston strokes, thus every 12 minutes, a pressure measurement took place by using the manometer of McLeod. Table 1 shows the results of such series of measurements.

The last column of the table indicates the quotient between two consecutive pressure values. In the first part of the series, this quotient precisely corresponds to the ratio existing between the space to be evacuated and the receiver of the pump of Toepler, said quotient considerably increasing only towards the end of the series. The lowest obtainable pressure amounts to exactly 0,00002 mm.; this value coincides with a value of 0,000012 mm., found by Hagan.

2. *Mercury Jet Pump of Zehnder.*

The results of tests made by Zehnder, who obtained end pressures down to 0,001 mm., have been confirmed. Of course, the period of time required therefor had been considerably greater, amounting to several hours as compared with about 25 minutes in connection with a receiver of 600 ccm., by Zehnder.

3. *Pump of Gaede.*

For testing purposes the newest model of the pump of Gaede has been used, said pump having been provided with a porcelain drum encircled by a rubber valve ring, as required the pump had been filled up with 1500 ccm., of mercury, rotating at a rate of speed of 22 revolutions per minute.

In its second column, starting from a pressure of about 12 mm., and using the water air pump as preliminary pump, Table 2 indicates the decrease of the pressure according to the readings made at intervals of 5 minutes on the manometer of McLeod. The lowest pressure amounts to about 0,00006 mm., being obtained in about 45 minutes.

TABLE 2

Pump of Gaede

Time Minutes	Pressure in mm. Prepumped with	
	Water Air Pump	Valveless Pump
0	12	12
5	—	0,066
10	0,0180	0,00552
15	0,00273	0,00054
20	0,00057	0,00009
25	0,00016	$0,00001_8$
30	0,00011	$0,00001_2$
45	$0,00006_5$	$0,00001_3$
60	$0,00006_6$	$0,00001_1$

Much better results are produced when using a rapidly conveying oil pump instead of employing a water air pump. In the present instance the valveless pump of Gaede was used. The results obtained therewith have been indicated in the third column of Table 2, after 25 minutes. As the lowest pressure 0.00001 mm. was obtained.

In order to appreciate this value, attention is called to the fact that the entire system including the pump of Gaede continuously supplies a quantity of gas, which in 20 minutes would increase the pressure about 0,0001 mm. (approx. 0,0008 mm. after 24 hours).

4. *Mercury Pump of O. Roden S. Rosenthal.*

The pump is similar to a double-acting pump of Toepler. Its advantages as compared with the pump of Toepler, reside, on the one hand, in that it requires but a small amount of mercury (3,15 kg.), and on the other hand in that there is almost constantly a connection present between the receiver of the pump holding about ½ liter and the space to be evacuated. Another advantage to be considered is that the mercury does not come in contact with the open air during the operation, it being moved solely between vacuum and pre-vacuum, the use of hoses, being avoided. Finally, it is to be mentioned that the pump is to be constantly driven by a motor.

As expected, the pump rendered much better results, than could have been accomplished with a pump of Toepler provided with the same size of receiver. From Table 3, the progress of the vacuum within a space holding 6 liters, may be noted starting from a water air-pump-vacuum.

TABLE 3
Pump of O. Roden S. Rosenthal

Time Minutes	Pressure in mm.	
0	about 15	
35	0,0324	
45	0,0105	0,33
55	0,00308	0,29
65	0,00094	0,31
75	0,00042	0,45
85	0,00017	0,40
95	$0{,}00007_4$	0,44
105	$0{,}00004_2$	0,57
115	$0{,}00003_5$	
125	$0{,}00002_1$	
135	$0{,}00002_0$	
145	$0{,}00002_0$	

if the receiver of the pump carries out 10 to 12 semi-piston strokes per minute. The end pressure is the same as it occurs in connection with the pump of Toepler, (0,00002 mm.).

5. *Carbon in Liquid Air.*

The carbon had been prepared from coconut shells by glowing same for 3/4 of an hour in a covered porcelain crucible exposed to a blast flame, previous to its being placed, in a glowing state, into a vacuum—"Exsikkator", where it remained until required for use. During the test the carbon (each 15 g.) remained in two cylindrical glass vessels I and II, which were fused to the system to be evacuated and which could be individually shut off from said system by means of cocks provided with large bores.

TABLE 4
Coconut Shell in Fluid Air.

Time Minutes		Pressure in mm.
—		12
0	Carbon I in fl. A.	
6		—
12		0,0149
18		0,00358
24		0,00186
30		0,00153
36		0,00142
42		—
48		0,00127
	Carbon II from G.	
52		>0,1
60		0,0286
72		0,00225
78		0,00147
84		0,00184
94	Carbon II in fl. A.	
108		0,00123
114		0,00094
126		0,00071
138		0,00054
150		0,00039
162		0,00034
174		0,00031
186		0,00029
198		0,00027
210		0,00026
270		0,00031

The tests were made in such a manner that, at first, both vessels containing the carbon were heated by using an interengaging drying pipe at the water pump. As soon as could be noted that the discharge of gas from the carbon stopped, then the heating was interrupted after disconnection from the water pump. After cooling of both carbons, carbon I was admitted to the fluid air acting upon the system.

The pressures as measured at intervals of 6 minutes have been indicated in Table 4. The decrease of pressure in the system at first takes place very rapidly, and, upon reaching 0, 001 mm., almost stops.

In continuation of the test carbon II had been extracted from gas, by heating into the vacuum of the system. Thereby the pressure increased to more than 0.1 mm., however, it was rapidly lowered to the former value of 0,001 mm., by the action of carbon I. Now, carbon I was disconnected, while carbon II was led into the fluid air; after 120 minutes, the lowest pressure of 0,00026 mm., had been reached, said result is supposed to be due to the yield of gases contained in the atmospheric air, which could not be absorbed by the carbon. If this non-absorbable portion was removed after the disconnection of the carbon from the receiver by using the pump of Gaede, then the gas reproduced by heating the carbon in a test analogous to the preceding one, had again been absorbed by carbon I up to a pressure of 0,0025, and by carbon II up to a pressure of 0,0001 mm.

TABLE 5

Coconut Carbon in Fluid Air (Prepumped with a Pump of Gaede)

Time Minutes	Pressure in mm.
0	0,0059[illegible]
4	0,00380
10	0,00189
16	0,00062
22	0,00021
28	$0{,}00006_8$
34	$0{,}00002_1$
40	$0{,}00001_1$
52	$0{,}00001_1$
82	$0{,}00000_9$
112	$0{,}00000_7$

More favorable results were obtained within a short period of time with the coconut carbon in fluid air when starting out not from a water air-pump-vacuum, but from a lower pressure, say for instance 0,01 mm., as it can be produced by using the pump of Gaede in connection with the use of the water air pump as preliminary pump, even at large spaces, and with other pumps, at least as long as the receiver remains small. The Table 5 contains the results of such a series in which the starting vacuum 0,006 mm., had been produced by using a pump of Gaede. A pressure of 0,00001 mm., had been obtained after using of but one vessel filled with carbon after 40 minutes, apparently decreased slightly within the following hour.

This result is especially important because it shows that a vacuum of 0,00001 mm. may be produced and maintained for a longer period of time, without subjecting the apparatus to shocks, etc., as this is the case when operating mercury air pumps.

DEFENDANT'S EXHIBIT No. 4.

Physikalische Zeitschrift,
Vol. 29, pp. 46-50

[TRANSLATION]

Treatise Dealing with a New Construction of the Mercury Pump of Toepler, Also Describing Some Experiments Made Therewith.

By ERNST BESSEL-HAGEN.

As to the various experiments which Mr. Crookes recently made regarding electric discharge and radiometric phenomena in strongly rarefied gases, he accomplished extraordinary evacuations, using the mercury air pump of Sprengel, improved by Ch. H. Ginningham (see Proc. Roy. Soc. 25 p. 396-402 Beibl. 1 p. 175-1877). According to the theory, this device permits of obtaining any degree of rarefaction provided that the mercury which continuously passes through the down pipe of the pump does not carry along any small quantity of air from the open atmosphere, discharging such air into the spaces to be rarefied. The chief drawback of the air pump of Sprengel, which will be obvious to everyone who had an opportunity of operating therewith, resides in that the rarefaction proceeds but slowly. Now, Mr. Ginningham has endeavored to lessen said drawback in that he built a pump based upon the principle of Sprengel, according to which he made use of three interconnected downpipes, instead of using but one; to these pipes the mercury being supplied from a common tank.

As far as its efficiency is concerned, the apparatus as constructed by Mr. Ginningham is, no doubt, thoroughly perfect, and Mr. Crookes has obtained with it the highest rarefactions as could possibly be had ever before. The apparatus, however, is complicated and fragile to such an extent that it became desirable to investigate whether it would not be possible to produce rarefactions just as high by using the extraordinarily ingenious and far simpler mercury air pump mentioned by Mr. Toepler, than it could be obtained with the one of Sprengel-Ginningham used by Mr. Crookes. It has been found that this not only had been the case, but also that it is even possible to obtain a considerably higher degree of rarefaction therewith (compare p. 138).

For the purpose of my experiments, I have slightly changed the original form of the air pump of Toepler, and refer to the main treatise as to its construction. Due to these changes, a pump has been produced in which, without using any cocks or the like, the connection with the recipient is established by glass and mercury only, whereby the limit up to which the rarefaction of the gas may be effected, is considerably increased than it would be the case in connection with the original construction, also its fragility is being materially decreased.

Description of the pump:

The arrangement and instalment of the pump may be seen from Table III, Figs. 7 and 8.

The glass tube A, the lower end of which is connected with the mercury tank Q by the thick-walled, black rubber hose S provided with a hemp lining, carries the air pump ball K on its upper end, from which ball branches the downwardly bent outlet tube B, being 2 mm. in width and 815 mm. in length, said outlet tube being bent upwardly opens into the tube C having a width of 13 mm. and a length of 250 mm.

The sections of the tube A located beyond and below the bulb K are connected with one another by a tube D of rather large diameter and bent in an obtuse angle, the purpose of said tube D being to avoid violent shocks which otherwise would occur upon the air passing from the recipient into the ball of the pump. At a point located below the lower end of the ball K, an ascending pipe open at its top and having a length of 110 cm. is molten to the tube D. By means of a suitable cork a pipe F serving as a mercury trough (made of a bottle, the bottom of which is burst off) is placed upon the ascending pipe E, mercury-tight (compare Table III, Figs. 7 and 8). In order to establish the connection between the pump and the recipient the apparatus is equipped with two long U-shaped pipes. One of these pipes (Table III, Fig. 7, designated G_1) carries the horizontal pipe H, to which the recipient (for instance as in our drawing a Geissler tube R) is molten, this being effected subsequent to the introduction of a small amount of phospheric anhydride into the drying ball M, and after the pipe I has been closed by melting. If now, upon opening the wooden member J, the free portion of the pipe G, be put over the ascending pipe E, until its lower end is sufficiently immersed in the mercury of the trough, and furthermore, if the pipe C and the mercury tank Q upon both of which a drying pipe containing calcium chloride is mounted, are filled with mercury, then the apparatus is ready for use (compare remark 1).

Remark 1: On publication of his sketch (Wied. Anm. 11, p. 522-1880) relative to a double acting, not yet manufactured mercury air pump, Mr. Neeson has changed his mercury air pump, as described in Wied. Anm. 3, p. 608, 1878, which, by the way, has been entirely unsatisfactory as to obtaining high rarefactions, in that he does away with the glass valves, substituting therefor, the construction of the outlet pipe of Toepler, as suggested by mr, and which advantages have been outlined on p. 433. In this manner, he has constructed an apparatus which, in its essential parts, covers the air pump of Toepler as hereintofore described. I wish to call attention to the fact that Mr. Florence Mueller (Berlin W. Kronenstr 71) for a period of three years, manufactures the air pump of Toepler according to my directions, i. e., a pump provided with a side pipe D and a pipe C directly sealed to the pump, these pumps are used by the Physical Institute to its full satisfaction.

The purpose of establishing a connection between the recipient and the air pump by putting over the one shank of the U—pipe G,—an arrangement, the construction of which is due to an identical suggestion made to me by Mr. Helmholtz—is to dispense with the application of a ground joint, yet to be in a position to easily connect the recipient with the pump or to disconnect it therefrom, also to use only glass and mercury as a closing means. If, namely, the recipient be evacuated by means of the pump, then the mercury rises from within the trough F into the space formed between the ascending pipe E and the shank or portion turned upside down of the U-shaped pipe G, however, it does not permit of any air from the open to pass into the recipient, since the length of the tube E as measured from the bottom of the trough F considerably exceeds that of the barometric mercury column.

One realizes that in this manner all faulty sources are excluded, which in connection with any other pumps equipped with ground cocks and lubricants must necessarily be present.

It is for this reason, that the present pump is extremely well adapted to be used in the manufacture of standard barometers, etc. For common use in laboratories, where, a rarefaction as high as possible is ordinarily not sought, and where fat vapors do not act destructive, it will of course be more preferable and convenient to establish the connection between the recipient and the pump by using suitable ground joint. For this purpose, the pump is provided with a second U-shaped connecting pipe G_2 (Table II, Fig. 8), which in these instances is intended to substitute that one just described above. Said second pipe G_2 also is provided with a drying ball M, adapted to receive phospheric anhydride, and equipped with a *"tubus"* and ground plug, to the upper portion of which is molten a ground joint N, into which a T-piece provided with two cocks may be inserted. Said T-piece serves as a connecting means with the recipient, and it also permits through cock W, of feeding air or gas either into the evacuated recipient or to the pump.

In order to again introduce air into the evacuated pump, without danger for the latter, on application of the first mentioned U-shaped connecting pipe, and subsequent to the experiment accomplished, it is advisable to pull out the tube I to be filled with phospheric anhydride into a very narrow capillary and to seal the latter subsequently. Then, all that is necessary in order to admit air after the experiment has been made is to open the point of the capillary tube. Of course, in order to accomplish this it is necessary that the tank Q previously be brought into its lowermost position so that the aperture of Pipe E leading to the ball K of the pump becomes free.

If it is desired to again introduce other gases into the recipients without resorting to a cock or the like, then it is necessary that an upright U-shaped pipe (compare Table [illegible], Fig. 8^a) located between the recipients and the vessels to be filled with such gases be used, the U-shaped pipe being 80 cm. in length. Said U-shaped pipe is furthermore provided with a smaller pipe molten thereto, which is connected with a mercury tank identical to that indicated at Q in Table III, Fig. 7. Any up- or downward movement of the tank forces the mercury to pass into the shanks or portions of the U-shaped pipe, or compels it to escape therefrom, thus it interrupts or restores the connection of the recipient with the gas filled spaces, as desired.

As far as the instalment of the pump is concerned, the entire pipe system is attached to a board in such a manner that the lower portion of the ball K is embraced by a sufficiently wide metallic strip which is filled up by gypsum, the remaining parts of the pipes are secured to the wood by means of screws. Upon the back of the board, a strutted board, horizontally arranged is secured to said first board so as to render it possible to fasten the pump to the experiment table by means of a screw. It is advisable to use this very way of installing the apparatus as the latter, in spite of its considerable weight, is not oscillating as it would be the case when using supports such as feet, etc. As can be seen from the figure a cork lined metallic clamp screw, at U, secured to the support serves for fixing the pipe H leading to the recipient and to the ground joint N respectively. The adjustable board fastened to the wooden support of the pump itself serves for the purpose of supporting the mercury vessel Q, when carrying the pump. In use the vessel is loosely held by the carrier T to be adjusted in any suitable height.

The manipulation of pumping is exceedingly simple, it merely consists of lifting and lowering the mercury vessel Q. I wish to briefly state this operation of the pump, taking into consideration the original treatise of Toepler: "If the mercury tank" is raised, then, as soon as the mercury within the pipe A rises until it reaches the point where pipe E opens into the recipient, the communication of the ball K and the recipient is interrupted by the mercury column rising in pipe E, whereas the air contained in the ball K is more and more compressed, until it escapes in the form of bubbles by passing through the mercury in the outlet pipe B C. If the tank Q be lifted to such an extent that the entire ball K is filled with mercury up to the mark O, and if there be no longer any escape of air bubbles at C, then the vessel Q is lowered, the mercury forthwith returns from the ball K and from the ascending pipe E, the opening of the latter becomes free, and the air contained in the recipient passes through the pipe D into the ball K. At the same time the mercury will rise in outlet pipe B from C, likewise from the trough F, in the space produced between the ascending pipe E and the pipe G, to a height which corresponds to the difference of the tension of the open air and of the air contained in the recipient. If the mercury drops from the bulb K until it reaches a point below the point of attachment of the pipe E, then the mercury vessel Q is again lifted, thus the connection between the ball K and the recipient is again interrupted by the mercury column rising within the ascending pipe, the tension of the air increases, the mercury column in B drops, until finally again a portion of the air previously contained in the recipient is removed to the open through the mercury located in the pipe C. It is noted that the air, if once removed from C, will never again return to the apparatus, as the pipe C is longer than is the height of the barometric mercury column. This kind of pumping is continued, until none or very few air bubbles escape at C. The outlet pipe B remains filled with air, the tension of which being equal to that of the atmosphere, augmented by the small mercury column, so that the mercury stands higher in C than in B. This amount of air filling the pipe B corresponds to that quantity having been left in the so-called "injurious" space of the ordinary air pumps. However, in order to eliminate same, it is necessary to lift the vessel Q slowly higher, until the mercury enters the outlet pipe B from the bulb K, thereby driving before it the air that has remained in the pipe, into the atmosphere. If now the mercury vessel be brought to its lowermost position, then a Toricelli-vacuum is formed above the mercury in the ball K, into which vacuum the air contained in the recipient is expanded as soon as the opening of the pipe E becomes free. The mercury flowing from tank Q to C during this pumping operation causes that the difference in height between the mercury level in the pipe C and the highest point of the tube B became smaller than is the length of the barometric mercury column, and, therefore, the atmospheric pressure automatically forces back the mercury which had been transferred to C, until the difference in height again becomes equal to the length of the barometric mercury column.

It is evident that the rarefaction may be carried on very far by repeatedly carrying out the process. In order that the air left in the pipe B be completely eliminated by the flowing mercury, the pipe B is given a suitable width (about 2 mm.), it also must terminate into the funnel-shaped pipe C (not hemispherical). This is important in case best possible rarefactions are to be obtained. If, for instance, as this is the case in connection with the original construction of the pump of Toepler, the pipe B (no matter whether straight or inclined) would be cut off below and immersed in a small upright cylinder partially filled with mercury, then the air bubble to be removed would obstinately adhere to the lower, acute edge of the outlet pipe B, is forced back by the mercury flowing back into the ball K, thereby rendering further evacuation slow, if not making it entirely impossible.

It has already been stated before that the final lifting of the tank Q is to be effected *slowly*, by means of which the flowing of the mercury from the ball K into the pipe B is effected so as to force the quantity of air left in said ball into the open. This is necessary, as otherwise the mercury jet entering the outlet pipe B at high rarefactions, during which the whole amount of air remaining in the ball K is finally compressed to a microscopic air bubble, would strike the mercury column in the pipe B so violently that the apparatus would be liable to be destroyed. For the reason, the support or carrier T of the mercury vessel Q is given only a restricted movement by using stop pins operating in one of the holes X and Y of the wooden column of the support either up- or downwards so that the mercury level Q in the highest and in the lowest position of the carrier T remains lower, i. e., almost equal to the length of the barometric mercury column, than the upper or lower discharge point of the pipe D. It is now possible without any danger to the pump, to always convey the mercury tank Q directly from its lowermost position into its highest position by means of the crank and the shaft secured to the support, the atmospheric pressure then rapidly removes the greater portion of the mercury from the vessel Q to the pump ball K, so that now, after this has been accomplished, the almost empty tank Q may be taken off the carrier T and be lifted so far that an overflow through the outlet pipe C is taken place. After the air has been carried off into the open by means of the mercury in the outlet pipe C, then the vessel Q is again attached to its carrier T where it is moved in its lowermost position by means of the crank.

Method of Measuring Pressure. A very marked advantage of the pump (to which Mr. Toepler made as yet no reference in his original description of the apparatus) consists in the fact that it permits the measurement of the pressure with every single stroke of the piston. (Mr. Toepler, in the Sitzungsber. der naturw. Ges. Isis in Dresden, 1877, p. 135, mentioned shortly). For this purpose there is fixed behind the tube B a scale which carries on one side a millimeter division, on the other side a volumetric division of tube B from 1/10 ccm. up, calculated from the intake point O forward. Furthermore, the common volume V of sphere K and the lateral tube D is determined by the mark O to the point of contact of tube E leading to the receptacle (recipient).

In order to make a measurement of pressure (this method of measuring pressure originated with Arago. See Regnault, relation des expériences. I. p. 491, Footnote, 1847) it is to be observed what is the position of the upper head of the mercury column in discharge pipe B:

(1) If reservoir Q is so far depressed that the pump ball K comes in contact with receptacle by means of tube E;

(2) When the quantity of gas contained in ball K is so far depressed by lifting mercury container Q as to fill with mercury the entire ball K to the point O, that is that the entire quantity of gas which before filled pump ball K

(3) only assumes now but a certain number v of decimal cubic centimeters in tube B.

If we name the volume of the gas V in the first case, x the pressure sought, v the volume of gas in the second case and h the number of millimeters constituting the difference of the two readings 1 and 2 of the position of the mercury column in tube B, then (if the cross section of tube B is small against that of C) manifestly this h is the increment of pressure which arose by compressing gas volume V to volume v, whereby its pressure must have risen to the magnitude (x + h). According to the Law of Mariotte there is found:

$$V.x = r(x + h)$$

and hence the sought for pressure obtaining in the receptacle

$$x = \frac{v}{V - v}.h$$

or, under the admissible supposition that V is very large in comparison with v:

$$x = \frac{v}{V}.h.$$

Data of the rarefactions obtainable by means of the Geissler, Toepler and Sprengel Air pumps.

I. Geissler Pump of the old construction (Wuellner, Exp.-Physik. 3 Edit. 1, p. 405, 1874, Mousson Physik 3rd Edit. 1, p. 178, 1879). In order to determine the limit of rarefaction for the Geissler mercury pump of the older construction, in which the doubly perforated cock by the well known method permits the reciprocal connection of the air-pump ball with the receptacle or direct with the atmosphere, tube described in Table III, Fig. 7, with H of the previously described Toepler Air Pump, was connected by means of a Kundt glass spring through soldering to the connecting pipe of the Geissler Pump (Kundt, Pogg. Footnote 155, p. 364 and 365, 1875). The first formed so to speak the receptacle for the latter, was exhausted by means of this and the rarefaction obtained after 20-25 strokes of the piston was measured by means of the Toepler Pump used only as pressure measuring device. The exhaustion was continued until there was no further indication of the diminution of the pressure.

The maximum of the rarefaction obtained was found to be 0.11 mm = 145 millionth of an atmosphere.

The reason why this pump does not permit of an even larger rarefaction degree is found in the fact that the mercury does not lie perfectly uniform on the glass walls when the gas contents of the air pump ball are driven out, whereby the wall of that part of the ball which is situated directly under the cock becomes invested with an air layer of the tension of one atmosphere, and furthermore chiefly in the fact that exactly in this space there arise unavoidably some small air bubbles which accordingly obstruct every further exhaustion of the quantity of air remaining in the so-called injurious space of the ordinary pump.

II. Geissler Pump of the new construction. The last-mentioned drawback was in the first place eliminated in a pump constructed in 1873 for the local institut and later on pretty generally by placing above the two-way cock an intermediate piece Z (see Table III, Fig. 9) closable by means of a special cock. In this construction the ball of the air pump never comes in direct contact with the atmosphere, and the rarefaction obtained by means of these pumps is incomparably higher.

Similarly to the above the Toepler Air pump was used as receptacle and pressure measuring appliance and exhausted with the Geissler pump.

The maximum rarefaction was found = 0.0082 mm,
after another 25 piston strokes x = 0.0085
25 0.0089
25 0.0086
25 0.0034
25 0.0084
average 0.0085 mm.

which numbers show that a further pumping would be of no use.

The pumps were now left in unaltered connection, in the first place in order to test the airtightness of all the cocks and slide pieces and then pumped a few times with the Toepler air pump, so that now the Geissler pump served as receptacle.

After pumping five times with the Toepler pump the pressure sank to 0.0075 mm. after a further pumping five times to 0.0064 mm.

It is recognized that the rarefaction here takes place much faster, which is all the more remarkable as the volume of the Geissler air pump ball was almost 800 ccm. that of the Toepler pump used only 474 ccm.

III. Toepler Pump (new form). In order to determine the limit of rarefaction of the Toepler pump of the construction before us, tube indicated with H in Table III, Fig. 7, was directly soldered, after phosphoric acid anhydride was poured into the dry ball through tube L and L was also thereupon closed by means of soldering. The rarefaction can be carried so far that there arises only a very small almost imperceptible depression of the mercury column in tube B, when the gas volume V in pump ball K is compressed to point O, that is to a certain volume v of the discharge pipe by means of suitable lifting of mercury receptacle Q. This depression had therefore to be measured by means of a microscope provided with a thread micrometer of long focal length. Before every reading, the mercury column was shaken by means of a slight tapping, so that the mercury head become freely settled. This is of course not entirely exact, but the following numerical data, obtained independently of one another, give us an idea how far this was the case, and regarding the absolute magnitude of the pressure increment h resulting from the diminution of volume. At the same time pressures p are also indicated alongside of the observation data required for their calculation: Marks V, v, h have the meaning indicated on p. 435.

V	v	h	Attained Rarefaction p
			mm.
615.4 ccm.	0.112 ccm.	0.075	0.000 014 = 1/54 millionth atmosph.
" "	0.112 "	0.084	0.000 015 = 1/50 " "
" "	0.104 "	0.054	0.000 009 = 1/84 " "
" "	0.112 "	0.078	0.000 014 = 1/54 " "
" "	0.112 "	0.044	0.000 008 = 1/95 " "
" "	0.104 "	0.060	0.000 010 = 1/76 " "

Average limit of rarefaction attained = 0.0000012 mm. corresponding to 1/63 millionth atmosphere, while

Mr. Crookes could reach only a rarefaction up to 0.000 046 mm = $\frac{1}{17}$ millionth of an atmosphere with the Sprengel-Ginningham pump. The reason why the Sprengel pump did not allow of the attainment of a still higher rarefaction was indicated at the beginning of this paper. According to a newspaper report (Rood, The New York Times, Nov. 19, 1880, p. 2, Sp. 3), Prof. Ogden N. Rood, of Columbia College in New York, succeeded in developing the rarefaction limit of the Sprengel Pump to $\frac{1}{64}$, and in one instance even to $\frac{1}{110}$ millionth atmosphere, by transmitting the mercury from a vessel which was itself exhausted into the drop tube of the air pump and thus made the taking along of the air bubbles impossible.

It is absolutely necessary that all the parts of the pump should be dry in order to attain such high rarefactions, and it is advisable to heat the tubes or vessels to be exhausted during the operation of exhaustion, during 24 hours if possible, to about 300° in the air bath, in order thus to separate the air film which adheres to the glass with extraordinary tenacity. If therefore exhausted vessels are desired to be closed by fusion under a given pressure, the respective part should be heated beforehand almost to the point of the softening of the glass and until an increase of pressure no longer takes place through further heating. The elimination of the air film may be obtained still more perfectly by sending electric discharges through the vessels to be exhausted during the pumping. Electricity needs the ponderable air particles as venicle in order to pass from one electrode to the other, and the result is that the air adhering to the glass wall is gradually loosened through the electric discharges, which may be directly proven by the increase of the pressure. The Geissler tube illustrated in Fig. 7, Table III, was exhausted down to 0.0009 mm., when during a certain time electric discharges were sent through it from an influence electrification machine; the gas glowed feebly, the glass wall was strongly phosphorescent. When the pressure was again measured in the usual way, it was found to be = 0.017 mm., hence had risen to almost double its previous magnitude. A part of the loosened air was again exhausted through further pumping, until the pressure was again almost 0.0009 mm. After electric discharges were again passed through for 5 minutes, the pressure became = 0.013 mm. That this increase of pressure could not be due to the rise of the temperature of the gas residue, may be proven simply by the fact that the volume of the Geissler tubes through which the electric sparks passed was about 300 cm., while that of the pump ball, dry vessel, etc., with which it was in constant connection, was over 500 cm. Whether this quantity of air originated from the electrodes or from the glass wall, could not be determined in advance; but that it did not originate only from the metal electrodes, may be seen from the fact that the pressure increase arose even in an electrodeless tube produced according to Gassiot's suggestion (Gassiot, Phil. Mag. 16, p. 308, 1858) on which two tinfoil layers were pasted on the outside, and which was made luminous only through the effect of induction. If the spark current is stopped and the tube is allowed to remain uninfluenced, the original pressure again returns gradually (after about 6 hours) even if not exactly, still at least approximately—whether through the absorption of the previously loosened air on the electrodes or the glass wall was not decided.

It was of special interest to verify whether under the highest attainable rarefactions the vacuum is really perfectly impervious for electric discharges or not. It is well known that the so-called Geissler absolute vacuum tubes, which according to Andrews' (Andrews, Phil. Mag. (4), 3, p. 104-108, 1852—Pogg. Ann. Footnote 88, p. 309-314, 1858) suggestion are first filled with carbonic acid, then exhausted and entirely cleared of their last vestige of gas through absorption by means of potassium hydrate, do not allow electric discharges to pass through between their wire-like electrodes brought to within 2 mm. of each other. Accordingly, the gas seems to be impervious to electric discharges at such high rarefactions. However, this is not at all the case. If fairly large metal plates are taken instead of the wirelike electrodes (the tube illustrated in Fig. 7, Table III, contained, besides the wirelike plates two other square, rolled up aluminum plates of a lateral length of 10 cm.), there still occurs electric passage in the interior of the tube under application of strong sparks, strengthened by means of Leyden jars, from an efficient influence machine, which is discernible through an intermittent, even though feeble phosphorescence of the glass wall, while at the same time the electricity discharges outside at the tube between the electrodes in loud crackling sparks. As a rule it is not possible to perform this experiment for a considerable time, for the tubes are almost regularly punctured by the sparks in the proximity of the one or the other electrode, which is then discernible on the immediately altered light phenomenon. This by itself very noteworthy phenomenon seems to be explicable by saying that the outer and inner wall of the Geissler tube charges itself from the electrodes similarly to a Leyden jar, until the tension difference becomes so high that the wall is broken through.

Of course, all the above gas pressure measurements indicate not the true, but only the partial pressure of the rarefied gas, for the pressure developed by the vapors of the mercury of the pump cannot be measured in the above way. Regnault gives the following values for the tension of the mercury vapor: (Regnault, Rel. d. Exper. 2, p. 520, 1862).

at 0° e = 0.0200 mm.
20° = 0.0372 mm.

These figures are somewhat too high as I found after a series of verifying experiments; the results of the latter, which I hope to be able to publish shortly, were found:

at 0° e = 0.0148 mm.
20° = 0.0201 mm.

It is never possible to get below this absolute pressure in the interior of the vessels to be exhausted, (Provided it is not possible to absorb the mercury vapors through some chemical means, e.g., metal gold, in a vessel containing only mercury vapors, with the vessel completely sealed on all sides) for with the use of mercury air pumps we have manifestly always to deal with spaces which contain saturated mercury vapors. It is surprising that the electric discharge phenomena, while the vessel is being exhausted, alter so strongly with the increasing gas rarefaction, although the true pressure—which is then chiefly represented through the tension of the mercury vapors—relatively hardly changes. According to this, the mercury vapor seems to have no importance in the electric discharges, it seems to be an insulator of electricity, similarly to water gas, which is an insulator, while running water is a conductor.

However, that we really have to do with spaces in all the parts connected with the mercury pump, which are filled with mercury vapor, may be proven with ease. All we need is to keep at a lower temperature for a considerable time any part of the wall of the spaces to be examined for this purpose, in order to obtain clearly discernible balls of condensed mercury.

Even if—as Mr. Crookes has done (Crookes, Phil. Trans. 2, p. 547, 1875)—the spaces to be exhausted are heated to red incandescence during the process of exhaustion and then sealed, even then upon cooling the apparatus to room temperature the partial pressure of the mercury vapor is still almost fifty times as high as that of the rarefied gases (Zoellner, Das Scalenphotometer, p. 37, 1879), and it must not be neglected of course in the considerations and calculations of the radiometric movements. On the other hand, the radiometric movements are unquestionably dependent on the pressure of the mercury vapor, as the two following experiments show.

(1) If a radiometer filled with air is exhausted almost to its limit, to which there is fused below a tube

of the length of about 15 cm., and at which the maximum sensitiveness arose for Mr. Crookes, so that, however, the latter has not yet been reached, and then it is caused to rotate by means of a candle and then the tube mentioned and sealed below is cooled by means of a cooling mixture, the pressure in the interior of the device is then diminished by the fact that the mercury vapors assume the correspondingly lower tension of the temperature of the cooling mixture, and as a result of this diminution of pressure the radiometer receives a higher rotational speed, which is of course not considerable, but which can still be measured with certainty. (Proportion of the number of rotations in one minute in an apparatus exhausted down to 0.04003, as 24:26, in other experiments 41:44).

(2) There was attached to a very thin, about 30 cm. long glass thread a mica plate 30 mm. wide and 70 mm. long, which was coated with soot on the respective halves of its front and back side, and which carried a round mirror α connected with it. The entire thing was enclosed in a wide tube illustrated in Fig. 10, Table III, which carried an about 10 mm. wide cooling tube, like the radiometer in the previous experiment, while at the upper end of the apparatus there was attached a tube, which latter was connected with tube H (Table III, Fig. 7) of the mercury pump by fusion. After the apparatus was protected against all influence of rays by covering it with a cylindrical double mantel, the rest position of the mica plate was determined and now the apparatus was exhausted as far as possible. The torsion apparatus still showed a turning even under the utmost attainable rarefaction (0.00001 mm.) as soon as said metal mantle was lifted off and the mica plate was exposed to the radiation of a light source. This deviation was observed by means of a telescope and scale, and it became appreciably less when the lower end of the apparatus was dipped into a cooling mixture as in the case of the above-mentioned experiment and thereby the tension of the mercury vapors was diminished. In or-

der to exclude the possibility of heat conduction in this as in the previous experiment, the upper part of the cooling tube was surrounded by a water vessel and the upper part of the apparatus was protected against rays from below by means of a double metal screen δ. As in the previously described experiment, the volume of the cooled part of the device was to be considered extremely small in comparison with the others, all the more so as both the radiometer and also the torsion apparatus was left in constant connection with the air pump ball during the experiment.

Experiments About Diffusibility of Hydrogen by Means of Continual Exhaustion.

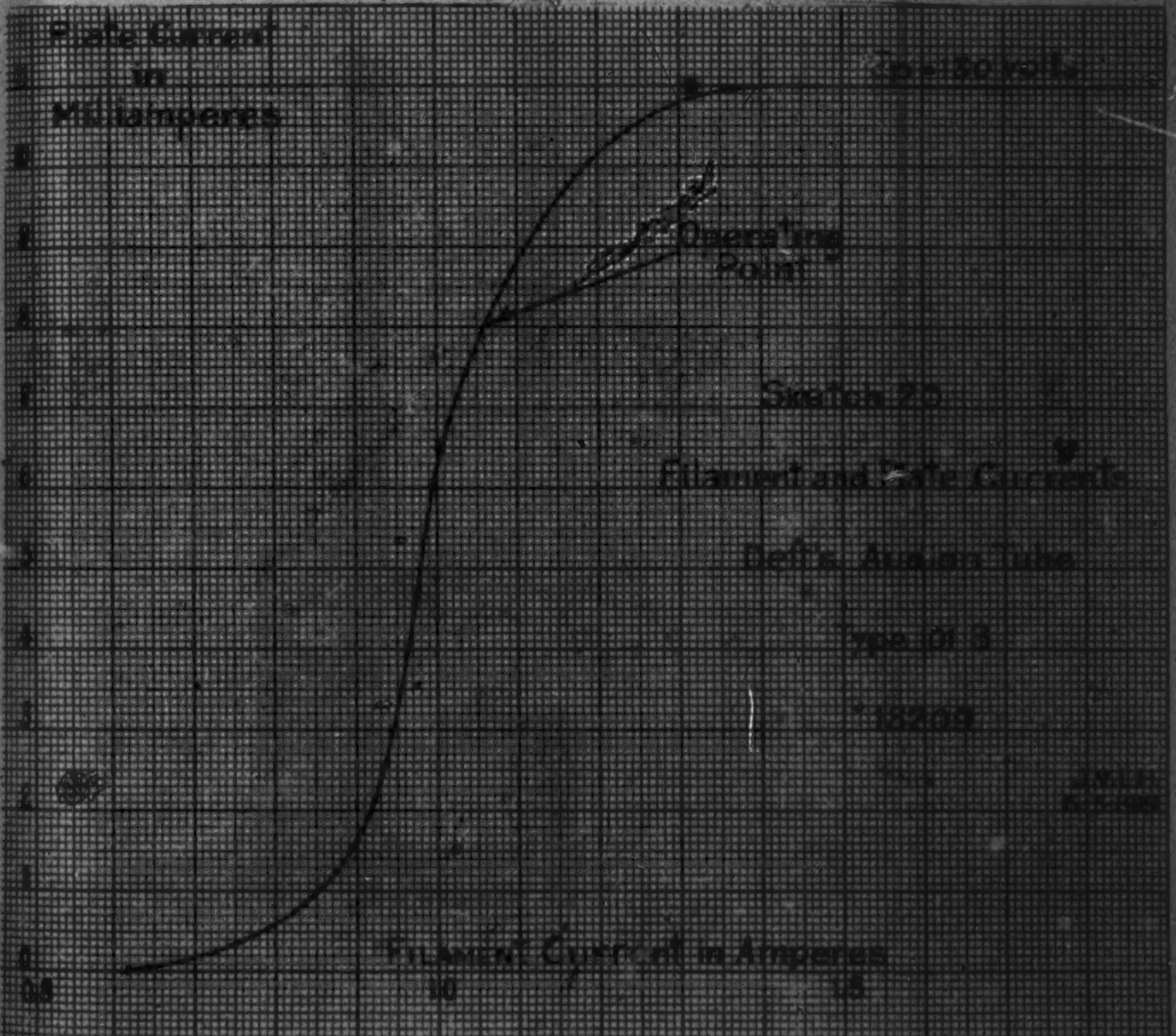
It was mentioned above that the air film resting on the glass is eliminated only very slowly by means of continual exhaustion. It is always observed (even though all parts of the pump are completely tight) that there is a small increase of pressure, when the exhausted apparatuses are allowed to stand for a while. This phenomenon gave occasion to the suspicion that diffusion of the gas might have taken place through the glass itself, unless air seeps through the interjacent space between the glass and the mercury. However, this is not the case, as far as observable from the experiments to be presently described. Direct measurements of pressure could not of course decide this question, much less weighing attempts—as those made by Mr. Quincke (Quincke, Pogg. Footnote 160, p. 118, 1877), who wanted to prove egress of the gases by diffusion through the glass wall through the eventual diminution of the weight of a glass tube filled with hydrogen and with carbonic acid under high pressure (25 to 126 atmospheres). Even the most sensitive scale becomes a relatively insensitive instrument for this verification. The only experiment that gave promise of success seems to be the proof by means of the spectral analysis. For the purpose the tube combination illustrated in Table III, Fig. 11, was attached to the air pump. No. 1 is a spectral tube provided with aluminum electrodes, while in tubes II and III no electrodes are fused, there is attached to tube III a dry ball containing a somewhat concentrated sulphuric acid. Tubes Beta, Gamma, Delta, Epsilon, which connect the three spectral tubes among themselves and with the tube leading to the pump, are drawn out to thick-walled capillaries, in order that they can be easily fused off later on. The apparatus filled with atmospheric air was exhausted to a pressure of about 0.11 mm. (Maximum of the conductivity of the rarified air, corresponding to which the maximum of luminosity, See Morren, Compt. rendu 54, p. 735-737, 1862), thereupon fused off from the pump at Beta and then left hanging for five months, in the meantime several daily put into a slanting position, whereby the sulphuric acid again bedecked the walls of the dry ball and gradually absorbed every trace of water from the other three tubes. After this period the tubes was fused off first at epsilon, then at gamma, and delta. There were thus obtained three spectral tubes separated from one another, and filled with air of the same thickness and the same composition, of which tubes II and III were provided with rolled tinfoil coating for spectral analytic experiments. The spectral analytic examination showed that none of the tubes contained even a trace of hydrogen. Tubes I and II were next imbedded in another tube, which were later tightly drawn, then filled with hydrogen gas and sealed by fusing. Each of these spectral tubes was then surrounded with a hydrogen atmosphere, and when diffusion of the latter arose, the tubes I and II, investigated spectralanalytically, show another spectrum than that which was merely used as a compraison tube No. III, kept in a vessel filled with dry atmospheric air. However, after the lapse of almost one year, there was not shown in either of the tubes such a change, although the spectral analytic indication of hydrogen is, as is well known, very sharp.

It is also to be observed that the further divisions of the spectral tubes were constructed of thin-walled reagent glass.

Physikal. Inst. d. Univ. zu Berlin, Dec. 1880.

DEFENDANT'S EXHIBIT No. 1.

(Pltf.'s Ex. No. 52, Hewitt v. A. T. & T. Co., S. D. of N. Y.)



Defendant's Exhibit No. 4

Taf. III

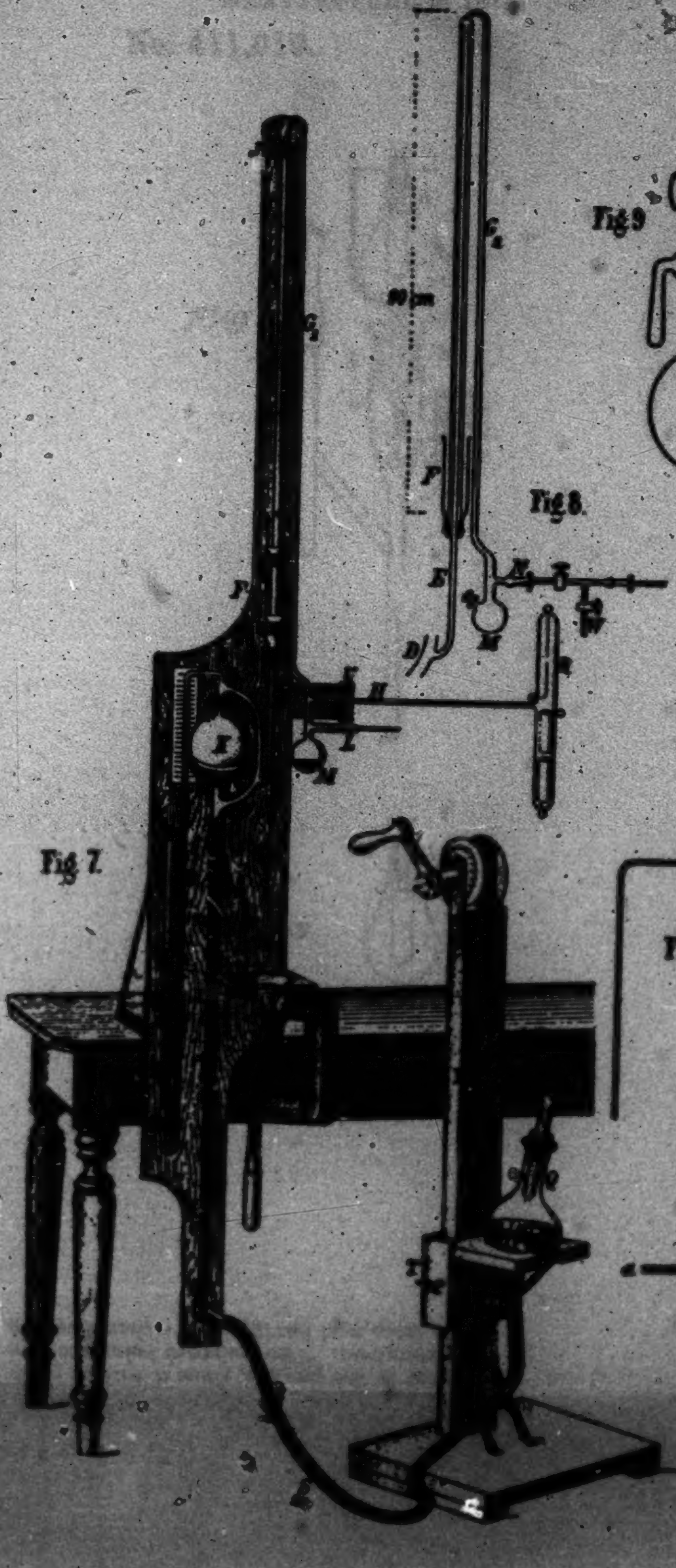

G2
90 cm
F
E
D
N
M
W
R
G2
F
K
H
M

Fig. 7.

Fig. 8.

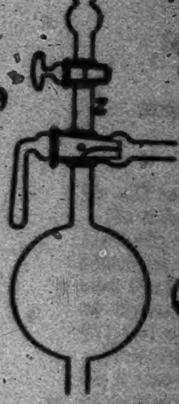


Fig. 9

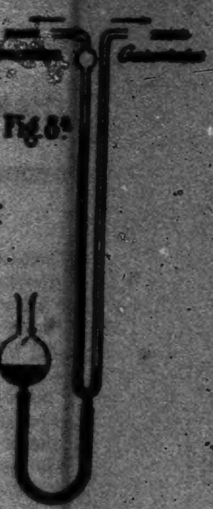


Fig. 8a

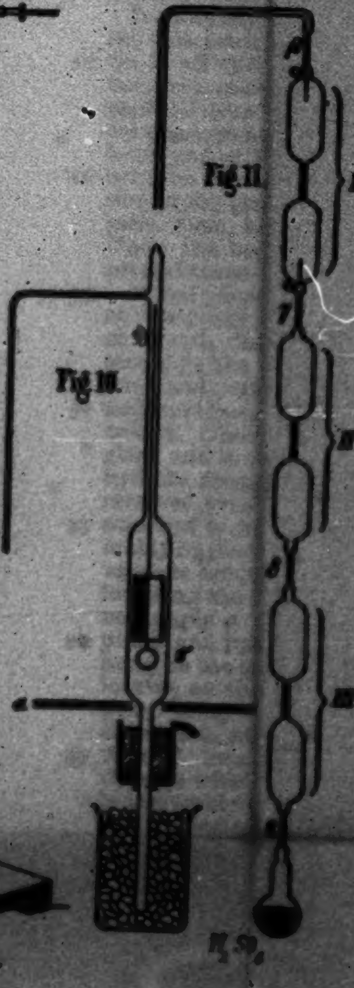

I
II
III
a
H_2SO_4

Fig. 10.

Fig. 11.

DEFENDANT'S EXHIBIT No. 5.

(No Model.)

T. A. EDISON.

MANUFACTURE OF INCANDESCENT ELECTRIC LAMPS.

No. 411,019. Patented Sept. 17, 1889.

Fig. 1.

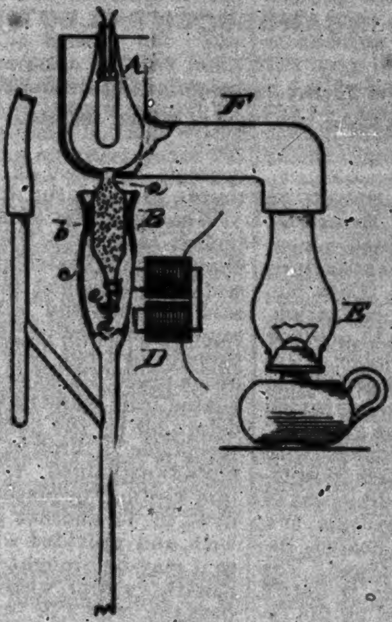

A
F
a
B
b
C
c
e
d
D
E

Fig. 2.

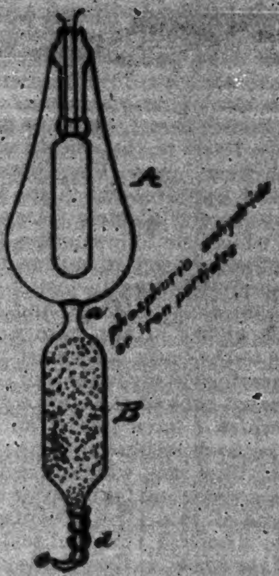

A
a
phosphoric anhydride or iron particles
B
d
e

Fig. 3.

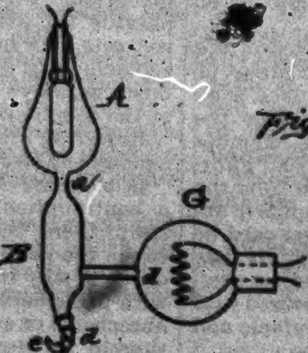
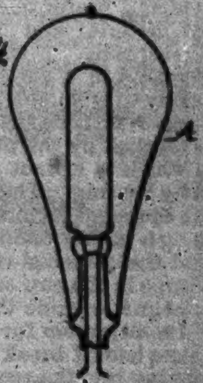


Fig. 4.



ATTEST:

INVENTOR:

Thomas A. Edison

UNITED STATES PATENT OFFICE.

THOMAS A. EDISON, OF LLEWELLYN PARK, NEW JERSEY.

MANUFACTURE OF INCANDESCENT ELECTRIC LAMPS.

SPECIFICATION forming part of Letters Patent No. 411,019, dated September 17, 1889.

Application filed July 30, 1888. Serial No. 299,001. (No model.)

To all whom it may concern:

Be it known that I, THOMAS A. EDISON, of Llewellyn Park, in the county of Essex and State of New Jersey, have invented a new and useful Improvement in the Manufacture of Incandescent Electric Lamps, (Case No. 671,) of which the following is a specification.

The object of my invention is to produce high vacuums in the inclosing-globes of incandescing electric lamps, and especially to rid such globes of the watery vapor which adheres to the inner surface of the glass.

In carrying out my invention I connect with the exhaust-tube of the lamp a glass receptacle in which I have placed an absorbent of moisture, such as phosphoric anhydride, or a material like iron, which, when heated, decomposes water and takes up its oxygen. The lower end of this glass receptacle is drawn out into a hooked tube and sealed by the fusion of the glass, so that the lamp and receptacle form together an air-tight chamber. Upon the hooked end I hang a small coil of several turns of iron wire.

When phosphoric anhydride is used in the attached receptacle, I prefer to coat pieces of glass with that material and to place such pieces in the receptacle. I then place the lamp and receptacle in a suitable chamber and heat the same to from 600° to 800° Fahrenheit. The vapor is thus driven from the glass, and is absorbed by the phosphoric anhydride, from which it cannot afterward be removed even by heating. The whole is then attached to the Sprengel vacuum-pump, preferably by placing a rubber band covered with vaseline around the attached receptacle and inserting the same in the cup of the pump. I now apply a magnet outside the tube of the pump, and by its attraction for the iron wire hung on the glass hook I break off this hook, leaving an opening into the receptacle. The pump being now put in operation, the lamp is exhausted, any vapor which may have remained being absorbed by the material through which the air must pass. The lamp is preferably heated externally while it is being exhausted by means of a heating-lamp having a chimney surrounding the electric lamp. After the exhaustion is completed, the neck between the lamp and the attached receptacle is sealed off, there being a contraction in the neck for this purpose.

When particles of iron are placed in the attached receptacle, the lamp is placed in the chamber and heated as before to 600° or 800°, while the attached receptacle projects from said chamber and is separately heated to a much higher temperature, so that the iron is brought to a red heat and the vapor is thus decomposed, its oxygen combining with the heated iron, while its hydrogen remains to be drawn off by the pump after the end of the receptacle is broken off by the magnet, as already explained. Instead of this, a spiral of iron wire may be placed in the attached receptacle, or in another globe connected therewith, and provided with circuit-connections, so it may be brought to incandescence by an electric current, whereupon it acts to decompose the vapors in the same way as the iron particles above mentioned.

The accompanying drawings illustrate my invention. Figure 1 represents complete apparatus for exhausting the lamp; Fig. 2, a separate view of the lamp with attached receptacle; Fig. 3, a view of a modified arrangement as above described, and Fig. 4 a view of the completed lamp.

Referring first to Figs. 1 and 2, A is an incandescent electric lamp.

B is a glass chamber or receptacle forming a continuation of the exhaust-tube of the lamp, there being a contracted neck *a* between the lamp and the receptacle. This receptacle may contain pieces of glass covered with phosphoric anhydride or other moisture absorbent; or such absorbent may be placed therein by itself, or the chamber may contain particles of clean iron or other metal with which oxygen combines when the metal is heated.

As above explained, the lamp is placed in a chamber and heated to set free its moisture; or if the receptacle B contains iron it is heated separately from the lamp to a much higher temperature. The heating may be done in a furnace or in any other suitable way. It is not thought necessary to illustrate this step of the process, since it will be readily understood. The moisture being set free of the lamp, and having been either absorbed by the phosphoric anhydride or decomposed by the heated iron, which absorbs its oxygen and leaves its hydrogen, the lamp is attached to the Sprengel pump C, as above described, and as shown in *Fig.* 1, *b* being the rubber band covered with vaseline or similar material, so as to make an air-tight connection. An electro-magnet D is then brought close to the cup *c* of the pump and moved so that its attraction for the iron wire *d*, hung on the sealed hooked end *e* of the receptacle B, causes such hook to be broken off. The pump is then put in operation and the lamp is exhausted. Preferably during the process of exhaustion the electric lamp is heated by the flame of a heating-lamp E, from whose chimney a tube F, having an aperture for the exhaust-tube, extends, so as to surround the lamp. This heating drives off any moisture which may have remained in the lamp. If there is hydrogen in the globe, it is very readily removed by the pump. After the lamp is exhausted it is sealed off at *a*, and is then in the completed form shown in Fig. 4.

In the modification shown in Fig. 3 a chamber G, connected with a receptacle B, contains a spiral *d* of iron wire, which is heated to incandescence by an electric current while the lamp is being heated in the closed chamber, and also, if desired, while the lamp is being exhausted. It acts to decompose the moisture in the same way as the iron particles, as already explained.

What I claim is—

1. The herein-described method of removing moisture from the inclosing-globe of an incandescent electric lamp, which consists in hermetically sealing said globe to a sealed chamber containing a material capable of absorbing or decomposing such moisture and then externally heating said globe.

2. The herein-described method of exhausting an incandescent electric lamp, which consists in hermetically sealing the lamp to a sealed chamber containing a material capable of absorbing or decomposing such moisture, heating said lamp, and afterward withdrawing the air from said lamp.

3. The herein-described method of exhausting an incandescent electric lamp, which consists in hermetically sealing such lamp to a sealed chamber containing a material capable of absorbing or decomposing such moisture, heating the lamp, forming an opening in said receptacle, and withdrawing the air from the lamp through said opening.

4. The herein-described method of exhausting an incandescent electric lamp, which consists in hermetically sealing the lamp to a sealed chamber containing a material capable of absorbing or decomposing such moisture, heating the lamp, attaching the said receptacle to an air-exhausting apparatus, forming an opening in said receptacle, and exhausting the lamp by means of said apparatus.

5. The herein-described method of exhausting an incandescent electric lamp, which consists in hermetically sealing such lamp to a sealed chamber containing a material capable of absorbing or decomposing such moisture, heating the lamp, attaching said receptacle to an air-exhausting apparatus, forming an opening in said receptacle by the attraction of a magnet for a magnetic body attached to said receptacle, and exhausting the lamp by means of said apparatus.

6. The herein-described method of exhausting an incandescent electric lamp, which consists in hermetically sealing the lamp to a sealed chamber containing a material capable of absorbing or decomposing such moisture, heating the lamp, and then withdrawing the air from the lamp and at the same time heating it again.

7. The combination, with an incandescent electric - lamp globe, of a sealed receptacle hermetically sealed thereto containing a material capable of absorbing or decomposing moisture and having a magnetic body attached to it, substantially as and for the purpose set forth.

8. The combination, with an incandescent electric-lamp globe, of a receptacle hermetically sealed thereto containing a material capable of absorbing or decomposing moisture and having a sealed hooked end, and a coil of iron wire hung on said hooked end, substantially as and for the purpose set forth.

This specification signed and witnessed this 20th day of July, 1886.

THOS. A. EDISON.

Witnesses:
WM. PELZER,
A. W. KIDDLE.

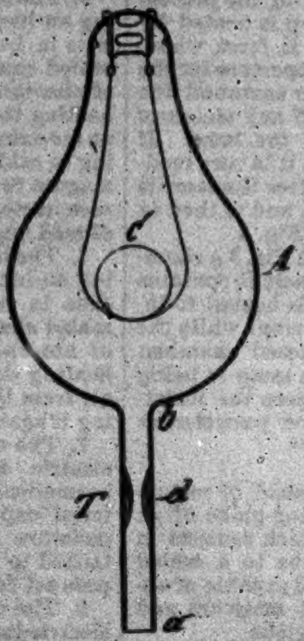
(No Model.)

DEFENDANT'S EXHIBIT No. 6.

A. MALIGNANI.

PROCESS OF EVACUATING INCANDESCENT LAMPS.

No. 537,693. Patented Apr. 16, 1895.



Witnesses

Inventor
Arturo Malignani
by
Attorneys

UNITED STATES PATENT OFFICE.

ARTURO MALIGNANI, OF UDINE, ITALY.

PROCESS OF EVACUATING INCANDESCENT LAMPS.

SPECIFICATION forming part of Letters Patent No. 537,693, dated April 16, 1895.

Application filed August 18, 1894. Serial No. 520,593. (No specimens.) Patented in Italy January 7, 1894, XXVIII, 3,550, LXX, 46; in Austria March 16, 1894, No. 44,486; in Hungary May 5, 1894, No. 354, and in Belgium July 16, 1894, No. 110,854.

To all whom it may concern:

Be it known that I, ARTURO MALIGNANI, a subject of the King of Italy, and a resident of Udine, in the Kingdom of Italy, have invented a certain new and useful Improved Process for Evacuating Incandescent Lamps, of which the following is a full, clear, and exact description, and for which I have obtained a patent in Italy, dated January 7, 1894, Vol. XXVIII, No. 3,550, Att. LXX, No. 46; in Belgium, dated July 16, 1894, No. 110,854; in Austria, dated March 16, 1894, Reg. 44, Fol. 486, and in Hungary, dated May 5, 1894, No. 354.

The present invention consists of a process for evacuating incandescent lamps and bulbs.

Reference being had to the accompanying drawing, the bulb A is provided with a small glass tube T for the purpose of extracting the air and the gases therefrom as hereinafter specified. Substances, adapted under certain circumstances to generate gases or vapors, such as arsenic, sulphuric or iodine are then introduced into the interior of the bulb A advantageously at about the center of the tube T. The gases thus generated are intended to combine with the gases generated by the filament of the lamp when brought to incandescence and form a liquid or solid precipitation.

The most convenient method is to dissolve or dilute a powder in or with appropriate liquids, such as alcohol, essence of tremandra or the like in which case the same can be applied most easily. The lamp is then connected with a vacuum pump of any kind by means of the tube T and exhausted to the extent of about two millimeters of mercury. The vacuum having been obtained, the lower end of the tube is soldered up and the carbon filament is then brought to intensive incandescence, which has the effect of generating the gases contained therein. During this time the part containing the substance, is heated by suitable means such as a spirit lamp or the like, which causes the said substances to be transformed into gases or vapors. These latter then combine with the gases and vapors generated by the filament to form a solid or liquid precipitation, so that an almost perfect vacuum is obtained. The introduction of a small quantity of ether vapors or other hydrocarbonates into the lamp renders the combination of the above gases and vapors easier and more energetic and assists the production of the vacuum. After having obtained the vacuum it only remains to solder up the tube T at the lower part b of the bulb so that the latter can be removed and the lamp is ready for sale. These operations can be performed very quickly as it is possible to obtain a vacuum in from one to three minutes and even less, according to the nature of the filament, which varies. The quantity and nature of the gases generated by the filament vary also, so that it is necessary that the substances, the vapors of which are to be precipitated in a solid or liquid state, should be carefully chosen due regard being had to the nature of the filament and the proportion should be varied accordingly.

I claim as my invention—

1. A process for producing a vacuum in the bulbs of incandescent lamps consisting in first introducing into a tubular elongation of said bulb suitable substances capable of being gasified by heat and combining with the gases generated by the filament when brought to incandescence to form solid or liquid precipitations, then exhausting the said bulb by means of a pump and sealing the said tubular elongation up, then bringing the filament to intensive incandescence and simultaneously heating the substance in the elongation aforesaid and finally sealing off the said elongation in the manner and for the purpose substantially as described.

2. In a process for producing a vacuum in the bulbs of incandescent lamps consisting in first introducing into a tubular elongation of the bulb a substance or substances having the qualities specified, exhausting the bulb by means of a pump, sealing the said tubular elongation then bringing the filament to intensive incandescence and simultaneously heating the said substance or substances in the elongation and sealing off the said elongation, the application in the bulb of ethers or other suitable hydrocarbonates during the process in the manner and for the purpose substantially as described.

In witness whereof I have hereunto set my hand in presence of two witnesses.

ARTURO MALIGNANI.

Witnesses:
ADOLF LINDERMANN,
H. ABERT JOHNSON.

DEFENDANT'S EXHIBIT No. 7.

(No Model.)

E. F. DWYER.

PROCESS OF PRODUCING HIGH VACUUMS.

No. 596,654. Patented Jan. 4, 1898.

Fig.1.

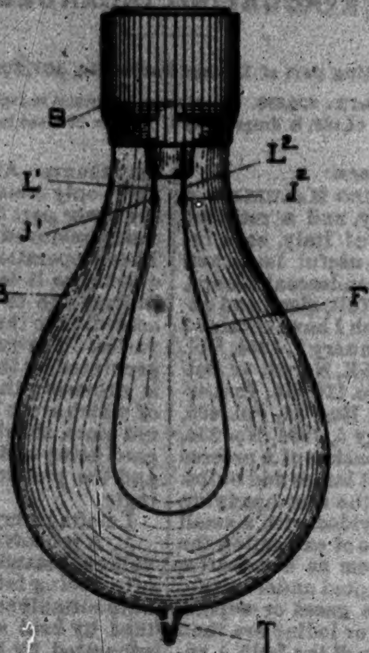

S
L²
L¹
J²
J¹
B
F
T

Fig.2.

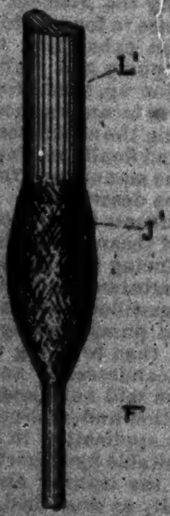
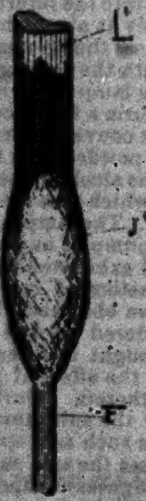


Fig.3.



WITNESSES.

John W. Gibboney

INVENTOR.

Edwin F. Dwyer

UNITED STATES PATENT OFFICE.

ELMER F. DWYER, OF LYNN, MASSACHUSETTS.

PROCESS OF PRODUCING HIGH VACUUMS.

SPECIFICATION forming part of Letters Patent No. 596,654, dated January 4, 1898.

Application filed October 26, 1897. Serial No. 656,430. (No specimens.)

To all whom it may concern:

Be it known that I, ELMER F. DWYER, a citizen of the United States, residing at Lynn, in the county of Essex and Commonwealth of Massachusetts, have invented certain new and useful Improvements in Processes of Producing High Vacuums, of which the following is a description.

My present invention relates especially to a process for exhausting air and other gases from incandescent electric lamps or similar receptacles during their manufacture and repair; and its object is to render this operation speedy and with a minimum of attention required on the part of the operator, while the production of the high vacuum required in an incandescent lamp is assured, and discoloring of the lamp-bulb is largely reduced. In the past such lamps have been exhausted by mechanical pumps having cylinders and pistons, by mercury-pumps of the Geissler and Sprengel types and their modifications, by chemical processes involving the displacement or absorption of the gases contained in the lamp, or by combinations of these processes. A partial or incomplete vacuum, but one not carried sufficiently high to serve the purposes of the best grade of incandescent lamps, is readily obtained by a good mechanical or mercurial pump, but it is in the removal of the residual gases remaining after such exhaustion that the greatest difficulty is encountered, since that part removed by each stroke of the pump or by the successively-falling drops of mercury in the case of the Sprengel pump becomes continually smaller and smaller, being simply a certain fraction of the expanding remaining gases; and soon a limit is reached, which is, however, still below the desired vacuum, beyond which no further exhaustion by this means is possible. To carry the vacuum still higher, it has been a common practice to heat the lamp-bulb by either an external source of heat, such as a gas-flame, or by an electric current passed through the lamp-filament, or by both of these means combined, so as to expand the gases in the lamp, and also to drive off from the lamp-filament itself and its supports, more particularly the joint between the leading-in wires and the filament, which joint is usually made of some form of hydrocarbon paste, gases occluded therein, while continuing the pumping operation. It is possible to make commercial lamps in this way, and they have been so made for a number of years, but the process is prolonged and costly, and therefore to obtain greater rapidity and economy in this work the method has been practiced of placing a chemical substance in a space connected with the lamp, which gives off vapors or gas when heated, which vapors or gas mingle with or displace the gases remaining in the lamp, and the combined gases are afterward removed by continuing the pumping or by absorbing them by some other substance having a strong affinity therefor. For example, ammonia-gas has been introduced and absorbed by phosphoric anhydrid, or solids—such as mercury-vapor, the vapor of sodium, potassium, iodin, &c.—have been introduced, the pumping continued, and the residue allowed to condense in a cooled auxiliary vessel connected to the lamp during exhaustion. Arsenic has been proposed to be introduced as a vapor and is supposed to form a chemical combination with the residual gases of the lamp and go down as a solid deposit. Still further, it has been proposed to use a substance having in a large degree the power of absorbing gases, such as spongy platinum, which, being heated, gives off retained gases during the process of exhaustion and afterward occludes or takes up the residual gas when the heating has been discontinued and pumping stopped.

I also in my present invention employ a chemical to obtain the condition of highest vacuum, depending mainly on the displacement of the original gases by a gas evolved from the heated chemical, this substance having the property of evolving a condensable gas or vapor which, when the heating is discontinued, goes down as a solid upon the cooler portions of the receptacle and requiring quite a high temperature to be afterward again vaporized.

In my improved process, and according to the theory of action just alluded to, I aim to reduce the amount of this added gas or vapor, so as to limit the ultimate deposition of foreign substance upon the inner surface of the lamp-bulb after the pumping is stopped, and to this same end and for the further purpose of avoiding the necessity for skilled and close attention on the part of the operator I make the production of the added gas and the disengagement from the filament and its supports of occluded gases simultaneous and automatically so, or at least with such definite relation as to time as will give the best results with the minimum of attention required on the part of the operator and in the shortest time. By "best results" I refer to a lamp having the very high vacuum required in an incandescent lamp to insure a long life and one having the least possible or least permissible amount of foreign substance deposited as a film upon the inner surface of the lamp-bulb, which deposited film will in most cases tint the lamp.

I will now describe my process, reference also being made to the accompanying drawings, in which—

Figure 1 represents an ordinary incandescent lamp in its completed condition; and Figs. 2 and 3 are magnified representations of the leading-in wires, the joints, and portions of the lamp-filaments.

In Fig. 1, B is the lamp-bulb; S, the socket for attachment to a lamp-fixture; L^1 L^2, the leading-in wires; F, the lamp-filament, and J^1 J^2 the joints which unite the filament to the leading-in wires.

The same letters of reference are used in Figs. 2 and 3 for similar parts shown, J^1 being the joint between the filament and leading-in wire. This joint is usually, if not always, made of a carbon paste or hydrocarbon paste. It is from this joint that by far the larger portion of gases is evolved when it becomes heated, as by passing an electric current through the filament. In my improved process I mix with or place upon this hydrocarbon-paste joint J^1, Fig. 2, or apply to or paint upon the leading-in wire L^1, Fig. 3, a substance having the properties of amorphous phosphorus, which when heated gives off its vapor, such chemical being applied, of course, prior to the placing of the lamp upon the pumps. I then place the lamp in connection with any good air-pump, mechanical or mercurial, at its exhaust-passage, as at T, Fig. 1, and make the usual rough exhaustion. I then pass an electric current through the lamp-filament, preferably limiting the current at first, so as not to raise the filament to full incandescence, and continue the pumping. The heat from the filament first expands the gas remaining within the lamp-bulb, permitting its further removal by pumping. Gradually the heat is conducted back to the joints J and to the leading-in wires L, when upon an increase of current the disengagement of the occluded gases and the gases produced by the paste joint is partially effected, while the production or evolution of the condensable or displacing gas, as from phosphorus, begins, and then, lastly, the current passing is still further increased for a short time to or above that required for the normal operation of the lamp in use, when practically all of the occluded or retained gases are driven off from the joint, filament, and leading-in wires, while at the same time the vaporization of the phosphorus is completed, and the volume of gases now permits further pumping, the excess gas being that derived or obtained from the phosphorus. The lamp is now sealed off. The gas now remaining in the lamp is mainly that which has been purposely added, say phosphorus-vapor; but as the lamp cools this gas or vapor condenses upon the cooler portions or goes down as a solid, as an extremely-attenuated film upon the inner side of the lamp-bulb, and will not again arise as a gas unless again subjected to a temperature as high as that which produced it. Having by trial determined quite accurately just what minimum amount of condensable gas is required to be produced in this way to perfect the vacuum to the stage desired, I am enabled to limit the deposit formed by its condensation upon the bulb-surface to the greatest extent and therefore to produce a superior lamp, while at the same time the processes of expanding the free gases in the lamp, driving off the occluded and retained gases from the joints, &c., and evolving the condensable gas follow naturally in their proper order to insure the best results with a minimum of skilled attention and in a very short time. The operator soon learns by simply noting the color within the lamp during exhaustion when to seal it off, and I find in the practice of my invention that I am actually enabled to greatly facilitate the process of exhaustion, so as to produce a greater number of lamps in a given time with less labor and giving a superior product as compared with the processes hitherto known or used. I show no particular form of pump or its connection to the lamp, these things being so well understood.

It is understood, of course, that an external source of heat may be employed for assisting in expanding the gas within the lamp during the pumping operation; but it is evident that such heating has no particular use in producing the condensable or displacing gas, since the source of the latter is far removed from the externally-applied heat. Such external heating is mainly useful in driving off gas from the inner surface of the bulb and preventing predeposition of the condensable gas on the bulb-surface.

Besides phosphorus I have used with greater or less success iodin and ammonium-cuprous chlorid. In general it suffices to employ a substance which will, when sufficiently heated, give off a gas capable of subsequent condensation; but such substance must not again be able to be vaporized by the heat of the lamp in normal operation. I prefer phosphorus to other materials.

Having thus described my invention, what I claim is—

1. The process of producing high vacuums consisting in, removing the main portion of the gases contained within the receptacle to be exhausted by pumping, heating the remaining gas while continuing the pumping, driving off occluded gases and producing or evolving a condensable or displacing gas by an electric current passed through a circuit within said receptacle, and finally sealing said receptacle.

2. The process of exhausting incandescent lamps which consists in, removing the main portion of the gases contained within the lamp by pumping, heating the remaining gases while continuing the pumping, passing an electric current through the lamp-filament whereby occluded or retained gases are disengaged while a condensable or displacing gas is evolved from a suitable substance previously applied in the lamp while still continuing the pumping, and, finally, sealing off the lamp.

3. The process of exhausting incandescent lamps consisting in, removing the bulk of the original gas by pumping, further expanding by heat the remaining gas and continuing the pumping, passing an electric current through the lamp-filament and its connections for disengaging occluded or retained gases therefrom and vaporizing phosphorus previously applied to said connections while continuing the pumping, and then, finally, sealing off the lamp, substantially as described.

4. As an improvement in processes for exhausting incandescent lamps, the method of producing the higher states of vacuums consisting in simultaneously disengaging the occluded or retained gases in the lamp-filament and its connections and producing or evolving a condensable or displacing gas from a suitable substance, such as phosphorus, carried by the filament-supports, by passing an electric current through the lamp during the operation of pumping, and afterward sealing the lamp to perfect the vacuum, substantially as described.

In witness whereof I have hereunto set my hand this 23d day of June, 1897.

ELMER F. DWYER.

Witnesses:
JOHN W. GIBBONEY,
WINIFRED GIBBONEY.

DEFENDANT'S EXHIBIT No. 8.

8 AMERICAN ELECTRICIAN [Vol. VIII, No. 1

Crookes Tubes and Experiments With Roetgen Rays.

BY THOS. DUNCAN.

After using a Crookes tube a number of times it was observed that it required a greater electromotive force to operate it. This phenomenon has been noticed by several experimenters with Crookes tubes recently, but has been known for years to incandescent lamp makers.

If the vacuum of an incandescent lamp be tested by means of a spark coil when first made, and is found to show a luminescence inside, after being put in circuit and used for a month or so, it will be found upon trying it again with the spark coil, that little or no luminescence will take place with the original pressure or spark length. The writer has even found this to take place when a new lamp is subjected several times to a voltage double of that for which it was designed. The duration of contact must be very short or as nearly instantaneous as possible, not only to protect the filament, but also to prevent the interior of the bulb from being blackened.

I have also prepared lamps in this way for comparison with other makes, when showing intending purchasers the difference between the vacuum obtained in the lamps I represented and those sold by other makers. It undoubtedly shows that there are tricks in all trades.

The theory I always entertained regarding this increase in the rarefaction of the lamp was, that when incandescence takes place, the remaining air combines with the vaporized carbon particles or molecules that are undoubtedly thrown off from the filament, and is precipitated as a solid upon the interior surface of the receiver or bulb.

How far this theory involving chemical change with resulting precipitation can be applied in the case of Crookes tubes, I am unable to say, but would be inclined to think, as Prof. Elihu Thompson has suggested, that the improvement in the vacuum of the Crookes tube is due to the carriage of metallic aluminum or other metal forming the electrodes, to the sides or interior walls of the bulb, the residual gas being absorbed in so doing.

The success attending the production of good skiagraphs depends more upon the degree of rarefaction of the tube than anything else, and can be verified by any one who has had the misfortune of trying to obtain Röntgen rays from domestic tubes, or those made by makers of incandescent lamps.

It is possible that good Crookes tubes will be turned out upon the market by lamp makers, but it is to be regretted that some of these have been making and selling for the past month or two tubes that are as unfitted for the purpose intended, as their makers are to represent Professor Crookes in a mental capacity.

I have tried eight Crookes tubes made by four different incandescent lamp companies, but with only one tube could I obtain any good results, the vacuum in the other seven being so low and poor that it was useless to experiment with them. They did not seem to have any better vacuum than that shown by an ordinary incandescent lamp. The one tube which bore all the characteristics of a genuine Crookes tube was made by a St. Louis Company, and if all their lamps are exhausted in as thorough a manner as exhibited by this tube, they must undoubtedly receive credit for it.

There seems to be one thing certain, and that is, if any one undertakes to make Crookes tubes for skiagraphing through opaque matter, they will have to improve upon the ordinary practice and methods employed in exhausting lamps.

The very first step to be taken is to see that the pump is as clean and dry as it is possible and practical to make it. This may partially be accomplished by preventing moisture from entering either the mercury or the high vacuum chambers (mechanical or automatic Geissler pump), by causing the outside air which enters the mercury chamber at every operation of the pump, to pass through granulated calcium chloride, and interposing between the high vacuum chamber and the bulb to be exhausted, some anhydrous phosphoric acid, which has a great affinity for moisture. In the latter precautions the introduction of the anhydrous phosphoric acid prevents any moisture that may be contained in the bulb to be exhausted from passing down into the high vacuum chamber and coming in contact with the mercury. It must be remembered however that the anhydrous acid must be renewed often and not allowed to form a surface film or crust on top, when it is useless.

The foregoing suggestions are well known and understood by makers of incandescent lamps, so are given more with the view of assisting and aiding the casual reader who may not be so well informed or initiated into the precautions necessary for the production of high vacua.

If an incandescent lamp be exhausted until no air can be seen escaping through the valves of the pump, and the filament then incandesced, considerable quantities of air will be expelled at each operation of the pump, thereby showing that this air has been occluded in the pores of the carbon filament, and could not have been gotten rid of without heating the filament and driving the air out into the vacuous space surrounding it.

This heating also assists in drawing off the air which clings or adheres against the glass upon the inside of the bulb. Therefore in exhausting Crookes tubes, I should think that it would be good practice to smoke the bulb thoroughly upon the outside, then set an oil lamp or other source of heat under it, at the same time covering it over with an asbestos hood also smoked upon the inside, in order to concentrate the heat and distribute it as evenly and efficiently as is possible. This would help to remove the air from the inner surface of the bulb.

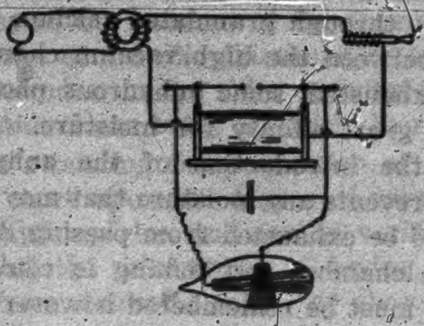


FIG. 1.

If the electrodes are made from aluminum or other porous metal, the secondary terminals from a spark coil can be applied to them, and set in operation in a similar manner to that in which the tube is to be used afterwards. This can not help but be a ready and satisfactory means of eliminating the air occluded within the electrodes.

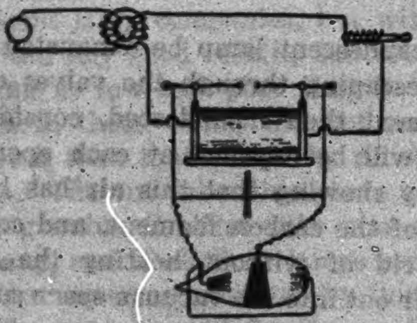


FIG. 2.

When we consider that mercury evaporates so readily even at ordinary temperatures, it might be admitted that a certain amount of mercurial vapor gains admission to the bulb, but even this may be prevented

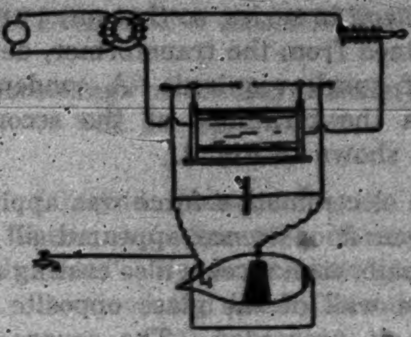


FIG. 3.

by interposing in the tube connecting the high vacuum chamber and the bulb being exhausted, a small quantity of iodine (next to the high vacuum chamber) which absorbs the mercury vapor, then some sulphur which in turn absorbs any vapors given off by the iodine, and lastly powdered silver, which completely absorbs any sulphurous vapor that may be evolved. This method of getting rid of the mercurial vapor has been employed by Professor Crookes himself, in connection with measuring the degree of rarefaction obtained with a Macleod gauge.

While experimenting with a Crookes tube, I noticed that a cathode stream was thrown off from both electrodes, due to the current used being an alternating one. With the object of trying to suppress one of them and increase the density of stream from the other, I tried the following experiments, which may prove of some interest to those experimenting in the production of Röntgen rays.

The current employed was the ordinary high frequency alternating current, making about 16,800 per minute, corresponding to a frequency of 140 periods per second.

The induction coil was capable of giving sparks up to eight inches; the primary was supplied from the secondary on a one hundred volt transformer, and had an inductance coil in series, so that any current strength could be obtained from the transformer, depending upon the length of spark required. A condenser was employed across the terminals of the secondary of the spark coil, as shown in Fig. 1.

When an electromotive force was applied, the usual yellowish green fluorescence appeared all over the interior of the bulb, each stream also casting a dark square spot upon the wall of the glass opposite the electrode from whence it proceeded. The square form of the dark spot was due to the electrode having a square surface.

Upon applying an external electrode of tinfoil, about the size of a silver dollar, to the end opposite the electrode whose cathode stream was thrown out horizontally, or across the greatest length of the tube, and then connecting with the electrode, it appeared to throw off a counter stream which perceptibly diminished the density of the stream from the inner or opposite electrode. This was also accompanied by a reduction in the fluorescence at the ends of the tube, and by an increase of the stream thrown off by the remaining or upper electrode, which in turn produced a marked increase in the fluorescence upon the opposite side of the tube. This arrangement is shown in Fig. 2.

When the hand was brought in contact with either or both of these end electrodes, the respective streams of cathode rays and resulting fluorescence were again reduced to a very marked degree, with an accompaning increase in the stream thrown off by the upper electrode.

This last result naturally suggested grounding the end electrodes, which was done by connecting to a water pipe; the experiment was then complete, the upper electrode throwing off a very strong and dense beam of cathode rays, causing the opposite wall to be very bright with fluorescent light, while the two other electrodes were as inactive looking as if they were not present at all. This arrangement is shown in Fig. 3.

DEFENDANT'S EXHIBIT No. 9.

Proceedings of the Royal Society A,
Vol. 64, pp. 231-238.

"Application of Liquid Hydrogen to the Production of High Vacua, together with their Spectroscopic Examination." By JAMES DEWAR, M.A., LL.D., F.R.S. Received and Read December 15, 1898.

As an illustration of the extraordinary power of the new cooling agent—liquid hydrogen, the extreme rapidity with which high vacua can be produced by its use is, perhaps, one of the most striking. The absolute boiling points of hydrogen, oxygen, and chlorine are respectively 35°, 90° and 240°, in other words oxygen boils at a temperature two and a half times higher than liquid hydrogen, and liquid chlorine similarly at two and a half times that of liquid oxygen. From this we infer that liquid hydrogen as a cooling agent ought to be relative to liquid air as effective as the latter is compared to that of liquid chlorine. Now chlorine at the temperature of boiling oxygen is a hard solid, some 80° below its melting point, and in this condition has an excessively feeble vapour pressure. When liquid hydrogen freezes air out of a sealed tube by immersing the end in the liquid, it is to be inferred that no measurable pressure of air ought to be left in the vessel. If we apply Van der Waal's law of corresponding temperatures to the case of hydrogen, the above inference is made unimpeachable. An approach to some knowledge of what the tension of air must be about the boiling point of hydrogen can be attained by extrapolating the vapour pressure curves of oxygen and nitrogen. Taking the following range of boiling point temperatures for nitrogen and oxygen, viz., from the critical point to the boiling point under diminished pressure, two Willard Gibbs formulæ were calculated, with the following results:—

Nitrogen	Temp. abs.	127°	78.6°	59°
	Pressure in mm.	25,900	740	26

Nitrogen. $\log_{10} p = 11.5561 - \frac{400.02}{T} - 1.8980 \log_{10} T$ . . (1).

Oxygen				
	Temp. abs.	154°	90.3°	61.3°
	Pressure in mm.	37,592	740	7.5

Oxygen. $\log_{10}p=9.4699-\frac{422.22}{T}-0.9843\log_{10}T$ . . (2).

Another Gibbs formula was calculated, taking Estreicher's values for the vapour pressure of liquid oxygen below its boiling point, viz.:—

Temp. abs.	91.44°	78.1°	62.8°
Pressure in mm.	743.8	141.8	7.5

Oxygen. $\log_{10}p=16.0670-\frac{524.72}{T}-3.8024\log_{10}T$ . . (3).

We deduce from these formulæ the following vapour pressures at the temperature of boiling hydrogen:—

(1) Nitrogen ...... 0.0015 Pressure in mm., 35° abs.
(2) Oxygen .... 0.000076 do.
(3) " .... 0.000016 do.

The results of calculation, taking the formulæ for the widest range of pressures, viz., (1) and (2), may probably be the surest, but in any case those values must be taken as a *maximum*, seeing they refer to the liquid state, while both oxygen and nitrogen, at the temperature of 35° absolute, are hard solids, and must therefore have dropped to lower tensions than that of the extrapolated liquid vapour pressure curves. It is curious to note that at this low temperature the theoretical ratio of the tensions of nitrogen and oxygen is as 20 to 1. Direct measurements of the vapour pressure of nitrogen at the melting point, or 60° absolute, gave the value of 26 mm., and a ratio of the tensions of nitrogen to oxygen of 6 to 1, whereas from the curves the value ought to be 6.7 to 1. Olszewski gives the tension of nitrogen at —214° as 60 mm., and as at this temperature the oxygen tension is 3.8 mm., the ratio of the saturated pressures of the two gases at the melting point of nitrogen would be as 16 to 1, which is far too high. Probably the oxygen value will be nearest the truth, seeing it has the lowest melting point. The tension is about a ten millionth of an atmosphere. In the case of nitrogen, the maximum theoretical pressure would be one five-hundred-thousandth of an atmosphere. It is safe to infer that the vacuum left after liquefying the air out of a vessel by means of liquid hydrogen cannot exceed the millionth part of the atmospheric pressure, exclusive of the pressure resulting from any incondensable material other than nitrogen and oxygen. This is just about the pressure of the vapour of mercury at the ordinary temperature in the Torricellian vacuum, so that as good an exhaustion ought to result as can be got by boiling out a space with mercury. There is another way in which the question may be put. Assuming the molecular latent heats are approximately proportioned to the absolute boiling points, then we can, from a comparison with the oxygen value, deduce that of hydrogen, and thereby get the constants in a two-term formula for the vapour pressures. For pressures below an atmosphere, the following formulæ were deduced:—

$$\text{Oxygen} \;\ldots\; \log p = 7.2058 - \frac{392.6}{T}\,\text{mm.} \;\ldots\; (4).$$

$$\text{Hydrogen} \;..\; \log p = 7.2428 - \frac{152.7}{T}\,\text{mm.} \;\ldots\; (5).$$

From these expressions it follows that at its boiling point, or 35° absolute, hydrogen has 7/852000 times the pressure of oxygen, or the latter pressure is about the eight millionth of an atmosphere. A similar formula, calculated from the critical and boiling point data, gives substantially the same order of quantities. Formula (4) for oxygen tensions must be fairly accurate, seeing it gives a theoretical latent heat of about 56 units per gram of liquid evaporating at the boiling point, whereas direct determinations result in 55 units. To test this inference, the following plan of experimenting was adopted:—Ordinary shaped vacuum tubes, like A, B, used for the spectroscopic examination of gases, with and without electrodes (figs. 1 and 2), having a capacity ranging from 15 to 25 c.c., had pieces of quill tubing about a foot long sealed on. The tubes were contracted at D to about 1 mm., so that they could be sealed off with rapidity.

The end C sometimes terminated in a small bulb (fig. 3), in order to give increased cooling surface, and when necessary, to allow many times the volume of air in A, B, to enter and be condensed with the object of accumulating any incondensable residuum.

Fig. 1.

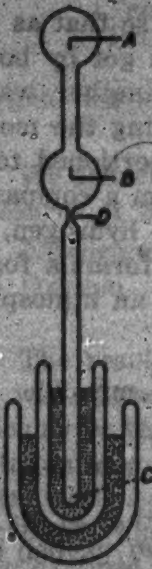


Fig. 2.

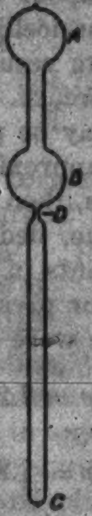
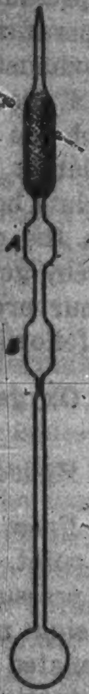


Fig. 3.



The tubes were filled with air, oxygen, and nitrogen at the atmospheric pressure. The liquid hydrogen collected in the vacuum vessel, immersed in another similar vessel full of liquid air, being ready, the end C was dipped in the liquid for a little over a minute, and the tube AB sealed off at D, so that on removal from the hydrogen bath the solid air might melt and distil off without generating any pressure. On attempting to pass the spark through vacuum tubes prepared in this manner, their excellent exhaustion was revealed by great resistance to the passage of the discharge, and the high phosphorescence of the glass. Two tubes, kindly prepared by Sir William Crookes with platinum electrodes that he had previously sparked to remove gases and impurities on the glass before filling with dry air, gave, when treated in the manner described, such high vacua that the tubes had to be heated in order to get any spark to pass. Thus it is proved that the tension of solid nitrogen and oxygen at the temperature of boiling hydrogen is below the millionth of an atmosphere, seeing there is less difficulty in getting a discharge to pass in tubes exhausted to this extent. In order to get some definite idea of the limit of the exhaustion produced, two tubes, such as have been described as suitable for the liquid hydrogen experiments, might be joined together and filled with oxygen or nitrogen at atmospheric pressure, and simultaneously exhausted with the mercural pump to a small fraction of an atmosphere, and then sealed off from the pump and each other. One of these two identical tubes could then be subjected to the hydrogen cooling, following the directions already given, and the two vacuum tubes now compared. If there was a marked difference in resistance to the passage of the discharge in the frozen tube, then something must have condensed, and by a few tentative trials a limit might be reached when the initial exhaustion was unaffected by the hydrogen cooling. Such experiments have not yet been made. The presence of any vapour of mercury would require to be carefully eliminated, otherwise the method would not be satisfactory. Tubes that are prepared without taking special precautions to exclude organic matter and water from the glass, deteriorate, especially with electrodeless tubes after the discharge has taken place for some time.

The rapidity with which the vacua are attained is such as theory would suggest; assuming a hole of a square millimetre in section through which the air rushes into the condenser, and that a velocity of current between 600 and 700 feet a second is attained, then a vessel of 20 c.c. capacity could be reduced in pressure in 1 second to $1/10$ of the initial pressure, and if the same rate is continued at the end of 60 seconds to $(1/10)^{60}$. Sir George Stokes has been good enough to consider the problem and writes as follows:—

"Let V be the volume of the vessel, A the area of an aperture by which the air is conceived as rushing out with the velocity v, ρ the density of the air in the vessel at the time t, D the initial density, that is, the atmospheric density.

"Then, according to our hypothesis, $Av.dt$ is the volume of air, and, therefore, $Av\rho.dt$, the mass of air, which rushes out in the time dt. But this equals the loss of mass of air in the vessel during the time dt, and, therefore,

$$Av\rho.dt = -Vd\rho,$$

a differential equation of which the integral is

$$\rho = D e^{-Avt/v}.$$

"Suppose now V to be 20 c.c., or 20,000 c.mm., A to be the area of a circle of 1 or 2 mm. diameter, say 2 sq. mm., v to be 333 m., or 333,000 mm., t (in seconds) to be 60; then

$$\log_e \frac{D}{\rho} = \frac{2 \times 333{,}000 \times 60}{20{,}000} = 1998,$$

$$\frac{D}{\rho} = 5254 \times 10^{484}.$$

"This would give a density of almost inconceivable smallness. Doubtless the supposition made above as to the rate of discharge is very wide of the mark, being much too great. If the velocity of rushing is about half the velocity of sound, the ratio of densities would become 72×10^{217}. If so it is satisfactory to find that the mathematical following out of the hypothesis leads to a density of the residual air in the vessel which is enormously below what suffices to account for the observed result." A practical mode of rapidly attaining a high vacuum in any vessel is to displace the air with carbonic or sulphurous acid, either at the atmospheric or under diminished pressure, and then to freeze out the remaining gas by the use of liquid air, just as in the experiments with liquid hydrogen.

The first vacuum tube was an electrodeless one, the air had not been dried, nor the glass specially cleaned. On spectroscopic examination it showed hydrogen lines bright along with the second or compound line spectrum of the same gas, and a series of bright bands defined on the less refrangible side; diffuse on the more refrangible, which occur in the yellow, green, blue, and indigo. These bands were found to be identical with the carbonic oxide spectrum. With a Leyden jar in the secondary circuit the line spectrum of hydrogen disappeared, leaving the second spectrum fainter; but the carbonic oxide bands remained bright, and there was no appearance of the hydrocarbon spectrum. The second tube had aluminum electrodes, and, like the last, had no special treatment in filling in the air. This tube showed also the line spectrum and the second spectrum of hydrogen; the latter being bright along with the carbonic oxide spectrum; but on sparking the latter disappeared. No appearance of the hydrocarbon spectrum could be detected, but there was a suspicion of bands in the indigo like the negative pole spectrum of nitrogen. The addition of a Leyden jar brought out nothing new, only intensifying the line spectrum of hydrogen, while leaving the second spectrum bright. In neither of the above tubes could any lines of nitrogen or oxygen be recognised. The third tube was filled with air drawn over cotton wool, red-hot copper oxide, and phosphoric pentoxide, no rubber joints being employed. The spectrum showed the carbonic oxide bands and the hydrogen line spectrum as before. Only the second hydrogen spectrum was feeble. There was a yellow line W. L. 5849, identical with one occurring in the natural gas from the King's Well at Bath. In a paper on "The Liquefaction of Air and the Detection of Impurities,"* the separation of helium from this gas is described by liquefaction and fractionation, and it was observed that during the sparking the helium lines were well marked along with "*others, the origin of which must be settled later.*" It was further observed, "*With a modified form of apparatus it will be possible to collect any residuary gas from the use not of 3 cubic feet of air or Bath gas, but from hundreds of cubic feet of such products.*" The helium and other associated material was shown to be more volatile than nitrogen. Pursuing this course of investigation in the summer of this year, the volatile portion of air was examined, when the presence of material giving the same lines as Bath helium was recognized. While this investigation was in progress, Professor Ramsay and Dr. Travers observed the same spectrum in the more volatile portion of argon which they have associated with a new element called neon. The use of liquid hydrogen, as described, proves that the most characteristic line of neon in the yellow, about W.L. 5849, can be detected in 25 c.c. of ordinary air, and the presence of helium in the atmosphere is confirmed.†

---

* 'Chem. Soc. Proc.,' November, 1897.

A fourth tube, filled like the preceding one, had a phosphoric pent-oxide tube left on. This showed again the carbonic oxide bands, but no hydrogen lines could be detected; while the oxide of copper ought to have removed all free hydrogen and transformed all the organic matter into carbonic acid and water. Yet it appears that the spectrum of the carbon compounds is difficult to remove from electrodeless tubes, probably owing to carbonic acid coming from the glass. There were some broad diffuse bands that may arise from the drying agent. The absence of hydrogen in this tube suggests that its presence in the third tube was due to vapour of water coming slowly from the glass. I am greatly indebted to Professor Liveing for making a careful examination of the spectra of these tubes.

---

† In a paper along with Professor Liveing, "On the Spectra of the Electric Discharge in Liquid Oxygen, Air, and Nitrogen," 'Phil. Mag.,' 1894, we noted that during the distillation and concentration *in vacuo* of liquid oxygen and air under diminished pressure that two bright lines appeared in the spectrum at wave-lengths 557 and 555, and that one of these lines was very near the position of the auroral line. These lines are now attributed by the same chemists to a new element, crypton.

Sir William Crookes was good enough to prepare two tubes with platinum electrodes, which he sparked in vacua till all hydrogen disappeared, and then filled with dry air, but without the use of red-hot copper oxide or any agent for the absorption of carbonic acid or the destruction of organic matter. After the cooling with liquid hydrogen, he found on spectroscopic examination, in one no hydrogen, but two faint lines, one about 5852 W.L. and the other 5676 W.L. The second tube showed the same yellow about 5852, the helium line along with 5939 and 6145, the hydrogen lines C and F, and some red lines. The observations of Crookes confirm the presence of neon, helium, and hydrogen. The absence in his tubes of the carbonic oxide spectrum is important, seeing all the electrodeless tubes gave this spectrum. In these tubes the vacuum was very high, and it was difficult to observe the gaseous spectrum. Still, the fact of finding hydrogen in one and not in the other, leaves the presence of free hydrogen in the atmosphere as a question for further inquiry. The tube that did not contain hydrogen was heated very hot in order to get a discharge, and then the spectrum showed some bands like the negative glow of nitrogen. Occasionally, a jar discharge was got to pass, and when this took place the nitrogen lines could be seen. An electrodeless tube filled carefully with oxygen made from fused chlorate of potash, which was contained in an extension of the vacuum tube gave nothing but the carbonic oxide bands. In future experiments it will be easy to concentrate all the most volatile material in air or other gases, and thereby to make a more thorough examination of the spectrum. In the meantime my object is to show one of the scientific uses of liquid hydrogen.

I have to thank Mr. Robert Lennox for efficient aid in the conduct of the difficult experiments. Mr. Heath has also helped in the work.

DEFENDANT'S EXHIBIT No. 10.

Annalen der Physik.
Vol. 2 (1900).
PP 359-374,
[TRANSLATION]

PRODUCTION OF CATHODE RAYS BY ULTRA-VIOLET LIGHT

By P. Lenard

(From the Sitzungsber. der Kais. d. Wissensch. in Wien' vom 19 October 1899[1])

[359]

The property possessed by ultra-violet light, discovered by Hertz and first demonstrated in a simple manner by Hallwachs, of expelling negative electricity from bodies has been investigated in many of its characteristics. One has been able to penetrate into its mechanism in so far as to determine the paths of the escaping electricity in air-filled and also in rarified space.[2] What, however, the carriers of electricity along these paths may be, has remained in doubt.

1. Researches on the "Disintegration of Bodies by Ultra-Violet Light"[3] have shown that possibly ponderable material parts of the body subjected to radiation may be those carriers. That such an immediate inference from the results of previous experiments is hardly justified special researches have shown me, of which one will be here touched on.

A clean surface of sodium amalgam in an atmosphere of hydrogen was subjected to radiation for such a length of time that 2.9×10^{-6} coulombs of negative electricity escaped from it, and the electric field was so impressed on the amalgam that the aggregate quantity of electricity must have been carried to a clean platinum wire. If sodium atoms had been the carriers, their [360] aggregate mass would have amounted to 0.7×10^{-6} mg. corresponding to the electro-chemical equivalent of sodium; and still more if larger parts of sodium had been the carriers. Now according to Bunsen, less than 0.3×10^{-6} mg. of sodium is detectable in flame with the greatest clearness. When, however, the platinum wire, which received the carriers, was tested in the flame there was no trace of sodium reaction.

2. To the other inference, which is indicated in the title of this work, I was led by the marked unipolar character of the photo-electric effect, as has been established beyond doubt especially by Elster and Geitel[4)], together with the knowledge that cathode rays may be important carriers of negative electricity[5)]. I was strengthened in this inference, after experiments with negative results, by a remark of Right.

He finds [6)] that the discharging action of light on a body with a large negative charge increases as the air is more and more rarified up to maximum which occurs at that pressure "at which the air most easily assumes an electric charge," but that it decreases with further rarification. He finds further that the action of light on an originally uncharged body in bringing it to a positive charge by the expulsion of negative electricity always increases with increasing rarification of the air and he adds the remark that both properties of the photo-electric action clearly cannot be the results of a single cause.

The present research begins at this point. When many phenomena are superposed on one another, one must endeavor to isolate a particular one. I endeavored, therefore, to study the phenomena when the air was excluded, whereby it was above all to be decided whether with the passage to the most extreme vacuum a reversal did not occur with cessation of the action, as is really the case with other discharge phenomena.

3. The apparatus employed, an evacuated glass [361] tube with sealed-in electrodes, is represented in Fig. 1 to one third scale size. U is the electrode to be subjected to radiation, a disc of clean aluminum foil of 1.5 cm. radius. Of the same size and material is the

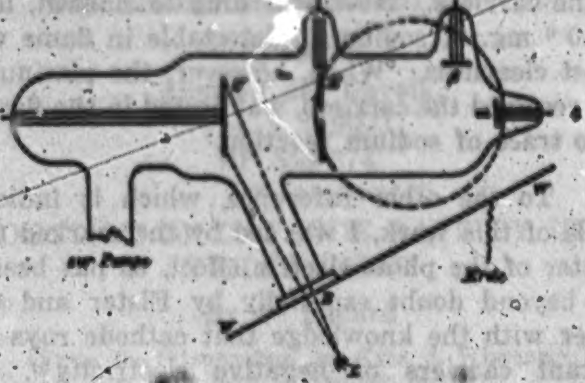


Fig. 1.

second electrode E which is placed parallel to the first and which is always grounded. The 5 mm. side opening in the electrode E as well as the additional electrodes α and β were not present in the first experiment (3, 4). The light source was as usual formed by the 15 mm. spark path of a large inductorium provided with a Leyden jar; the sparks jump between zinc wires which yields much ultra-violet light. A shield B composed of tin foil of 4 mm. breadth prevented the light from striking any parts of the tube interior other than the electrode U. The shield was laterally extended in the form of a sheet, indicated by WW in the figure, which protected the tube and the measuring instruments from the electrical action of the light source. The tube was closed at B by a 3 mm. thick quartz plate. The light source was always more than 4 cm. distant from B.

By prolonged heating and the discharge of a large inductorium we bring the tube into the steady condition in which it no longer passes the discharge through, the discharge passing outside around the tube. The mercury air pump[7] produced then no detectable gas from the tube in time intervals of hours.

If we now connect U with an electroscope its [362] leaves collapse instantaneously when negatively charged, when U is illuminated, and also their separation is rapidly reduced when a Leyden jar of medium size is connected to them. Positive charges remain or decrease with extreme slowness[8]. With the quadrant electrometer it is shown that the originally uncharged electrode under the influence of the light assumes a positive charge which increases up to a limit of about 2.1 volts. All these phenomena are completely suppressed when a thin sheet of mica is placed between the light source and the apparatus. In short, all the characteristic actions of ultra-violet light, known to exist in air, occur also in the most complete vacuum and indeed with striking intensity. Quantitatively we shall establish soon (4) a sharp distinction between the action occurring here and that occurring in rarified air. It may also be remarked here that the cooling with solid carbon dioxide and ether of a vessel containing phosphorous-pent-oxide located between tube and pump did not affect the quantities of escaping electricity to be measured.

In regard to the photo-electric action, the experiment seems to me to teach that this to a first order has nothing to do with the air. A further point of interest of the research resides in the fact that it shows electricity to exist in the most extreme vacuum which, according to prior knowledge, one must have pronounced impossible. The same thing has been observed previously, and for the first time, with cathode rays which were produced by gas discharge[9], and it is noteworthy that it is only negative electricity which appears in the extreme vacuum. In order to take into account these relations I shall in the following designate with the particular name quanta the discrete quantities of electricity to be [363] observed here and which, as will be shown again, are endowed with inertia and which in motion constitute cathode rays, as previously known.

4. A measurement of the quantity of electricity driven into the vacuum by the action of the light is afforded if one allows this quantity before entering the electrode U to flow through a very large resistance in series with this electrode, and measures the potential difference between the ends of this resistance by aid of

an Exner electroscope or a quadrant galvanometer. This measuring instrument and the resistance composed of twine or graphite, were placed inside a conducting enclosure, insulated from ground to which the negative electricity was conducted at measurable voltage.[10] The difference of this last voltage and that observed between the ends of the resistance is the electrode potential of the following table; opposite are the quantities calculated from Ohm's Law.

TABLE I

Potential of the Electrode subjected to radiation.	Escaping Quantities of Electricity.
—45000 volts[11]	24.5 . 10^{-10} $\frac{\text{Coul}}{\text{Sec}}$
—25000	26.6
— 8900	22.5
— 4100	24.8
— 3110	24.5
— 1300	24.3
— 500	23.4
— 120	21.9
— 14	19.9
— 9	15.9
— 1	7.
0	4.
+ 1	4.
+ 2.1	0

[364]

If we consider first the upper part of the table, we see that the quantity of electricity escaping per second is within wide limits independent of the voltage present. In the second part of the table, on the other hand, that is, for voltages under 100 volts, the quantity of electricity discharged decreases markedly with a further decrease of voltage. This relation does not admit of immediate explanation; for if the impressed voltage has a true effect on the radiation from the electrode, it would have to show itself most pronouncedly at the highest voltages; this is, however, not the case. The explanation which I have formed is that at insufficient impressed voltages the radiation is not indeed diminished, but that a part of the already emitted quanta are returned to the electrode under the action of their own forces. That this effect occurred in our research from 100 volts downward depends on the peculiarity of the applied light source of having extraordinary intensity for extraordinary short time intervals. This point will not be further entered on here; it suffices to have indicated for further application definite and steady quantities of escaping electricity in our research. There may be further noted the obviously explicable decrease to zero of the escaping quantity, shown in the third part of the table, when the impressed voltage is positive; when therefore the removal of the radiated quanta is opposed (cf. 8). The voltage +2.1 volts, to which corresponds the quantity zero, is the same as that attained by radiation by an originally uncharged electrode.

For comparison of the relations in vacua with those in air of different rarefactions we may here place the following results of a series of related experiments with our apparatus, undertaken for this purpose.
[365]

TABLE II

Potential of Electrode subjected to Radiation	Pressure in mm. of Mercury 0	0.002	0.03	0.7	20	209	760
Volts, negative	Quantity of Escaping Electricity Coulomb 10^{-10}/sec.						
800	20.2	21.6	47	3.4	0.62	0.12	0.05
4000	20.3	26.2	..	..	40	1.41	0.42
10000	20.2	28.2	..	..	...	...	0.93

Blanks in the table indicate that the air could no longer sustain the applied voltage.

One sees from the table that the Emission Constant is only to be determined at zero pressure. At 0.002 mm. air pressure and more markedly at high pressures the escaping quantity of electricity increases very markedly with increasing voltage, which indeed was the result of previous researches on this subject. In the conclusion (9) we shall return to the question of the air.

5. As regards the question of the path which the quanta escaping from U take, we can make our start again from Righi's basic work which shows that in ordinary air these paths are given by the lines of force of the electric field, but that with increasing rarefaction of the air they approximate more and more straight lines.[12] We inquire now as to whether in a vacuum also we can arrive at the formation of distinct separate rays. The opening in the electrode E (cf. Fig. 1) and the neighboring electrodes α and β are now made use of. If U is sufficiently charged, say to about —30000 volts corrseponding to a spark length of about 1 cm., one observes in an Exner electroscope connected to α a divergence of negative sign beginning with the illumination and increasing slowly. The electricity therefore passes through E to α. That the electricity does not occupy the entire cross-section of the tube is shown by the fact that on the side electrode β a divergence is not obtained; obviously the quanta form a beam which [366] coming to the opening in E, pass through to α.

We find this confirmed when we test the putative beam (ray) by its magnetic deflectability which is to be expected. For this purpose a wire coil is brought close to the tube either above or below; the common axis of the coil is vertical; its windings appear in Fig. 1 as a dotted circle. If now a current of suitable strength flows through the coil, it results that it would deflect to β a cathode beam identical with our beam, so that we obtain the divergence of the electroscope now on β while it is excluded from α, to appear again on α when the current is opened.

The behavior is therefore exactly that which is to be expected when cathode rays are emitted from U. Yet it is not possible to produce [13] cathode rays in our extremely evacuated tube by the usual application of electric force alone; rather ultra-violet light is the means to render possible this production also in a perfect vacuum, and indeed in accordance with the information contained in Table I, not only with large but with as small impressed voltages as one desires. As the immediate source of the quanta of our rays the illuminated electrode is indicated while in the usual discharge tube it appears to be the indispensable gas.

6. For the quantitative study of the magnetic deflectability of our rays, we use instead of the electroscope a quadrant electrometer which may be connected with α or β. The conductor connected to the instrument in the screening metallic enclosure is connected to ground by a shunt conductor in series with a large graphite resistance. By this means the occurrence of disturbing potential differences in the space between E, α and β is avoided, and at the same time the measurement of the quantities or electricity caught by α or β is made possible without time observations by reason of the constant deflection of the electrometer. The outer walls of the tube for the following experiment are cov- [367] ered with tin foil from E to α and β and out of this only the insulated lead wires of the last two electrodes project; the enclosure as well as the particular electrode which is not used in the experiment, are connected to ground. To the illuminated electrode two large Leyden jars are connected to hold its potential constant. After this potential is brought to the desired value the experiment is so conducted that the electrometer deflections, corresponding to a series of different currents in the coil are measured for both α and β[14)].

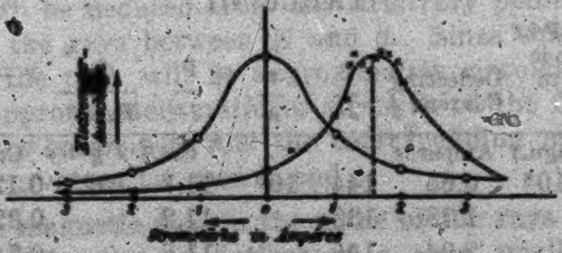


Fig. 2.

Fig. 2 shows graphically the results of such an experiment and at the same time gives a picture of the boundary of the rays. The curve which is symmetrical with respect to zero current and whose points are indicated by circles refers to the electrode for both α, and β. To determine the location of the axis of symmetry of the last curve (denoted by a dotted line) and also the current which deflected the axis of the ray to the center of the electrode β was the object of every experiment. The second and third current values J, given in Table III are mean values of such graphical determinations. The first current value, corresponding to the smallest potential of U, could only be gotten by rapid variations of [368] the current with simultaneous electrometer readings; for, on account of the weakness of the rays at this low voltage, the spark illumination had to be replaced by an intense zinc arclight[15)] which latter was of very fluctuating intensity. The potentials of the electrode U, indicated in the first column of the table, were determined during the experiment by the divergence of a suitable electroscope. The calibration of the electroscope gave the highest or the mean applied potential corresponding to a sparking distance of 3.40 or 0.880 mm. measured between clean spheres of 1.0 and 0.7 cm. radius respectively, from which the corresponding values P of the table follow. The electroscope used for the lowest potentials was tested electrostatically on spark lengths with the aid of large capacities downward and upward by voltages measurable by current flow; from the calibration curve so obtained the first number P is taken.

TABLE III

Potential P of the electrode subjected to radiation.	Deflecting Current J	$\frac{P}{J^2}$	$\frac{\varepsilon}{\mu} = \frac{P}{J^2} \cdot \frac{Z}{H_1^2R^2}$	$v = \frac{2P}{H_1RJ}$
C.G.S. (magn.)	Amperes		Cm.$^{1/2}$ g$^{-1/2}$	Cm. sec.$^{-1}$
607 . 10^8	0.65	144 . 10^9	11.7 . 10^6	0.12 . 10^{10}
4380	1.78	138	11.2	0.32
12600	2.94	146	11.8	0.54

With the data so obtained, we now test quantitatively the assumption that the particles of our rays set in motion by the light with the initial velocity v_0 behave like the particles of a cathode ray, that they therefore in the first place are accelerated, in a uniform electric field under the potential difference P, to the velocity v in accordance with the equation, $v^2 - v_0{}^2 = \frac{\varepsilon}{\mu} P^2$ 16), [369] and that, secondly, in a uniform magnetic field H at right angles to their motion have the radius of curvature

$$R = \frac{v}{H} \cdot \frac{\mu}{\varepsilon}$$

Since we estimate H from the current J we write $H = H_1 J$ where H_1 denotes the field due to a current of one ampere.

We add the special hypothesis of a very small initial velocity and therefore set $v_0 = 0$. It follows then $\frac{P}{J^2} = \frac{1}{2} H_1{}^2 R^2 \frac{\varepsilon}{\mu} =$ constant, a relation which is confirmed by the third column of Table III. The whole of our assumptions meet with no contradictions. Concerning the real magnitude of the initial velocity, we shall later obtain information (8).

7. In order to calculate the density relation $\frac{\varepsilon}{\mu}$ and the velocity v, a knowledge of H_1 and R besides $\frac{P}{2}$ is needed, two corresponding values of field and radius which can be deduced from any arbitrary point on the path of the rays between E and β. Since this entire part of the path will be approximately circular owing to the approximately uniform strength of the field, we choose the mean field and the corresponding mean radius of curvature between E and β.

The magnetic field in the plane of the rays was investigated by the oscillations of a very small highly magnetized needle loaded with lead. The following are the observed oscillation periods.

Distance from the axis of the coil	0	1	2	3	4	5 cm.
Oscillation period with 1 amp. current	1.08	1.11	1.23	1.51	2.21	4.15 sec.

[370]

At 6 and 7 cm. separation from the axis, the position of equilibrium of the needle departed greatly from the direction of the axis of the coils which was placed normal to the meridian. The magnet field was therefore at this place already of the same order of magnitude as the field of the earth and therefore out of consideration for our purpose. The electrode E was separated 3 cm. and the electrode U 6.6 cm. from the axis of the coil. The magnetic field at the center was calculated as 16.0 C.G.S. units for a current of one ampere, from measurements of a very finely adjustable coil system. From this with the aid of the oscillation period, the mean magnetic field between E and β was calculated as $H_1 = 13.0$ C.G.S.

The mean radius of curvature is the radius of the circle which goes through the centers of E and β and whose direction is given at E. If this direction coincides exactly with the common axis of U and E, the radius, according to measurements made on the tube, would be 8.7 cm., but even before passing E the ray is influenced by the edge of the field of the coil and although this effect is small it nevertheless causes the ray to be deflected through a small angle from the axis toward β before it passes E and this would slightly increase the radius of curvature. According to our equations the angle is given by

$$\frac{\sqrt{\sigma}}{H_1 R} \int_0^\sigma \frac{Hds}{\sqrt{s}}$$

where σ is the distance of U from E on graphically evaluating the interval and making use of the above approximate value of the radius the angle becomes 5° 12′. The corrected radius is therefore 12.1 cm.

The values of $\frac{\epsilon}{\mu}$ which can now be calculated are given in the fourth column of Table III. They differ from the value of $4.6 \,.\, 10^6$ which I previously obtained with cathode rays[17]. There is no reason to compel us [871] to look upon this difference as genuine, since those experiments as well as these were not undertaken for the purpose of this determination and at that time they could not be undertaken for such a purpose[18]. It would therefore be the more interesting to make a direct comparison between the rays produced by ultra-violet light and those produced by gas discharge. For this purpose suitable quantities of air were let into the tube and the electrode U was connected with the influence machine. The phosphorescent patch which was sharply bounded covered almost the entire electrode α. The currents necessary to make the fluorescence cover the electrode β were $J = 1.7$ to 2.5 amperes for potential differences $P = 3300$ to $9300 \,.\, 10^8$ C.G.S., which gives $\frac{P}{J^2} = 114$ to $149 \,.\, 10^9$ and this is in good agreement with the values obtained with our rays (cf. Table III, column 3). This experiment is, of course, not decisive, because the objection may be raised that the rays in the last named experiments were not pure in that they were produced in the midst of a disturbing gas, and furthermore, it may be doubted whether the whole potential difference between the electrodes can be reckoned with here, since it is used not only for accelerating but also for the production of the rays. The question regarding the constancy of the density relation $\frac{\epsilon}{\mu}$ seems to me to be still open[19]. The velocity v of the rays given in the last column of Table III shows that here we partly deal with rays that are slower than any that have thus far been investigated. The velocity of the rays which was produced under the influence of a potential difference of 607 volts—corresponding to a mean divergence of an ordinary electroscope—is about $\frac{1}{30}$ of the velocity of light. It is not to be wondered why these rays did not produce phosphorescence on the glass wall of the tube. It is also explainable why in my experi- [372] ments very much faster rays that were produced with high voltages remained invisible, because cathode rays that I observed before and which carried quantities of electricity of the same order of magnitude could only be noticed on the glass in a completely dark room while in the present experiments a good deal of unavoidable diffused light was present. The use of suitable phosphorescence screens would be appropriate in this case.

8. A few more conclusions can be drawn from the observations. In the first place, we see that on account of the weakness of the rays that were produced at 607 volts (cf. 6) the radiation from the surface which was subjected to the ultraviolet light did not take place normally to the surface as would be the case in an ordinary discharge tube, but it was diffused in all directions, because we see from Table I that the same quantity of electricity is emitted with this voltage as with higher voltages which, however, gave much more intense rays back of the diaphragm E. This difference in intensity can be accounted for when the radiation takes place in all directions. In this case the higher the voltage the more the rays are bent under the influence of the electric field between U and E so as to have a common normal direction and so more rays would pass through the opening in E. Also the necessity of avoiding an illumination of the edge of U when we want to obtain pure rays behind E under the influence of small voltages can be accounted for by the diffuse radiation, (compare notations page 367). For if not made innocuous by strong forces this would permit the radiation to pass over the outer edge of E.

The diffuse radiation is also closely connected to a finite initial velocity of emission. In order to obtain an estimate of the value of the initial velocity in our experiments I conductively connected E and U together and to earth so that there was no electric force between them, at least not at the beginning. At the same time two coils were so mounted that the region between U and E was in the center of their field. These coils were so mounted that the magnetic field of the earth could [373] be compensated with the help of suitably chosen currents. This was done in order, first, to see if the earth's field would have any influence on the radiation20). This was found not to be the case. There was no noticeable difference between the quantity of electricity emitted with or without the earth's field. If, however, the magnetic field between U and E was increased more and more, until at a field of about 6 C.G.S. there was a distinct diminution in the quantity of electricity emitted, with a field of 16 C.G.S. almost the whole radiation was suppressed21). This behavior can be explained as follows:

The quanta which in the absence of the external electric field have a constant velocity in all directions from the center of emission (cf. note 14) travel in circles or spirals in the homogeneous magnetic field. The radius of these paths becomes smaller with increase in the strength of the magnetic field. If the magnetic field is sufficiently large, one of these paths will not strike any body in the neighborhood any more, but will be bent back to the surface of the emitting electrode, and this is the beginning of the influence of the magnetic field on the escaping quanta 22). The diameter of the path that is bent back first is, with our apparatus, of the order of the distance between U and E, that is, 3.6 cm., and this corresponds to a field of 6 C.G.S., so that the velocity v_0 of emission is roughly 10^8 cm. per second.

The same result can be obtained by noting that the emission is reduced to zero when the potential of U becomes 2.1 volts positive (Table I). This process can be looked upon in this way, that the potential P is just sufficient to return all the quanta that have been emitted in all directions with the velocity v_0 to the electrode before they can strike any body in the neighborhood. The [374] velocity can then be calculated from the equation $v_0 = \sqrt{2 P \frac{\varepsilon}{\mu}}$ since the glass wall can be looked upon as sufficiently conducting to have the same potential as E—that is, ground potential. This also gives for v_0 10^8 cm. per second.

An initial velocity of this order of magnitude could be overlooked in our deflection experiments (6), since it is only $\frac{1}{10}$ of the least velocity dealt with. They would therefore be completely covered by an error of $\frac{1}{100}$ in the experimental observations.

9. Thus far we have only considered the phenomena in vacuum. From the results here obtained, however, conclusions can be drawn for the case in which gas is present. These may be pointed out here. They seem to agree well with results that are already known. The cathode rays proceeding from the illuminated surface would be absorbed by the gas and would give up their charges to it. From then on the electricity is transported by the gas along those paths and with those relatively low velocities which Mr. Righi has found and also explained on the assumption of charged gas molecules. If the pressure of the gas is not very small the transportation of electricity will be in the form of cathode rays only in a very small section in the neighborhood of the illuminated plate, since the low initial velocities (8) of the emitted rays would mean great absorption[22]. For small gas pressures this layer would become thicker in proportion to the small absorption by the gas [23], and can therefore be more easily observed[24]. The diffuse radiation on the illuminated electrode [25] which was observed by Mr. Righi for low gas pressures and which he explained as due to the motion of the gas

molecules, might consequently be identical with the diffuse emission of the cathode rays found here.

[375]

The presence of the gas would cause complications, in view of the conductivity imparted to the gas by the cathode rays when the latter are absorbed[26]. The illuminated electrode is then surrounded by a negative charge and by a conducting atmosphere. This can be understood if we consider that in the presence of gas the quantity of electricity discharged in unit time increases with the voltage, and secondly that in gas much larger quantities of electricity can be discharged than in a vacuum (4, Table II). The fact that the discharge decreases again for high gas pressures contradicts this explanation. Difficulties are met in considering the case in which the substance was initially charged positively in air. For the explanation of this there is a want of knowledge of the properties of gases which have been charged and made conducting by cathode rays.

Defendant's Exhibit No. 10

NOTES.

1. With regard to the notes to paragraphs 8 and 9 of this paper, attention is called in this edition to the allied investigation of Mr. J. J. Thomson which has now been fully published (Phil. Mag. 5, 48, page 547, 1899).

2. A. Righi, Mem. della Reale Acad. di Bologna (4), 9, p. 369, 1888, and Atti. della Reale Acad. dei Lincei (2) 6, p. 81, 1890.

3. P. Lenard and N. Wolf, Wied. Ann. 37, p. 443, 1889.

4. J. Elster and H. Geitel, Wied. Ann. 57, p. 24, 1896.

5. Cf. Wied. Ann. 64, p. 279, 1898.

6. A. Righi, Atti della Reale Acad. dei Lincei l.c.

7. The raps pump was used.

8. This was shown to be strictly dependent on the illumination within the tube; if besides the surface of U other parts of the tube were illuminated the decrease of the positive charge could be accelerated. Since [illegible] under normal conditions scattered reflected light strikes, for example, the electrode E, the above mentioned small loss of positive electricity appears to be explicable in the meaning of Elster and Geitel (l.c.).

9. Cf. Wied. Ann. 64, p. 279, 1898.

10. Concerning the mode of voltage measurement, cf. p. 368. The resistances were determined by the time of discharge of measured capacities.

11. Except at this voltage in my research no escape of electricity was detected in the absence of light.

12. A. Righi, Atti (l.c.).

13. At least not by forces which the glass of the tube employed was capable of continuously withstanding; cf. remarks with Table I.

14. It is to be remarked that in this experiment a quartz lens placed between L and B focused the ultra-violet light on the center of the electrode U, there illuminating a faintly bounded ellipse of about 10 mm. mean diameter (cf. 8).

15. A. Righi, memo. della Reale Acad. di Bologna (4), 9, p. 379, 1888.

16. A special test of this deduction I ~~carried~~ through with cathode rays previously (Wied. Ann. 65, p. 504, 1898). Subsequent to this work opportunity was given me to remark on the observations of de Condres (Verh. d. Phys. Ges. zu Berlin 17, p. 17, 1898) already published but unknown to

me, in which an influencing of the rays by electric force parallel to the rays had been shown, and moreover in the sense of the above equation. Almost simultaneously Wiechert's experimental determination of the propagation velocity of cathode rays had placed the subject on a new basis (Gött Nachr. Math. Phys. Klasse, 1898, p. 260).

17. P. Lenard, Wied. Ann. 64, p. 287, 1898; 65, p. 508, 1898.

18. As long as still inexplicable related phenomena come into play, an exact measurement is not in general possible. As a related phenomenon of this kind in the present experiment, I might name the double maximum of the deflection curve of Fig. 2 which was visible in every case and which was often very pronounced. As far as possible errors and known origin are concerned, I would give preference to these experiments over the previous ones.

19. Cf. also A. Shuster, Wied. Ann. 65, p. 877, 1898.

20. The induction apparatus producing the illuminating spark was placed 6 m. distant from the tube in the recorded experiment.

21. This is the phenomenon simultaneously discovered by Elster and Geitel (Wied. Ann. 41, p. 166, 1890) and Righi Atti, (l.c.).

22. As far as I can tell from an abstract at hand, the same conception of the disfractive magnetic effect has just been published by J. J. Thomson (Phys. Zeitschr. 1. October 1899).

23. Cf. Wied. Ann. 56, p. 255, 1895.

24. Indeed, in the cited notice (abstract) J. J. Thomson announces observations which concern the photo-electric discharge in a shell of rarefied gas and permit this to act as cathode rays.

25. A. Righi, Atti. l. c.

26. Cf. Wied. Ann. 51, p. 240, 1894.

TRANSLATOR'S NOTES.

(To Lenard's paper on
"Photoelectric Action")

The German word here translated as "electron" is "Quant." This is a word peculiar to Lenard, which he used for years to designate what all other German's were calling "Elektron". In his latest available article in volume 48 of the Annalen der Physik he uses both words to designate the same thing. (p. 496) That he is speaking of electrons in the article here translated is obvious from the fact that he gives 10^7 for the ratio of the charge of the "Quant" to its mass. This differs by some forty per cent from the value now accepted for the electron, but is of a totally different order of magnitude from the value for any other possible kind of charged particle.

The word translated as "ion" is "Träger."

The terms "carbon", "black", and "lampblack" have been used at different places to signify the coating of carbon deposited by a smoking flame on a metal surface. In this case it was obtained by burning turpentine. A "blackened" surface is one so covered. The corresponding German words are "Russ" and "berusst."

K. K. DARROW

DEFENDANT'S EXHIBIT No. 10-A.

[TRANSLATION]

PHOTOELECTRIC ACTION

(Ueber die lichtelektrische Wirkung)

by

P. Lenard

Annalen der Physik, Vol. 8, p. 149, 1902

[149]

In an earlier communication, I have shown that ultra-violet light falling on a body may excite cathode radiation from it[1]. This production of cathode rays was found to be independent of the presence of a gas; contrary to all previously known methods of production in discharged tubes, it took place even in the highest vacuum[2]. A characteristic was that as in a vacuum electric forces had no influence on this excitation. The quantity of radiation was not at all affected by increasing the force at the negatively charged illuminated surface from 100 Volt/3.6 cm. to 45,000 Volt/3.6 cm. This was in accordance with the hypothesis that the light produces the rays not outside but in the interior of the body where it is absorbed; and in such a manner that negative electrons are set free with given initial velocities, so that they can make their way out of the substance. In this case the outside electric forces would operate simply to produce an acceleration or a retardation according to its direction, of the emitted electrons. A retarding outside force corresponding to a positive charging of the illuminated body can cause electrons already emitted to return to the body and thus apparently stop the emission; this was also observed. It was surprising, [150] however, that a diminution of the amount emitted—according to our conception, a return of electrons already emitted—took place when the outside force was accelerating and less than 30 Volt/cm. while much greater forces have no further effect on it. Here we had to assume the presence of a particular retarding force of still unknown origin. In the interim, I have been trying to obtain further knowledge about this and about the general process of producing the rays[3].

10. I succeeded in making the rays visible on phosphorescent screens which made observation much easier. However, I shall here report only on the results of experiments with electrometers only, in which, first, the forces of electrical nature acting at the surfaces of conductors have an opportunity to make themselves manifest in a new way and, second, the initial velocities of the rays can be thoroughly measured. In respect to those forces we found, for example, that there is not a single clear indication of the existence of a specific attraction between conductors and electricity as was assumed to explain the contact potential differences of metals (38). In respect to the initial velocities, we find they are not of uniform magnitude and that for every conductor and every kind of exciting light there is a special distribution of velocities (22, 23, 26, 36). However, the magnitudes of the initial velocities are independent of the intensity of the light (25) and this last result makes it seem probable that in the process of excitation the light merely sets the electrons free with velocities which they must already fully possess inside the atoms of the substance (28).

11. If the illuminated substance is in a space filled with gas the phenomenon becomes similar to the action of light discovered by Hertz and Hallwachs (9, 47). There was a single apparent objection to this idea, to wit, the rigorously uni-polar character of this action, [*i.e.* of Hertz & Hallwachs]. For if the illuminated body [151] sends out cathode rays with the initial velocities peculiar to it and to the exciting light independently of the outside force—and hence, also, when it is positively charged—these cathode rays will traverse some of the gas even if they are quickly pulled back by the outside force and will consequently (according to previous knowledge)[4] make it electrically conducting. But if the body has a conducting layer of gas next to it, it will

lose its charge; and this is contrary to experience. It will be shown here that gases are made conductive by cathode rays only when the rays have a velocity exceeding a certain minimum (39, 40, 42, 43); and since we furthermore find that the highest initial velocities possessed by any detectable number of the rays excited by light, lie under this minimum, the contradiction disappears (46). The velocity of the rays studied in the present work is of the order of 10^7 to 10^8 cm. per second of about one one-thousandth of the velocity of light, consequently much smaller than before (7). It is seen that these slow rays must possess to a very high degree the properties of spreading out diffusely and of being absorbed in gases for after passing through only a few gas molecules (41), while the rays which I first studied having about one-third the velocity of light could pass through 5000 gas molecules before their path became noticeably curved or their motion slowed down.

EXPERIMENTS IN A VACUUM.

12. The present experimental runs were not carried out in the most extreme vacuum. I evacuated always to the limit of the mercury pump but did not apply any special means to remove the remaining gas from the electrodes and the glass walls, and used cement and greased joints. Since the principal features of the phenomenon in extreme vacuum had already been investigated (3 to 8), this seemed permissible⁵⁾.
[152]

13. The apparatus is shown in Figure 1. U is the electrode to be illuminated, which is a circular aluminium disc of 3.4 cm. diameter completely covered with turpentine black. Opposite it stands the metal disc E of the same size and similarly covered with black; part of it is cut away (e Figure 1 a) so that the narrow beam of light which traverses the diaphragms BB and gg from the source L, can reach U without touching E. This was completely avoided by setting the source of

light carefully. The plate E can be moved perpendicular to its own plane so that the distance UE can be altered. For distances UE less than 10 mm., a special electrode E_1, Figure 1 b, is put in place of E. This one has a conical metal tube r to give a free path to the beam of light; one mouth of this tube lies in the same straight line with the diaphragm gg and the other opposite U when the distance UE is equal to 5 mm. This plate E_1 is likewise covered with black together with its tube.

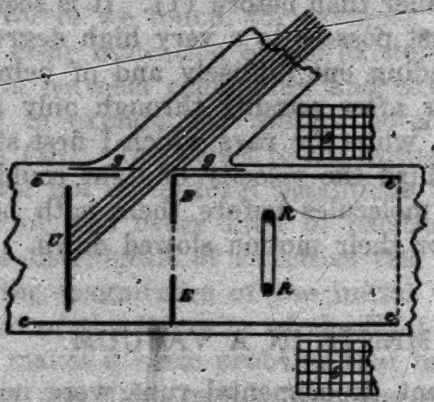


Fig. 4.

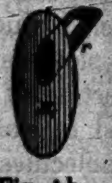


Fig. 1b.

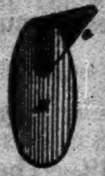


Fig. 1a.

At the beginning of every run a measurable potential difference is established between U and E [153] by using storage batteries; directly for high potential differences and with a potentiometer arrangement for lower ones. The plate U or E, for which we were to determine the change in charge due to illumination, was connected with a quadrant electrometer. The box containing the electrometer which extended over all the connections and over the pair of plates U and E (WW in Figure 1 and the diaphragm BB being parts of it), was brought at the beginning to the same potential as the plate connected with the electrometer. At the beginning of the observation we broke a spring contact which had been connecting the plate with the box; the charge on the plate then changes because of the action of the light and the electrometer gives the change. Since the potential difference between the two plates alters at the same rate, it is necessary to work only with small deflections of the electrometer. Unless we were using high potentials, the change of which is without influence (4), we added such a capacity to the electrometer and so adjusted the duration of the illumination[6] that the deflections amounted to only a few scale divisions corresponding (for average sensitivity of the electrometer) to a few hundredths of a volt[7]. The smallness of these deflections did not limit the attainable accuracy for the readings of the electrometer are reliable to .02 scale divisions[8] and the known adequate sources of ultra-violet light vary so much in their intensity that a great number of observations have to be taken on this account alone.

[154]

14. The quantity emitted in unit time is proportional to the intensity of the light. The total quantity emitted under the influence of the light is observed, according to our hypothesis (4), when there is a sufficiently great outside accelerating force. Two hundred volts were used for a distance UE of 40 mm. The light came from 6 mm. sparks (3) between zinc spheres. Known variations of the intensity of the light were produced by varying the distance between the sparks and the mica diaphragm gg; this diaphragm being smaller than BB always determined the cross section of the beam reaching U. The electrometer was connected to U. The results follow[9].

Column 5 shows that the light intensities varied in the ratio of 90 : 1.4, while the ratio between the effect Q and the intensity (Column 6) is as constant as was the source of light during their periods of time which [155] had to elapse before it could be readjusted. Not all the loss of electricity Q here observed took place by emission but only the largest part of it; a small part is due to the conductivity of the system (12, 45). The inverse relation is found in experiments in rarefied gases where the loss of electricity through conduction may

TABLE IV.

1	2	3	4	5	6
r	A	C	$Q=\frac{AC}{10}$	$\frac{1}{r^2}$	$\frac{Q}{1/r^2}$
0.105	7.65	1001	766	90.6	8.47
0.132	5.00	1001	501	57.4	8.75
0.206	2.21	1001	221	23.6	9.37
0.206	222.3	10.39	231.0	23.6	9.77
0.463	35.55	10.39	36.93	4.64	7.94
0.835	10.22	10.39	10.62	1.436	7.42
0.835	95	1.14	10.82	1.436	7.55

1. Distance from spark to mica diaphragm.
2. Electrometer deflection (scale divisions in 10 seconds).
3. Capacity of the electrometer system.
4. Quantity of electricity escaping in one second.
5. Relative light intensity.

exceed that by emission (compare 4, Table II, .03 mm. pressure). Now, since experiments of this latter kind have likewise found the effect proportional to the intensity[10)] of the light, our experiments show that this proportionality holds also for pure emission.

15. The period during which a zinc spark spectrum line was being emitted was about 5×10^{-6} seconds in the experiments of Schuster and Hemsalech[11)]. In the present experiments it must have been yet smaller for the capacity used in the spark apparatus was less. Since the sparks follow one another at intervals of .0062 seconds, the intensity of this source of light, while it was actually shining, was more than 1300 times greater than its average intensity. These experiments, therefore, were really performed with extraordinarily great intensities even when the source of light was furthest away. However, I have found with a carbon arc light, burning as feebly as possible, at distances of from 34 to 268 cm. from the mica diaphragm, that the effect is still proportional to the inverse square of the distance

at least insofar as could be expected, considering the inconstancy of the ultra-violet intensity of such an arc; at least, there was not the slightest indication of any value of the intensity near which the effect might diminish rapidly to zero. If such a value exists it must be very low as we see especially from the effect of the light reflected from the blackened surface U, to be quantitatively discussed in (22). These very small quantities [156] of light falling on E produced a correspondingly small effect which was seen to be a sensibly constant fraction of the effect of the light falling directly on Y independent of its intensity; which can only be the case if the very small quantities of light reflected from the lamp black still have an effect proportional to their intensity. The intensities there observed were as much as 3 x 10^6 times smaller than the largest momentary intensities used in Table 4.

16. The following run (Table V) is given to show the trend of the radiation at various outside potential differences. It is graphically represented by the two

TABLE V.

Distance UE = 10 mm.

Accelerating Forces Carbon Arc. Spark.			Retarding Forces Carbon Arc.		
1	2	3	1	2	3
Volt			Volt		
100	1.00*	1.00*	—0.66	0.162	0.029
10	0.94	0.96	—0.8	—	0.0094
2	0.85	0.84	—1.0	0.082	0.000
1	0.79	0.81	—1.2	—	—0.0041
0.5	0.73	0.74	—1.4	—	—0.0065
0.3	0.65	—	—1.8	—	—0.0072
0.2	0.55	—	—2.4	0.0000	—
0	0.40	0.34	—3.0	—0.0026	—0.0071

* Compare paragraph 12.

Column 1: P.D. between U and E; X, in volts
Column 2: Quantity escaping from U: U
Column 3: Quantity arriving at E: E

straight lines of Plate 1, Figure 1, marked with UE = 10 mm. The abscissa is potential difference. The ordinate is the quantity of electricity and points which belong together are connected with a straight line. The full line gives the quantity of electricity leaving U, the broken line the quantity arriving at E. These quantities we designate for shortness simply by U and E[12].

[157]

17. To this table and the corresponding graphs we append the following ideas, from which all that follows will proceed and which are justified thereby. For the sake of convenience in conceiving it, we divide the phenomenon into five separate stages which correspond to different ranges of magnitude of the outside force (compare Plate 1, Figure 1).

In stage 1 (large retarding forces) the entire quantity of electricity which the light causes to be emitted—we designate this quantity always by 1.00—is driven back to U before striking any object in the vicinity. In this stage the electrometer would show nothing if there were not some light reflected from U to E which produces an effect there. This effect is revealed by the small quantities of electricity which depart from E and arrive at U and which appear in Plate 1, Figure 1, as very small negative ordinates.

In stage 2 (retarding outside force, not so great) U begins to lose its charge steadily but nothing arrives at E; the part of the radiation which does not return to U goes to the glass walls of the apparatus (this is the part corresponding to the ordinate U). This is due to the tangential components of the initial velocities (8). The parabolic paths of the electrons beginning at the illuminated center of U do not quite reach E but do go so far over the edge of U that they finally reach the glass wall instead of returning.

In stage 3 (retarding force still smaller than in [158] stage 2) some paths extend as far as E and stop there so that the curve E begins to show positive ordinates. Of the total emission 1.00 a part, E, goes to E, another part, U-E, goes off sidewise to the glass walls and the third part 1-U goes back to U. The number of electrons going to E increases when the retarding force diminishes, as is shown by the rise of curve E. Since only such electrons can come to E as have velocities of which the normal component exceeds a certain amount corresponding to the potential difference UE, the shape of the curves in this stage will be suitable for finding the distribution of the initial velocities; of course, the sidewise escape of the electrons must be allowed for (18, 20, 22, 23).

In stage 4 the two curves coincide; the outside force which is now an accelerating force, brings all the electrons to E except those that return to U.

In stage 5, the accelerating force is so great that no electrons return to U and consequently the total emission—1.00 in our units—is measured. A further increase of the force produces no further alteration, as was completely proved up to very high values of the force in the earlier experiments (4, Plate 1).

18. Prevention of the sidewise escape of electrons by means of magnetic force.—A coil (SS in Figure 1) is slipped over the tube producing a magnetic field normal to U and E. This converts the tangential components of the electron paths into circles leaving the normal components unchanged. The sidewise escape of the electrons to the glass walls is, therefore, suppressed; however, the electrons which would have escaped except for the magnetic force do not go on to E but return instead to U as it should be (17, stage 2). This is shown as follows that the quantities reaching E—given in Columns 4 and 7 of Table VI—are not distinctly changed by the magnetic force while the quantities departing from U change (compare Columns 2 and 3 or 5 and 6 of Table VI), in such manner that they become nearly equal to the previously mentioned quantities E. The magnetic force, therefore, brings curve U nearly into

[159] coincidence with curve E which last remains unchanged; stage 2, therefore, vanishes.

The tests were carried out with the carbon arc light as well as with the spark[13].

TABLE VI.

Distance UE = 10 mm. Entire Emitted Quantity = 1.00

1	2	3	4	5	6	7
—0.66	0.16	0.032	0.029	0.094	0.0088	0.012
—1.0	0.082	0.0016	—	—	—	—
—1.12	—	—	—	0.019	—0.0031	—0.0038
—3.0	—0.0026	—0.0047	—0.0071	—0.0025	—0.0038	—0.0054

1. Potential difference between U and E in volts.
2. Arc light; charge departing from U, no magnetic field.
3. Arc light; charge departing from U, magnetic field.
4. Arc light; charge arriving at E.
5. }
6. } Corresponding to 2, 3, 4 for spark.
7. }

19. A direct observation of the quantity of electricity escaping sidewise was made possible by introducing a metallic sheath (HH, Figure 1), covered with lamp black, against the glass wall between U and E[14]. When the magnetic field was raised to about 15 C.G.S. units (measured at the surface of U), the sheath no longer took up any negative charge. No electric force was applied; the distance UE was 40 mm., the radius of the sheath 2.2 cm., the radius of the spot of light on U 0.3 cm. From this we obtain for the largest value of the tangential component of the initial velocity, possessed by any detectable number of electrons, the value

$$\frac{15(2.2-0.3)}{2}\,\frac{\varepsilon}{\mu} = 1.4 \text{ x } 10\,\frac{8\text{cm}}{\text{sec.}}\,.\quad{}^{15)}$$

[160] It is, therefore, of the same order of magnitude as the largest value previously obtained approximately for aluminium (8) and later on more exactly for carbon (36) for the observed normal component.

20. Prevention of sidewise escape of the electrons by bringing the plates U and E close together. — Bringing the plates close together must have the same effect

as making them larger (17, stage 2). For given magnitude and given direction of the initial velocity, the maximum distance traveled in the normal direction is equal to half the maximum distance traveled sidewise. Consequently the sidewise emission must cease, when the distance UE between the plates is smaller than half the distance between the edge of the plate U and the edge of the spot of light; that is, smaller than 7 mm. Experiment confirms this also. We need only to determine the places where the effect on U or on E just ceases corresponding to the boundaries between stages 1 and 2 or between stages 2 and 3, (plate 1, Figure 1); these can be found very accurately. When these two points coincide the curves U and E coincide entirely, and the sidewise emission vanishes. Below are given the abscissae of these two points in volts.

TABLE VII.

Points of Zero Effect; Arc Light.

Distance UE	5	10	25		40 mm.
—x (U = 0)	1.10	2.4*	far over 1.2	1.20	far over 1,2
—x (E = 0)	1.06	1.0*	1.0	1.06 with mdgn. force	1.05

We see that for distances UE greater than or equal to 10 mm., —x(U = 0) is always much greater than —x (E = 0) so that there is a great deal of sidewise [161] emission; while for UE = 5 mm. these two quantities become nearly equal so that the sidewise escape is nearly prevented. For the distance UE = 25 mm. the table shows further that the zero point of U is displaced towards that of E by normal magnetic force while the latter point remains undisplaced (18).

21. The point where the effect is zero depends on the potential difference between the illuminatd body and its surroundings.—The constancy of the numbers x(E = 0) in Table VII shows first that the plate E

takes up no further charge when the potential difference between it and U has a value 1.0 to 1.06 volts independently of the distance UE. Now, since by what precedes (18, 19, 20) U always is equal to E when there is no sidewise emission, we have U = 0 when E = 0; whence follows the principle stated above. This principle is also required by the hypothesis from which we started (17).

In air the phenomenon is different is known[16]; in this case the action becomes zero where a certain density of a positive electricity or a certain value of retarding normal force has been attained on the illuminated surface. This behavior in air must depend on the behavior in vacuum and on the properties of air, to which we will come back (47).

22. **Initial Velocities; Reflected Light.**—When sidewise escape is excluded, as we shall always assume from now on, and the curves U and E coincide, their form yields information about the distribution of initial velocities (17 Stage 3). We must still take account of the effect of the light reflected from U to E. For this purpose we examined the vicinity of the point of zero action more carefully. The following tables give the

TABLE VIII.

Carbon Arc Light
(33.6 cm. from the Mica
Diaphragm)

P. D. between U and E X	Quantity Escaping from U U
+ α[18]	+ 1.00 *
—0.90	+ 0.00913
—1.00	+ 0.00331
—1.10	+ 0.000189
—1.20	—0.00138
—1.30	—0.00383
—1.45	—0.00489
—1.65	—0.00553
—1.75	—0.00598
—2.50	—0.00609

TABLE IX.

Zinc Arc Light
(33.6 cm. from the Mica
Diaphragm)

P. D. between U and E X	Quantity Escaping from U U
+ α[18]	+ 1.00 *
—0.60	+ 0.0158
—0.70	+ 0.00582
—0.825	+ 0.00172
—0.91	—0.000186
—1.12	—0.00312
—1.33	—0.00378
—1.6	—0.00426
—2.5	—0.00463

[18] 20, 50, or 100 volts with correction (*) for conduction.

average values of 127 measurements in this vicinity carried out at the distance UE = 5 mm. which had previously been found sufficiently small; the sources were [162] the carbon arc and the zinc arc[17].

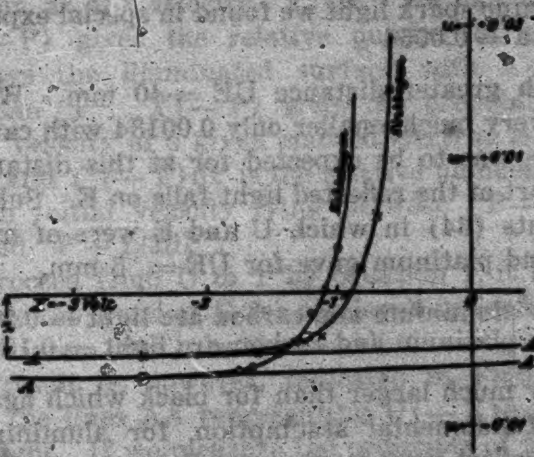


Fig. 2.

Figure 2 is a graphic representation of these tables on a large scale of ordinates. The curves approach a horizontal asymptote as was to be expected, for when the retarding force is sufficiently great there is no [163] emission from U to E, but all the emission from E produced by reflected light goes to U.

If the emitted quantities are proportional to the intensity of the light (14, 15), the quantity U(—a) simply signifies the fraction a of the light falling upon U which is reflected to E. But since the two plates U and E stand very close together and only the center of one of them is illuminated, it gives the fraction a of incident light which is reflected; that is, in the present case, the reflecting power of turpentine-oil-black. Correspondingly, the quantity U(—a) was found not to vary with the intensity of the light. The kind of light, however, had a marked influence. We take the following values from the last lines of Tables VIII and IX;

the trend of the curves is such that we may replace $U(-\alpha)$ by $U(-2.5)$

a, for turpentine-black and carbon arc light $= 0.00609$
a, for turpentine-black and zinc arc light $= 0.00463$ [10]

For zinc spark light we found in special experiments
$a = 0.0054$

at a much greater distance $UE = 40$ mm. We found $U(-\alpha)$ very much smaller only 0.00134 with carbon arc light; this was to be expected for at this distance only a small part of the reflected light falls on E. Subsequent experiments (34) in which U and E were of matt aluminium and platinum gave for $UE = 5$ mm.

a, for aluminium and carbon arc light $= 0.2069$
a, for platinum and carbon arc light $= 0.1066$

hence very much larger than for black which again confirm the fundamental assumption, for aluminium and platinum reflect very much more light than black.

Small a being thus known, we can start from the observed curve U which is a function of X, which we shall designate as $U(X)$ and obtain a curve $Y(X)$ free [164] from the influence of the reflected light. In the first place we have everywhere

$$U(X) = Y(X) + R(X)$$

wherein R represents the action of the reflected light alone; this must also be equal to

$$R(X) = Y(-X)\,a$$

From these, two equations follow:—

$$(1)\quad Y(X) = \frac{U(X) + U(-X)\,a}{1 - a^2}$$

In particular we have $Y(-\alpha) = 0$, $Y(+\alpha) = U(+\alpha) = 1$.

23. Outside Distribution of Velocities [20]—Since in what follows we shall have to do only with that component of velocity which is perpendicular to the surface of a body, we shall call this component simply the velocity: Then, if P represents the absolute magnitude of the retarding potential difference, $Y(-P)$ will signify the fraction of the total emitted quantity which

has a velocity greater than the greatest electron velocity which can be annulled by the potential difference P (17 Stage 3). This velocity—which conversely can just be produced by the potential difference P—we shall designate simply as the velocity "P"[21]. We can then say that $Y(-P)$ gives the relative number of electrons which leave the illuminated surface with a velocity greater than "P". $Y(-P)$ gives the probability that the initial velocity of a given emitted electron is greater than "P", and $Y'(-P)\,dP$ is the relative number of electrons with initial velocity lying between "P —1/2dP" [165] and "P + 1/2dP".

To proceed from U to Y by equation 1, it is necessary to note the trend of U for accelerating forces. This trend will later (29ff) be thoroughly investigated; the eventual result is, however, indicated in Figure 2 by means of the lines AA representing $U(-X)a$ for both kinds of light. If we measure the ordinates of the curve upwards from these lines we obtain Y; the factor $\frac{1}{1-a^2}$ may be set equal to unity without sensible error error in the case of carbon.

If we examine in this way the curve for carbon arc light, (for example) we deduce, first, that no definite maximum initial velocity can be assigned, but that velocities exceeding "2 volts" scarcely appear at all in our experiments, while smaller velocities appear in a very rapidly increasing proportion [22].

24. Two oppositely directed cathode ray beams in the same space do not interfere with one another.—It is now established that the zero point $U = E = 0$ of the directly observed action U corresponds to the potential difference for which the emitted quantity is equal to the quantity produced (from the other plate) by reflected light and coming into the plate. Rays going out and rays coming in here traverse the same space in opposite directions[23]. This would not be possible if the electricity in motion filled the entire space continuously; for any given volume element can have a velocity

in only one direction at a time. We can, therefore, use this phenomenon to demonstrate the existence of an intimate structure of the electricity here present in motion[24].

[166]

25. The initial velocity is independent of the intensity of the light—the question is, whether the velocity of distribution depends upon the intensity of the exciting light and in particular whether the larger initial velocities will not make up a higher proportion of the whole at higher light intensities; one would expect an affirmative answer to this question, provided that the kinetic energy of the emitted electrons is derived from the force of the exciting light.

It was to be ascertained whether the trend of the curve Y or U changed with the intensity of the light. I paid particular attention to the zero point of the latter curve $U = 0$; this point is favorably situated for this purpose and can be located with greater accuracy than any other point of the curve. It is necessary only to change the potential difference between U and E until we reach the value $X(U = 0)$ where the electrometer, connected either to U or E, remains at rest in spite of the action of the light. The results given in Table X were obtained in this way; the value was often obtained to hundreds of volts by interpolation between points at which the electrometer moved slowly in one direction and in the other. Yet another way is available to determine the zero point. If starting from the potential difference zero we allow the light to act long enough on U, the desired potential difference $X(U = 0)$ is established of itself and can be read on the electrometer when it comes to rest. However, this reading requires, when the insulation is not quite perfected, a correction which is hard to determine; I, therefore, abandoned it in favor [167] of the two others.

TABLE X.

Zero Point for Different Light Intensities.

Distance U E = 5 mm.

Source of Light and Current Strength in It.	Distance from Source to Mica Diaphragm	Total Effect $U(+\alpha)$ as measure for the average intensity of light.	$X(U=0)$	$X(E=0)$	Remarks
	cm.	10^{-10} Coul./sec.	Volts	Volts	
28 Amp.	33.6	2.76	—	—1.07	New carbons in the arc lamp.
28	33.6		—1.10	—1.05	
20	33.6	1.74	—1.12	—	Correspg. to Table VIII and Fig. 2.
28	68	0.317	—1.10	—	14 days between these two.
28	68		—1.10	—	
8	33.6	0.041	—	—1.06	
27 Amp.	33.6	21.8	—0.85	—0.85	Different electrometer & battery connections.
27	33.6		—	—0.87	
27	33.6		—0.88	—0.86	
27	33.6		—0.89	—	Correspg. to Table IX, Fig. 2.
27	87.9	3.19	—0.86	—	14 days between these two.
27	87.9		—0.89	—	
Zinc Spark	17.4	2.86	—1.00	—0.97	

In the table we observe, it is true, small differences between associated values of $X(U=0)$ and $X(E=0)$ which indicate a slight escape of electricity from between U and E (17 Stage 3; 20); but not the slightest dependent of one or the other of these quantities on the intensity of the light. Note in particular that within each group the runs are arranged in the order of decreasing intensity as we see in Column 3 (14). With the carbon arc light the intensity varies in a ratio of about 70 to 1. The value of $X(E=0)$ is not changed by as much as one per cent. This means, as we see from the trend of Y (Figure 2 and Table VIII), in the vicinity of $U=E=0$, that the number of electrons having an initial velocity in excess of 1.06 volts is not increased [168] by as much as 5% when the intensity is increased 70 fold; although this number is in itself very small, only .0057 of the total number.

Similar experiments with the same result when carried out with aluminium plates U and E (cf. 34) showed that the intensity of the carbon arc light was here varied in the ratio of about 1000 to 1 without sensible change in the zero point.

26. It is seen directly from Table X, and from Table VI, VIII, and IX, and Figure 2, that different kinds of light give different initial velocities. With zinc arc light large initial velocities are present in very much smaller proportion than with carbon arc light[25]; spark light lies between the two. This last light, while actually shining is far the most intense of all (15) from which we see again that intensity and initial velocity have no connection with one another.

27. Polarized light.—When light from the zinc spark falls under an angle of 58° upon the front surface of a plane quartz plate, which is cut perpendicular to the optic axis blackened on the rear surface, the ultra-violet part of the reflected beam is almost completely linearly polarized. This was verified with a second identical quartz mirror as analyzer. When the mirrors were parallel to one another, the twice reflected beam produced a brilliant green fluorescence on uranium glass and blue fluorescence on flint glass; these were almost completely extinguished when a glass or mica plate was inserted in the path of the beam or when the mirrors were crossed.

[169]

The polarized light was used in two different orientations; in case A, the electric vector was parallel to the surface of U, in case B it was perpendicular to the former direction and made the largest possible angle with the surface of U, to wit, 45°. In case A, the electric vector is perpendicular to the plane of the paper in Figure 1; in case B, it lies in this plane [26]. The results are as follows:

TABLE XI.

Zinc Spark Light, Polarized. Distance UE = 10 mm.

	Zero-point X(E = 0) volts	Total Emission E(+ 100) coul./sec.
Case A	—0.95	0.16×10^{-10}
Case B	—1.0	0.17×10^{-10}

There is consequently no certain difference between cases A and B either as regards the initial velocities (second column) or as regards the quantities emitted (third column)[27].

28. To the previous results (25, 27) the following may be added. People have learned to regard the strong absorption of light as a resonance phenomenon located in the molecules or atoms of the absorbing body. As a matter of fact even in our experiments action is not produced by light of every wave length; we find that a transparent leaf of mica or piece of glass held in the path of the light destroys all the effect. We may [170] consider that the same electrons which the light causes to be emitted have been vibrating under the influence of the light just before the emission and at that time must have been bound to the atoms by forces. If we assume as the simplest case that those forces are independent of time and are such that linear light vibrations excite linear resonance vibrations[28] the amplitude of these vibrations will increase until the accumulated kinetic energy exceeds the maximum potential energy that can be derived from these forces. The electron will then leave its atom with the excess kinetic energy. This excess, which represents that part of the initial velocity due to the light must have been acquired during the last half or whole resonance period. Hence, it must increase with the intensity of the light, but since we found that this was not so in actuality (25) it follows that the assumption of simple resonance motion does not account for the phenomena. We might assume more complicated motions in the interior of the substance or adopt the hypothesis which, for the present,

seems most appropriate that the initial velocities of the emitted electrons do not come from the energy of the light but from violent motions already existing inside the atoms before the illumination began; so that the resonance motions merely set them free.

Even the magnitude of the observed initial velocities, for example, "3 Volts" ($= 8 \times 10^7$ cm/sec) for aluminium (34, 36), contradicts the assumption that they can have been absorbed during half a period or even during several half periods of light of ordinary intensity potential differences of three volts are not found in such light. Furthermore, we found that the normal component of the initial velocity was not clearly altered, when the normal component of the electric vector of the incident [171] light was reduced to zero (Case A, 27).

29. **When the outside field is accelerating the field strength determines the action.**—Stage 4 of the phenomenon (17) was characterized by the fact that in spite of an accelerating outside force the emission was not yet complete. We investigate first the influence upon the phenomenon of changing the distance between the plates U and E. Table XII contains the relevent results which are graphically represented in Figure 1.

TABLE XII

P.D. between U and E X Volts	Charge leaving U; U.				
	UE = 5 mm.		10 mm.	25 mm.	40 mm.
	Spark			Carbon Arc	
100			1.00*	1.00*	1.00*
20	1.00	1.00	—	1.01*	—
10	—	—	0.94	—	0.79
3	—	—	—	0.78	—
2	0.94	0.95	0.85	—	0.29
1	0.88	0.90	0.79	0.57	0.26
0.5	0.84	0.87	0.73	0.29	0.24
0.3	—	—	0.65	—	—
0.2	—	0.74	0.55	—	—
0.1	—	0.56	—	—	—
0	0.39	0.46	0.40	0.26	0.20

* With correction for conduction: See Note to (12).

[172]

While in the case of the retarding forces the action depended only on the potential difference between U and E (21), we find here that it depends not only on the potential difference but also on the distance between the plates; approximately, however,—as we see from the graph—in such a way that the quotient of the two magnitudes, that is, the strength of the approximately homogeneous field between U and E, determines the action. The principal deviations from this rule occur when there is no outside force (last line of Table XII) when the action should be the same at all distance UE. It was suspected that in this case the glass walls which surround the plates had become charged by the rays which had escaped sidewise (17, stage 4) and thus caused disturbing outside forces. This was verified by repeating the experiments, the glass wall being covered with a metal sheath (EH, Figure 1) which was blackened like U and E and had an opening to let the light through. In order not to destroy the approximate homogeneity of the electric field between U and E, the potential of the sheath was always (except where otherwise stated) kept equal to the arithmetic mean of the potentials of U and E; this was for all distances UE greater than 5 mm. For 5 mm. the sheath and the plate E were connected together and hence at the same potential. The following results were obtained.

TABLE XIII.

Sheath in tube: Carbon arc.

P.D. between U and E X Volts	Charge leaving U; U.			
	UE = 5 mm.	10 mm.	25 mm.	40 mm.
100	—	—	1.00*	1.00*
20	1.000*	1.000*	—	—
3.96	—	—	0.908	0.888
1.96	0.852	0.909	0,865	0.799
0.97	0.831	0.864	0.781	0.751
—0.080	0.671	0.684	0.605	0.669

Mean Value U (— 0.080 Volt) = 0.645

* Corrected for conduction: See Note to (12).

[173]

Within the limits of accuracy, the emission at the potential difference zero or 0.030 no longer depends on the distance UE. Furthermore, the mean value of this emission 0.645 is much higher than any of the values obtained earlier with an uncovered glass wall and no outside force (Table XII, last line) which confirms the previous supposition about the influence of the glass wall[31].

If we arrange all the observed measurements on U in Table XIII in the order of diminishing field strengths, we obtain the series of steadily decreasing numbers in Column 2 of Table XIII-a; there is no relation between these numbers and the adjacent distances UE and the principle announced at the head of this paragraph (20) is verified. In this table the three values, numbers 2, 4 and 8, are from Table XII, Column 3; they fit in so well as to show that when the distance UE is equal to 5 mm. and the accelerating P.D. is greater than 0.5 volt there is no sensible influence of the glass walls[32]. The only values that do not fit in this series are numbers 3 and 6 taken from Column 2 of Table XIII. Re-

TABLE XIII-a.

Field Strength 5X/UE Volts/5 mm.	Charge leaving U	Distance UE	Number
20, 12.5, 10, 20	1.00	25, 40, 10, 5	1
2	0.95	5	2
1.96	0.852	5	3
1	0.90	5	4
0.98	0.909	10	5
0.97	0.831	5	6
0.79	0.908	25	7
0.5	0.87	5	8
0.50	0.838	40	9
0.49	0.864	10	10
0.39	0.865	25	11
0.25	0.799	40	12
0.19	0.781	25	13
0.12	0.751	40	14
0	0.645	Average	15

lative to these, note that they were taken immediately after U had been freshly blackened, while all the other values relate to surfaces which had been blackened one or several days before. I also observed values about 10% too low for small accelerating forces at another time, when the black had been applied immediately before. For what follows, only values obtained with old sur-
[174] faces were taken into account.

30. Only the value of the field strength at the illuminated surface affects the result. — Up to this time the electric field between U and E was nearly homogeneous; now, we compare such a field (a) with an inhomogeneous field (b). The potential difference between U and E was in both cases the same (4 volts accelerating); but while in case (a) the sheath has the mean potential (as always up to now), in case (b) it has the potential of U. The field is, therefore, in the second case stronger on the side towards E, weaker on the side towards U.

	POTENTIALS			
Case	U	Sheath	E	Charge leaving U
a	0	2 Volts	4 Volts	0.908
b	0	0 "	0 "	0.796
		UE = 25 mm.		

[175]

We see that the action in the two cases is markedly different, being smaller when the field at U is weaker. Note that in case (b) no charging up of the sheath could be detected, so that it can not be supposed that there was a direct action of the diminished potential of the sheath.

31. According to the preceding work (29, 30) the increase in the effect as the accelerating outside force increases—which we described as Stage 4 (17)—can

be regarded as a consequence of a special retarding force of electrical nature acting only very close to the illuminated surface. The presence of such a force is also indicated by the phenomenon that a negatively charged substance does not of itself lose any of its charge in a vacuum (4, Note 2) although its own electric field tends to drive the charge out of it, and the vacuum is capable of taking it up (3).

We will consider this force K, measured in volts per cm. as a function of the distances from the boundary of the body. The largest distance in which the force is still sensible, is represented by σ, and

$$\int_{\rho}^{\sigma} Kds = \int_{\rho}^{\alpha} Kds \text{ by } \Pi$$

wherein $\rho < \sigma$ represents a constant length of the order of magnitude of the intermolecular distance inside the substance. II signifies the diminution in velocity undergone by the electrons leaving the body because of the force K. The velocity remaining after the electron has traversed the field of the force K is the directly measured initial velocity (23) which we shall call the "outside initial velocity"; the sum of this and II volts is to be called the "inside velocity".

Now, let the function F (P) represent the number of electrons having an inner velocity greater than "P". This function has the same significance for the inner velocities as Y(—P) in (23) for the outer velocities. We have ($F(0) = 1$, $F(\alpha) = 0$, $F'(P)$ negative.

[176]

If now there is an outside retarding electric force of absolute magnitude X Volts/S cm., the quantity of charge that escapes will be represented by $F(II + X)$. If the force is accelerating it is to be subtracted from K, and since K may have high volume at small distances from the surface of the substance, there will be retarding force from the surface out to a certain distance T and accelerating force beyond this distance. T is a function of X/S; for $X = 0$ we have $T = \sigma$, otherwise $T < \sigma$. The electrons which are not turned back by the time they reach T will not return to U at all but will be definitely emitted. The number of these electrons is therefore.

$$F\left[\int_{\rho}^{T}\left(K-\frac{x}{S}\right)ds\right]$$

the integral, which like T is a function of X/S is designated by $\Phi(X/S)$. The nature of this function is entirely determined by the law of force $K(s)$; in any case we shall have from what has gone before

$$\Phi(0) = II. \qquad \Phi(XIS) = -1$$

Therefore, the function Y (22) representing the observed effect minus that due to the reflected light, is represented for the retarding potential difference of absolute magnitude X by

$$Y(-X) = F(II + X)$$

and for accelerating potential difference X by

$$Y(X) = F\,[\Phi(X/S)] \text{ where } S = UE$$

when the outside force is zero, either of these equations gives,

$$Y(\pm 0) = F(II)$$

The shape of the curve which represents Y as a function of X is determined for retarding X by the distribution of velocities alone, for accelerating X by the distribution of velocities and the law of force. The curve, therefore, consists of two branches of entirely
[177] different type, joining at $X = 0$. The slopes of the two branches are given by

$$dY/dX = -F'(II + X) \quad \text{for the negative branch.}$$

$$dY/dX = F'\left[\Phi\left(\frac{x}{S}\right)\right].\Phi'\left(\frac{x}{S}\right)\frac{1}{S} = -F'\left[\Phi\left(\frac{x}{S}\right)\right]\frac{1}{S}$$

for the positive branch

for $X = 0$ where the two branches meet we have on the negative side the derivative $-F'(II)$ and on the positive side the derivative $-F'(II)\frac{\sigma}{S}$. The two branches, therefore must form an angle with one another at which the slope alters discontinuously in the ratio of $\frac{S}{\sigma}$. When σ is small compared to the distance S between the plates as we assumed in the previous experiments, the positive branch at $X = 0$ must be nearly horizontal in spite of the steepness of the negative branch as found by experiment at this place.

32. These deductions from the hypothesis of a retarding surface force, acting within a narrow layer, have been confirmed by thorough investigations in the vicinity of value zero of the outside force. A galvanometer was substituted for the electrometer, since the latter gives only the mean value of the effect over the range of potential difference corresponding to its deflection and does not accurately reproduce singularities at some particular value of the P.D. The plates U and E were encircled by the sheath which had the mean potential (29); a magnetic field was impressed from the coil SS. Figure 1 (18), so that only the axial component of the electric field was used. In the following table each number is the mean of from 15 to 20 galvanometer readings, the current being alternately in opposite directions.

TABLE XIV.

U = 10 m.m. Zinc Arc Light

P.D. between U and E	1.0	0.5	0.2	0.1	0	—0.1	—0.2	—0.3	Volt
Galvanometer Deflection	30.0	29.3	24.0	24.7	21.3	16.3	11.6	9.45	Div.

[178]

In the graphical representation, Figure 3, the scale along the axis of the abscissa is very much larger than in Figure 1, Plate 1. The distances of the observed points from the curve lie within the probable error [34], so that there is no doubt about the discontinuity in slope or the general agreement with the electrometer observations. The discontinuity, however, appears at 0.04 volts instead of at 0 volts, which may be interpreted as meaning that the two carbon surface U and E had an intrinsic potential difference of 0.04 volts[35]. The discontinuity appeared likewise with aluminium and platinum plates which were not blackened (34) (compare

Plate 1, Figure 2) and similar small displacements from zero were observed.

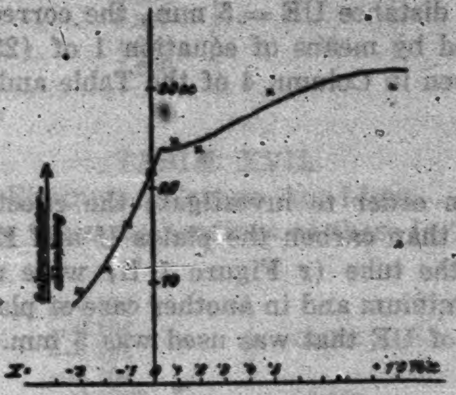


Fig. 3.

33. The action with carbon over the entire range is given in the following Table. Some of the previous observations have been averaged together and some new

TABLE XV.

Carbon Surfaces; Carbon Arc Light.

Column 1: P.D. between U and E: X (volts).
Column 2: Observed Effect U.
Column 3: Remarks.
Column 4: Effect Y corrected for Reflected Light.

1	2	3	4
—2.50	—.00609	From Table 8.	<.0005
—1.70	—.00576	Averages from Table 8.	<.0005
—1.38	—.00411		.0016
—1.20	0		.0056
—1.020	+.01097	New Observations 37)	.0165
—0.831	.0364	UE = 5 mm.	.0419
—0.609	.0920	Sheath connected	.0978
—0.412	.216	with E (cf. 29)	.221
—0.220	.358		.363
—0.030	.645	From Table 13.	.649
0	.720	According to Table 14 38)	.724
+0.12	.751	From Table 13a	.754
0.22	.790	Mean from Nos. 12, 13	.792
0.47	.859	Mean of Nos. 8, 9, 10, 11 Table 13a	.860
0.92	.906	Mean of Nos. 4, 5, 7	.906
2.0	.95	From Table 12	.95
20.	1.00		1.00

ones added where needed (compare Column 3). From the observed effect U (Column 2) which is everywhere reduced to distance UE = 5 mm., the corrected effect Y is computed by means of equation 1 of (22)[36], and is [179] given in Column 4 of the Table and in Figure 2 of Plate 1.

[180]

84. In order to investigate the effect with other substances than carbon the plates U and E, the sheath (29) and the tube (r Figure 1 B) were made in one case of aluminium and in another case of platinum. The only value of UE that was used was 5 mm.; the results follow:—

TABLE XVI.

Aluminium; Carbon Arc Light.

Column 1: PD. between U and E.
Column 2: Observed Effect U.
Column 3: Effect corrected for reflected light, Y.
Column 4: P.D. between U and E, when the zero is placed at the point where the slope is discontinuous.

Volt			Volt
—19.98	—0.205	<0.003	—20.25
— 9.98	—0.208		—10.25
— 5.98	—0.208		— 6.25
— 3.98	—0.205		— 4.25
— 2.78	—0.195	0.005	— 3.00
— 2.11	—0.188	0.010	— 2.38
— 1.732	—0.174	0.019	— 2.01
— 1.483	—0.160	0.032	— 1.76
— 1.226	—0.149	0.040	— 1.50
— 0.983	—0.1045	0.071	— 1.26
— 0.728	—0.0690	0.092	— 1.00
— 0.498	0	0.147	— 0.77
— 0.274	+0.102	0.240	— 0.55
— 0.023	0.264	0.397	— 0.30
+ 0.0031	0.292	0.425	— 0.27
0.052	0.318	0.450	— 0.22
0.087	0.349	0.482	— 0.19
0.18	0.427	0.560	— 0.09
0.290	0.497	0.626	+ 0.02
0.389	0.545	0.657	0.12
0.48	0.559	0.646	0.21
0.97	0.661	0.698	0.60
1.487	0.817	0.829	1.21

1.96	0.909	0.916	1.69
3.96	0.977	0.976	3.69
7.92	0.998	1.00	7.65
19.93	0.995		19.66
29.92	1.008		29.65
49.92	1.000		49.6

[181]

TABLE XVII.

Platinum; Carbon Arc Light.

Columns have the same headings as those in Table XVI.

Volt				Volt
−14.98	−0.107		<0.002	−15.12
−8.96	−0.106			−9.08
−4.97	−0.105			−5.09
−2.46	−0.104			−2.58
−1.96	−0.0973		0.003	−2.08
−1.47	−0.0815		0.018	−1.59
−0.935	0		0.097	−1.06
−0.601	+0.0890		0.172	−0.72
−0.308	0.292		0.379	−0.42
−0.010	0,567		0.652	−0.13
+0.093	0.686		0.771	−0.03
0.193	0.720		0.798	+0.07
0.293	0.720		0.785	0.17
0.742	0.827		0.852	0.62
1.99	0.936		0.934	1.87
3.49	0.981		0.985	3.37
9.97	0.99	1.00	1.00	9.85
19.97	1.01			19.85

It is to be noted that when aluminium was used the apparatus was put together and pumped out immediately after polishing of the metal surfaces with emery. Observation began when the limit of efficacy of the pump had been reached about an hour after the polishing. At that time the magnitude of the effect was still diminishing and continued to diminish for about three-quarters of an hour, or about as long as the pump was still removing bubbles of gas from the apparatus; thereafter the effect remained unchanged for ten days. The data in the table referred to this latter state. The discontinuity of the slope of curve U was located at 0.273 [182] volts; it was assumed as before (32) that the potentials of the electrodes U and E differed by that amount when they were in metallic contact and, consequently, the scale of potentials was displaced by 0.273 volts giving the final column of the table[39].

In the case of platinum, which was also freshly polished just before the observations, the discontinuity was at 0.12 volts; the scale of potentials was displaced correspondingly to give the last column of the table. Figure 2 of Plate 1 shows $Y(X)$ for all three substances, carbon, aluminium and platinum.

35. "Inside" Velocities. — As we saw in (31), the negative branch of $Y(X)$ gives the values of the velocity distribution function F for all values of the inside velocity greater than "II". We can form a judgment on the course of the function for velocities smaller than "II" from the positive branch of Y. The slope of this branch increases, as Figure 2 of Plate 1 shows, very rapidly as X increases from zero (where it is nearly zero). Since T can only decrease as X increases, F' must increase according to equation 2 of (31). Consequently, as we go towards the right from $X = 0$, the function F will increase at a constantly increasing rate, as is indicated by the dotted curve oa in Figure 2 of Plate 1 for the case of platinum. As X continues to increase, Y' rapidly approaches zero; this value is very nearly attained by $X = 10$ volts or $X/S = 20$ volts/cm. for all three substances; Y is then very nearly equal to one, as Figure 2 of Plate 1 and the Tables show. Equation (2) admits two possible forms for the function F. Either (A) T is already zero, so that F' can continue to have high values as far onward as $F = 1$ (aA in Figure 2 of Plate 1); or (B) T is not yet zero, so that [183] F' must become zero (aB in Figure 2 of Plate 1). Case (a) would signify that the integral II must be very small, scarcely 0.1 volts, and that most of the inside velocities of the electrons are vanishingly small. However, experiment contradicts the assumption made for this case: to wit that T is nearly zero when the force is 20 volts per cm. and, consequently (31) the force K does not have higher values than 20 volts per cm. anywhere. Outside forces opposed to K did not extract any

negative electricity from aluminium surfaces in vacuo even when they reached a magnitude of 45,000 volts/3.6 cm. (4, Table 1, Note 2). Consequently, we regard case (A) as excluded and case (B) as the true one. This means that by far the greater part of the electrons liberated by the light in the interior of the substance already possess there a definite relatively large velocity, which is to be designated as the most probable inside velocity of an electron; both smaller and shorter values of the velocity occurred, but only in a proportion which is small and diminishes rapidly to zero as the deviation from the most probable velocity increases[40].

We must take account of the fact that our data relate only to one component of the velocity, that perpendicular to the surface (23) while the existence of components in other directions has been demonstrated (8, 18, 19, 20, 29). As respects this, I have carried through computations on the basis of the observed distribution of the normal components of outside velocity as given in Tables 15 to 17; the results of these computations agree neither with the idea that there is a single definite inside speed and that all directions are [184] equally probable, nor with the idea that the inner velocities are distributed according to Maxwell's law[41]. The magnitude of the most probable inside velocity, corresponding to the greatest slope of F, seems for each of the three substances investigated not to differ very much from the corresponding value of "II". Our experiments permit us to say nothing about this last magnitude, except that in each of the three cases it must be greater than about 0.1 or 0.2 volts (for platinum, the abscissa of (B), Plate 1, Figure 2).

36. The following data gives values of the outside velocities for carbon arc light taken from the original data given on a large scale in Figure 2 of Table 1; the velocities are expressed in the customary units, centimeters per second; ε/μ is set equal to 10^{+7} C.G.S. units.

TABLE XVIII.

Number of Electrons Escaping with Normal Velocity:	C	Pt	AC
between 12 and 8 x 10^{-7} cm/sec.	.000	.000	.004
" 8 " 4 " " " "	.049	.155	.151
" 4 " 0 " " " "	.67 42)	.65 42)	.49 42)
Escaping with Assistance of outside Force	.28	.21	.35
Total	1.00	1.00	1.00

[185]

The predominance of relatively small outside velocities, already mentioned in (23), for carbon, is found with aluminium and platinum as well. Platinum, however, gives more of the larger velocities than carbon, and aluminium more than platinum.

37. I must not fail to mention the influence that the roughness of the surfaces employed must have had on the results. The carbon surfaces were naturally rough, the metal surfaces were roughened by the polishing with emery. Since the initial velocities have considerable tangential components (8, 18, 19, 20, 29), a part of the emitted electrons must have been caught by the projections of the rough surfaces. This influence of the roughness cannot have had any effect on the observations for large retarding or large accelerating forces; it would come to light only in a lowering of the values of U and Y in the vicinity of zero potential difference. With smooth surfaces we should expect a more rapid rise of the negative branch and a less rapid rise of the positive branch of Y. Such a change indeed is necessary to avoid a contradiction which is found to exist between the form of Y as experimentally determined and the assumption (made for smooth surfaces) that the force K acts within only a narrow layer. The general conclusions respecting the velocity distribution (35, 36), however, are not affected.

38. To account for the surface-force K (31) there are three possibilities:

(a) Electrical double layers on the surface.

(b) A specific attraction between electricity and the conductor, something as Helmholtz assumed to explain contact potential differences (8).

(c) The undoubtedly present electrical force between the escaping electrons and their electrical images in the surface.

In cases (a) and (b) the force would depend upon [186] the nature of the conductor; in particular we should expect a marked difference between the value of the integral II for aluminium on the one end and its values for platinum and carbon on the other, since the last two are far from the first in the contact potential-series. If the inside velocities are the same in each case the negative branch of the Y-curve of one would appear to be displaced horizontally relative to those of the others. But this is not the case, the displacement of platinum relatively to carbon for small values of Y(—X) is greater than that of aluminium relatively to platinum, while for large values of Y(—X) carbon is closer to aluminium than it is to platinum (Plate 1, Figure 2). However, II could vary from one substance to another without having the above consequence, if — making assumption (b) — a greater attraction between the substance and the electrons went with a greater inside velocity of the electrons; but, without further knowledge the converse would be more probable. It can, therefore, be stated, that no attraction between electricity and the substances tested differing for the different substances, can be detected. Hence, if we are to assume such an attraction (as electro-chemical reasons lead us to) it appears from our experiments that we must assign it a sphere of action smaller than the intermolecular distances in the substances investigated by us. In this case the attraction would contribute nothing to the integral II, and then it would have nothing to do with the appearance of contact potential differences at the surfaces of metals in contact.

It seems indubitable that electrical double layers exist at the surfaces of conductors in air[44]; nothing is known as to whether they persist in vacuo. One of the most powerful means of removing adherent layers of gas from a metal plate is to use it as cathode in the glow [187] discharge. I did this with the same platinum plate as was used before hand in (34). The apparatus was filled with hydrogen[45]; after this a storage battery with many cells was applied, and the platinum plate, acting as cathode, kept covered with negative glow for six hours; the opposite platinum plate E was the anode. If this had caused a decrease of II, this should have been recognized through an increase in Y(0). Nothing of the sort appeared; Y(0) was found equal to 0.5 at the end of the process after the apparatus had again been evacuated, which was a smaller value than before. Note also, that, to explain the phenomena, we would have to assume that all three substances, including platinum, after the above process, had a double layer with the negative charge destroyed.

About the force (c) we would say not merely that there is no doubt that such exists according to present-day knowledge, but even that its properties correspond directly to our observations. This force has at distance (S) the magnitude.

$$K = \frac{300e}{4S^2}$$

wherein small (e) represents the charge of a single independently mobile electron equal to 6.6×10^{-10} electrostatic units[24]. Hence, we derive the values

K(s) equals	When s equals	$II = \int_{\rho}^{\alpha} Kds = \int_{\rho}^{\sigma} Kds$	When ρ equals
$.0005 \frac{\text{Volts}}{\text{cm.}}$	0.1 m.m. $= \sigma$	0.5 volts	$10^{[illegible]}$ m.m.
5	.001 m.m.	5. volts	$10^{[illegible]}$ m.m.
5.10^6	.10[illegible]		

This force, therefore, satisfies the condition of becoming vanishingly small at distances which are small compared to plate-to-plate distances UE, but which compare with the intermolecular distances; furthermore, [188] it assumes, at distances which are still not below molecular size, values so great that we can account for the fact that unilluminated and highly charged conductors in vacuo lose none of their charge (4, Plate 1, Note 2); the value of the integral exceeds the lower limit indicated by our experiments[35].

EXPERIMENTS IN A GAS-FILLED SPACE

39. In earlier experiments I showed that cathode rays make air electrically conducting[46]; we shall now investigate to find whether rays of any speed do this, or whether rays moving more slowly than a certain speed are unable to do it as is indicated by the unipolar character of the photoelectric effect (9, 11). The apparatus used (Figure 4) will now be described. U is the plate to be illuminated; opposite it is the surface E, the central part of which consists of fine wire gauze (wires 0.1 mm. thick; meshes 1 mm. square); beyond the gauze is the aluminium ring R. U, E, and R are insulated from each other, so that two arbitrary electric fields can be established on the two sides of E; these

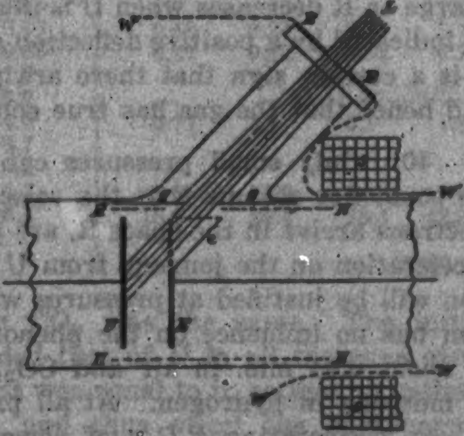


Fig. 1.

fields are made independent of each other by the tube ee, which is connected with E, closed at the right-hand end by a gauze, and perforated at g to allow the light to pass through. E is earthed; everything between U and E, including the gauze, is well blackened. The glass [189] tube surrounding the whole can be filled with any gas and the pressure measured. The coil SS, as before, prevents sidewise escape of electrons, so that nearly all the emitted electrons go to R, no matter what the magnitude of the accelerating force between U and E. The zinc arc was used.

The experiments were performed as follows. By changing the P.D. between U and E we can regulate the velocity of the rays which pass through the gauze to R; this velocity is always known from the preceding experiments. It is now to be ascertained whether, when the rays are absorbed in the gas around R, negative ions only are produced, or positive ones as well. Only in the latter case would there be true, as distinguished from unipolar, conductivity of the gas. R was therefore connected with the electrometer and negatively charged, together with the casing of the electrometer. If the charge on R decreases when U is illuminated—which will be indicated by a positive deflection of the electrometer—it is a certain sign that there are positive ions present and hence that the gas has true conductivity.

40. Only small pressures can be used; otherwise we could not assume that the velocities with which the electrons arrive in the space R, are produced by uniform acceleration on the journey from U to E. This assumption will be justified at pressures when further rarefaction has no influence on the phenomenon. This occurs at about 0.04 mm. in air and CO_2, at about 0.06 mm. of mercury in hydrogen. At all pressures below these values, accelerating P.D.'s of eleven or more volts between U and E, give large positive electrometer deflections at R; P.D.'s of eight volts or less give only very small deflections, as Table XIX shows in detail. The existence of a limiting speed is thus definitely demon-

[190] strated47); its magnitude will be discussed later (42).

TABLE XIX.*

P.D. between U an E accelerating	Atmospheric Air		Hydrogen.			All gas pumped out.
	Pressures in mm. of Mercury.					
	.04	.004	.03	.004	.00013	
Volts	2, Electrometer scale-divisions, on R, in 10 sec.					
0	0.11	.18	.12	.15	.18	.05
100						6380 48)

TABLE XIX.*

P. D. between V and E (accel.) x	Atmospheric Air 0.04	Atmospheric Air 0.004	Hydrogen 0.03	Hydrogen 0.004	Hydrogen .00013	All gas pumped out
	Pressures in mm. Hg.					
Volts	Z,	Electrometer	scale-divisions at R in 10 seconds			
.0	0.11	0.18	0.12	0.15	0.18	0.05
4.00	0.17	0.25	—	—	—	—
8.00	0.31	0.33	0.18	0.20	0.13	0.13
9.00	0.65	0.65	0.27	0.47	0.86	0.74
9.50	0.77	1.7	—	—	—	—
9.70	1.09	3.0	—	—	—	—
10.00	2.05	4.0	0.77	2.4	3.1	1.86
10.50	—	6.7				
10.70	—	10.2				
11.00	—	16.7	5.8	12.3	23.8	10.9
12.00	16.4	26.8	16.3	26.4	33.4	42.9
20.0	108.					
100.						6380 48)

The behavior in CO_2 was the same. The initial potential of R exceeded that of U in all the runs given in the table, or at least was equal to it, so that no cathode rays could reach R and thus affect the electrometer directly; 20 volts was the potential of R, except in one case specified below. Higher potentials up to more than 100 volts, gave no markedly higher electrometer deflections, whence it follows that the smaller P.D.'s were high enough to bring to R all the positive ions produced beyond E; use is made of this result below (45). If on the other hand the potential of R was lower than, or even equal to that of U, and that of U was less than [191] 11 volts, the electrometer connected to R gave a negative deflection. This shows that even when the potential of U was low, cathode rays passed through E into the space around R; so that the absence of positive ions at these potentials cannot be ascribed to absence of cathode rays. For example, a strong negative deflection was observed when U = 10 volts and R = 10 volts, both negative relatively to E, in air of 0.04 mm. pressure; also when U = 0 to 20 volts negative and R = 0 volts in air at .04 and .004 mm. and in hydrogen at .002 mm. pressure.

---

* This table crossed out in original Exhibit.

41. Free paths of the electrons. — Above the limiting pressures described in (40), definitely higher potentials than 11 volts were required in order to produce positive ions in the region R. This indicates that the electrons do not undergo uniform acceleration between U and E, or that their mean free path in the gas has become equal to the distance UE = 14.5 mm. The mean free paths of the gas molecules at these pressures are 1.9 mm. in air, 1.2 mm. in CO_2 and 2.3 mm. in hydrogen [49]; the free paths of the electrons, at their present velocities of one to ten volts[50], are some ten times as great as those of the gas molecules, or some twice as great as those of vanishingly small, rapidly-wearing bodies which cannot penetrate gas molecules[51]. The free paths of the rays previously investigated by me, of about 100 times this speed, were much greater[52]. Thus, in oxygen or hydrogen at 40 mm. pressure, such rays travelled 5 or 10 cm. without being much bent aside [192] or diffused[53], and it is proved[54] that the magnitude as well as the direction of the velocity remains the same over this distance. The free paths of the molecules of the gas in which this occurs are only .00019 and .00034 cm. respectively, so that the electrons have free paths 30000 times and 5000 times as long, respec-

tively, as small particles which cannot pass through gas molecules. This confirms the principles previously discovered for a small range[55] that cathode ray beams are less spread out and the rays less absorbed in gases, the smaller their magnetic deflection (by a given field); for this principle may be restated as follows[56] the free paths of the rays are greater, the greater their velocity.

The fact that free paths of the above lengths are possible while markedly longer free paths are not—considering the spreading-out of beams and the absorption of cathode rays, and the limiting pressure found in the present work—appears to indicate that the molecules and atoms of matter are structures made up of minuter parts with many interspaces and many possible kinds of internal motion; the structure as a whole being impenetrable to another similar atom. However, the study of the questions which have arisen since my earliest publications on cathode rays and since the establishment of the recent hypotheses, will not be profitable until further observations on rays of various speeds are made.

42. The value of the limiting speed, above which positive ions are formed, can be estimated from Table XIX in the following way. Plotting the accelerating P.D., x, as abscissa, and the electrometer-deflection, 2, as ordinate, we obtain curves which from $x = 0$ to (?) 8.5 volts run nearly horizontal and close to the axis of abscissae; then, within the interval $x = 8.5$ to 11 volts, turn sharply upwards and finally run steeply and almost linearly upwards; the last part of the curve points in the direction away from the point $X = 10.5$, $2 = 0$; the several runs given in the table agree very closely over all this range. This form of curve may be explained on the hypothesis that the number of ions produced by each electron is proportional (within the range of observation) to the excess of the velocity of the electron over the limiting velocity[57] and is zero when there is no such excess. Let N (v) dv represent the number of electrons which traverse the gauze with a speed between $v = \frac{1}{-2} dv$

and $v + \frac{1}{2} dv$; V the limiting speed, and C a constant; then the deflection of the electrometer would be

$$z = C \int N(v) . \quad (v - V) \; .dv$$

the integral extending over all values of v which are greater both V and x. Since $N(v) = Y'(x - v)^{58)}$, (23), we obtain

$$z = C \int_{\sigma}^{V-x} Y(-X) \, dX \quad \text{for } x \leqq v$$

$$z = z(x = V) + C(x - V) \quad \text{for } x > v.$$

$Y(-X)$ is to be taken from Table IX with the aid of equation (1), or from Figure 2 (23); it is very nearly zero for all values of X between a and 2.5 volts, from which onward it increases. If then we set $V = 11$ volts in equation (3), Z varies quite in the way observed and
[194] described above; for it remains nearly zero until $V - x = 2.5$ volts or $x - 8.5$ volts, then increases, and from $x = V = 11$ volts on becomes linear once more. The desired limiting velocity is then 11 volts, or in the customary units 1.5×10^8 cm/sec. or $\frac{1}{200}$ of the velocity of light; the corresponding kinetic energy is $e.V. 10^8 = 2.4 \times 10^{-12}$ ergs, e being taken as 6.6×10^{-10} electrometer units.

43. It must be pointed out that the same value of the limiting speed is found whether the apparatus contains air, hydrogen, or CO_2, or is kept pumped out by running the mercury pump continuously (cf Table XIX, last column). The formation of positive ions in the last case will be ascribed to the residual vapors (12); it may even be assumed that they were formed from these residual vapors in every case, for Table XIX displays no markedly greater deflections for gas filled than for evacuated apparatus. The limiting speed for the gases would then be higher than the one here given. But since a given number of electrons can produce only a given number of ions, we may for the time being also make the contrary assumption: that the limiting speed is the same for the residual vapor and all three of the

investigated gases, and perhaps for all substances whatsoever. In any case the result remains, that speeds less than the given limit make neither the investigated gases nor the residual vapors conductive.

44. As regards the first part of the present investigation (22-38) this last proved that the conductivity of the residues of gas or vapors played no part at any small accelerating potential, but even at the higher accelerating potentials where conductivity appears, its effect is only slight in comparison to the direct transport of electricity by cathode rays, as will be shown in the following.

45. Number of ions produced.—Suppose the potential difference UE to be 12 volts; then from the corresponding figure in the last column of Table XIX and [195] the capacity of the electrometer, it may be computed that the quantity of electricity carried by the ions formed in one second is .039 times 10^{-10} coulombs, while the charge on the electrons which produced these ions is 25×10^{-10} coulombs[59]. The ratio of the number of ions formed to the number of electrons is here ,0016; it is equal to .23 when UE is equal to 100 volts (according to Table XIX). These ions were formed in the space ER (Figure 4); the electrons which produced them enter through the gauze E with the velocity corresponding to the potential difference UE and were gradually slowed down at an almost uniform rate as they traversed the distance ER = 20 mm., turned around in the vicinity of R[60] and returned over the same path with the same velocities; thus, they traveled a distance of 40 mm. with nearly zero velocity at one end and the velocity corresponding to the potential difference UE at the other. We should, therefore, expect to obtain the same number of ions in the regions UE if the potential difference between U and E were the same and the distance between them 40 mm.; and if the distance were $\frac{1}{m}$ times as great, we should expect m times as many ions. The following table of corrections was made up in this way. The values for other potentials UE being found by linear interpolation (according to 42); the table gives the

quantity by which the charge lost by U is to be divided in order to allow for the loss due to conduction.

TABLE XX.

Distance U E

P.D. UE Volts	5 mm.	10 mm.	25 mm.	40 mm.
12	1.00	1.00	1.00	1.00
20	1.00	1.00	1.01	1.02
100	1.03	1.06	1.15	1.23
200	1.06	1.12	1.30	1.46

46. The unipolar character of the photoelectric [196] effect, which seems to be established without doubt in ordinary air and for all lower pressures, is explained—as already mentioned in (11)—by the magnitude of the limiting velocity (42) which far exceeds the initial velocity of the electrons driven out by the light (25, 26, 36). The action is unipolar even in the case of the alkali metals, photoelectrically the most active of substances, so that even for them the initial velocities must be less than 11 volts. It is different with the so-called radio active substances which even when not illuminated emit extremely small quantities of electricity but with extremely high initial velocities. Substances of the same kind with rays having initial velocities less than 11 volts might exist without being discoverable by the convenient present method.

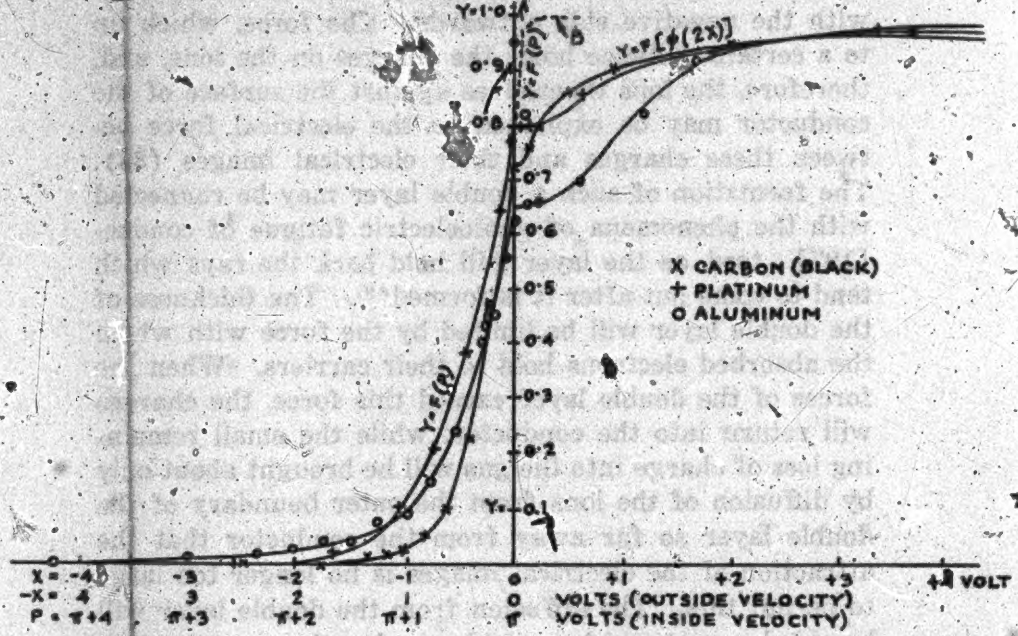
47. As regards the photoelectric effect in gases at atmospheric pressure it seems to me that no adequate explanation has yet been given for its astonishing smallness. For example, it is seen from Table II that when we have aluminium surfaces in air with an applied outside accelerating force of 83.5 volts per cm. not ¼ of 1% of the emitted electricity gets completely away; and even with a force of 2780 volts per cm. only 4.7% escapes. The following considerations are suggested by the results of the preceding work and can even satisfy a quantitative test on the basis of the experiments already performed; this is shown by computations which I am not publishing at present because I have no experiments to report. — Since, when we have a dense gas surrounding the surface, the emitted electrons must be absorbed in

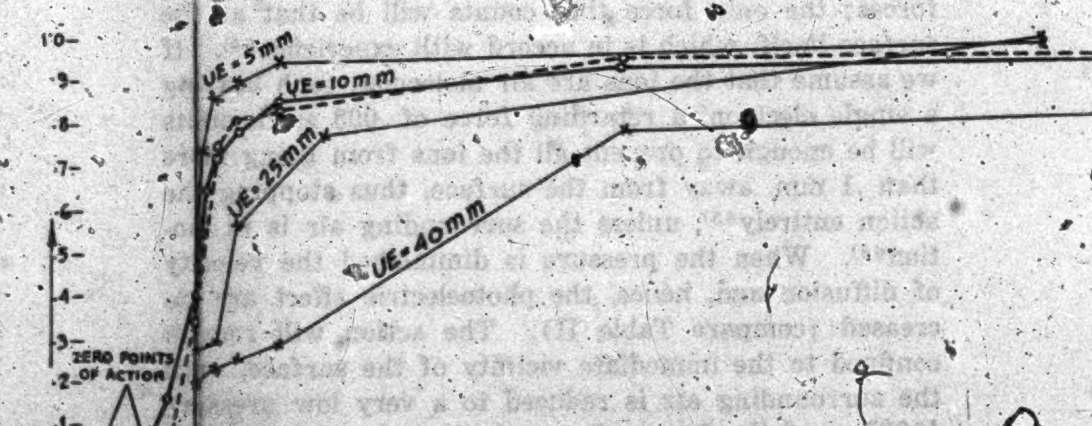
the immediate vicinity thereof (41), negative ions must accumulate there and thus rapidly form a double layer with the negative side outwards. The force, which up to a certain distance holds the charges on the ions, and, therefore, the ions themselves against the surface of the conductor may be explained as the electrical force between these charges and their electrical images (38). The formation of such a double layer may be connected with the phenomena of photoelectric fatigue of conduc-
[197] tors, as the layer will hold back the rays which tend to come out after it is formed[63]. The thickness of the double layer will be limited by the force with which the absorbed electrons hold to their carriers. When the forces of the double layer exceed this force, the charges will return into the conductor, while the small remaining loss of charge into the gas will be brought about only by diffusion of the ions from the outer boundary of the double layer so far away from the conductor that the attraction of the electrical images is no longer too large to permit this. The diffusion from the double layer will be aided or opposed by outside accelerating or retarding forces; the only force that counts will be that at the surface itself, which is in accord with experience[64]. If we assume that the ions are air molecules, each bearing a single electron, a retarding force of .003 static units will be enough to prevent all the ions from going more than .1 mm. away from the surface, thus stopping the action entirely[65], unless the surrounding air is in motion[66]. When the pressure is diminished the velocity of diffusion and, hence, the photoelectric effect are increased (compare Table II). The action will remain confined to the immediate vicinity of the surface, until the surrounding air is reduced to a very low pressure
[198] and the free paths reach the values of (41); in this state, when there is a decided accelerating force, the conductivity imparted to the air will aid in the manner indicated in (9), so that the loss of charge will be even greater than in vacuo[67].

Kiel, Middle of March, 1902.

Received March 17, 1902.

Defendant's Exhibit No. 10-A





NOTES.

1. P. Lenard, Wiener Sitzungsberichte, 108, IIa, 1649, (1899); also Ann. Phys. *2* 359 (1900).—Cf. also the somewhat later work of E. Merritt and O. M. Stewart, Phys. Rev. *11* 230 (1900).
2. In this respect it resembles the third means of production since discovered—i.e., by radioactive substances.
3. To facilitate reference to the earlier paper (l.c.) its numbering of tables and paragraphs is continued here.
4. P. Lenard, Ann. Phys. *51* 240 (1894).
5. Conductivity of the space made its appearance during the work, but not at P.D.'s below 8 volts (44). When necessary to accuracy, a correction was made to allow for it; data so corrected will be indicated by asterisks. For the way in which the correction was computed see (45) and Table 20.
6. The effect was proportional to the duration of the action; the data will therefore be reduced in some future cases to move convenient values of duration or of capacity.
7. The voltages to be given hereafter, when stated to hundredths of a volt, are the mean voltages during the deflection of the electrometer, obtained by adding half the deflection to the initial voltage.
8. High magnification (with a telescope) and a scale with diagonal rulings enabled us to read tenths of scale divisions directly, and to estimate hundredths.
9. Note that in these runs only U was blackened. E being an old unblackened aluminium surface; but this may be regarded as unimportant for the present purpose.
10. Cf. especially the experiments of Elster and Geitel, Ann. Phys. *48* 625 (1893).
11. Schuster and Hemsalech, Phil. Trans. *193* 189 (1899); Table 10, Fig. 19, and the corresponding text.
12. In connection with our notation, note that "quantity of electricity" always means "negative quantity" and that outside forces are counted positive when they accelerate [outwards] negative electricity coming from E. These conventions correspond to the hypothesis that we have to do with motion of negative electricity only. For example, the negative numbers in Column 3 of Table 5 mean that positive deflections of the electrometer connected to E were observed, i.e., in our form that negative charges were escaping from E.
13. The difference between the actions of the two kinds of light will be discussed later (26).
14. For the subsequent experiment we must think of this sheath as again removed.
15. For ϵ/μ we take 10^7. E. M. U.
16. A. Righi, Mem. Accad. Bologna (4) *9* 369 (1888).

17. A. Righi, Mem. Accad. Bologna (4) *9* 379 (1888).

18. This note inserted in text.

19. Apparently the very refrangible ultra-violet rays peculiar to the zinc arc and the spark are less reflected from the black than are the less refrangible ultra-violet rays of the carbon arc. For the infra-red Kurlbaum finds the reflecting-power of petroleum-black equal to 0.05 which is particularly large (Ann. Phys. *67* 850 (1899).

20. Later on (in 31) it is assumed that the velocity of the electrons undergoes an abrupt finite change at the surface so that inside and outside velocities are to be distinguished.

21. The velocity "P volts" is $\sqrt{2.\ 10^8.P.r}$, where r represents the ratio between the electron-change and the electron-mass, usually called ε/μ [nowadays e/m]. Cf. Ann. Phys. *64* 279 (1898). The quotation-marks will be applied to the voltage-measure of velocity, from now on, only when a misunderstanding might otherwise occur. Electrons having a velocity "V" acquire velocity "V ± S" after passing through a potential difference ± S (Ann. Phys. *65* 504 (1898)]. Note that in these units kinetic energy, not velocity, is measured.

22. For further data on the velocity-distribution, for A1 and Pt as well, see (36).

23. No secondary phenomena whatever being observed; even with A1 and Pt plates, where the backward rays are much stronger than with carbon.

24. Helmholtz was the first (Faraday address, 1881) to emphasize that certain phenomena, especially those of electrolysis, distinctly demand the assumption that electricity has structure; for in electrolysis we find electricity divided into elementary units, always of the same size, each associated with a material carrier. Whether this structure of electricity occurs without the influence of material particles can be determined only by experiments on electricity free from matter, as it is found in cathode rays. In what follows we assume this to be the case, taking the charge found by J. J. Thomson to be associated with material carriers [Phil. Mag. (5) *46* 518 (1898); (5) *48* 557 (1899)] to be equal to that of a single free, independently mobile charge of free electricity.

25. This holds for the effect on carbon (lamp-black). With A1 plates (34) the zero-point for the zinc arc was only about .02 volt below that for the carbon arc; when one of the arc carbons was replaced by an A1 rod the zero-point was not distinctly shifted. The kind of light therefore makes little difference with the initial velocities from A1 as compared to carbon.

26. Previously we had used a piece of quartz cut ⊥ to the optic axis: in these runs it was replaced by one cut || to the axis, in which the direction of the two principal vibrations were parallel to the two directions mentioned in the text. This piece of quartz was used for all later experiments.

27. Compare the experiments of Elster and Geitel on the plane surfaces of liquid and solid alkali-metal layers in rarefied hydrogen (Berlin Sitzungsber. *6* 134 (1894); *11* 209 (1895)). The authors established the fact that the dependence of the effect on the direction of polarization is due to peculiarities in the absorption of light by the substance [Ann. Phys. *61* 445 (1897)].

28. To this simple case correspond the forces which Helmholtz assumes in his electromagnetic theory of dispersion (Wiss. Abh. *3* 503) with considerable success in explaining the phenomena of dispersion and absorption.

29. We note, in comparing columns 2 and 3, that the effect of the spark is somewhat less than that of the arc, especially at the lowest value of outside force. I formerly (4) thought that this was due to the electrostatic forces which the electrons, which are simultaneously in the space between U and E, exert on one another; for these forces are to be set proportional to the number of these electrons, i.e., the momentary intensity of the light, and would be greater for the spark than for the arc; furthermore they would be directed oppositely to the outside force. The difference between the effects of the two kinds of light is, however, adequately accounted for by the difference in the initial velocities produced by them (26, 31); while no electrostatic forces of the supposed kind showed themselves in any other way.

30. As in column 2 of Table 5.

31. The fact that this occurs even at UE = 5 mm. shows to what a great extent tangential components of velocity are present.

32. Similarly, the data obtained with retarding forces greater than 0.5 volt and without the sheath (Tables 8, 9) were regarded as unaffected.

33. See (23) for the notation.

34. These are relatively large in this case, for the galvanometer records only instantaneous values of the very variable intensity of the light. In the corresponding investigation on Al and Pt I went back to the electrometer which gives readings corresponding to average values of the intensity, and, when the deflections are small enough (13) makes the position of the "corner" very clear.

35. If two plates of different metals were placed opposite one another in a perfect vacuum, the "corner"—in experiments like the above one—would indicate the true "magnitude of the contact PD between the metals.

36. The values of U(—X) required for the correction were obtained by direct observation or by graphic interpolation on a sufficiently large-scale diagram.

37. The difference between the —1.20 volts obtained for the zero-point in these runs, and —1.1 volts in Table 10, is probably due to the fact that the former runs were made with the arc burning steadily for some time before the observations began, and the latter with the arc lighted only for the moment of the observation and emitting a hissing sound. The hissing arc seems to act in more nearly the same way as the metallic arc (cf. 26).

38. The zero of P.D. was shifted to the abscissa of the "corner" which was obtained by interpolation (Figs. 3, 32); the ordinates were then reduced to the scale used elsewhere, setting U = 0.645 when X = —0.030 volts.

39 The P.D. between the plates—E negative to U—seems to have been established during the first illumination of U; which suggests polarization of E perhaps by a layer of negative ions formed by absorption of cathode rays in the residual vapor (12). With carbon and Pt the P.D. was in the same sense, but not so large.

40. Note that our observations prove nothing against the possibility of inside velocities of a much smaller order of magnitude.

41. Neither law gives the observed distribution of outside velocities, and each requires that the smallest inside normal components should be the most numerous. Perhaps the latter are suppressed by the very strong absorption of the outer layers of the substance for slow electrons such as would come from the inner layers.—In an experiment of Hallwachs [Tagebl. der Heidelberger Natur f.—Vers. 214 (1890)] a transparent silver coating precipitated on quartz, when illuminated from the quartz side, gave off negative charge on the other side; this shows that all the layer of the substance which is reached by the light plays a part in the effect.

42. These numbers would presumably be increased if the surface were smooth; those just below them would be diminished.

43. Helmholtz "Erhaltung der Kraft" p. 47, 1847.

44. Lenard, Ann. Phys. *46* 584 (1892); mercury Table XVII there.

45. Hydrogen seemed less negative than air, at least towards water [Ann. Phys. *46* 627 (1892)] according to J. J. Thomson [Phil. Mag. *37* 341 (1895)], it would even be positive towards water.

46. Lenard, Ann. Phys., *51* 240 (1894).

47. J. S. Townsend finds [Phil. Mag. (6) *1* 198 (1901)], that material negative ions, like cathode rays, can produce new ions in gases; apparently there is no definite limiting speed for those.

48. This deflection was not actually observed; the capacity of the electrometer system had been raised from 1.14×10^{-10} farad to 501.1×10^{-10} farad; the observed deflection was 14.5. The potential of R was 120 volts negative to E.

49. Computed, as proportional to the pressure, from O. E. Meyer, Gastheorie, Table on p. 192.

50. 4.5 to 14×10^7 cm/sec. (cf. 23).

51. The free path of such particles would be $4\sqrt{2} = 5.7$ times as large as that of gas-molecules [cf. J. C. Maxwell, Phil. Mag. (4) *19* 29 (1860)].

52. 0.67×10^{10} cm/sec. [Ann. Phys. *64* 287 (1898)].

53. Lenard, Ann. Phys. *51* 225 (1894); Figures 6 and 12.

54. l. c. *52* 23 (1894).

55. l. c. *51* 265 (1894); *52* 31 (1894); *56* 261 (1895).

56. l. c. *64* 279 (1898).

57. All velocities are measured as kinetic energies (cf. 23).

58. As we found that the tangential components were of the same order of magnitude as the normal ones (19, 20); and since we need consider only such velocities as have been normally accelerated till they exceeded 11 volts; we can replace N by Y' without error.

59. This is the quantity observed to escape from U in one second, UE being 5 mm., the accelerating P.D. being 50 volts, and having the same source of light at the same distance.

60. The P.D. ER, in the cases considered, was nearly equal to the P.D. UE (40).

61. Elster and Geitel, Ann. Phys. *43* 225 (1891).

62. Cf. Hallwachs, Ann. Phys. *37* 666 (1889).

63. The possibility of previously existing double layers, e.g., as found with mercury, is not excluded; Ann. Phys. *46* 628 (1892).

64. A. G. Stoletow, Journ. d. russ, phys. chem. Ges. *21* (1889); translation with additions by the author in Phys. Revue *1* 721 (1892).

65. The value assumed for the force is that given by Righi as causing the cessation of the effect on Al in air [Atti. del R. Ist. Veneto *7* 6 (1889)].

66. About the influence of blowing on the surface cf. Bichat and Blondlot, C. R. *107* 29 (1888); Elster and Geitel, Ann. Phys. *38* 511 (1889); Hallwachs, Ann. Phys. *40* 343 (1890).

67. A paper by J. S. Townsend on this last effect has just appeared; I refer readers to it.
[Phil. Mag. (6) *1* 198 (1901)].

DEFENDANT'S EXHIBIT No. 11.

May 21, 1904 963
ELECTRICAL WORLD AND ENGINEER

A RESUMÉ OF INCANDESCENT ELECTRIC LAMP EXHAUSTING.

BY S. E. DOANE.

The exhausting of incandescent electric lamps has developed into a highly specialized branch of the lamp manufacture. In order to crowd a description of the development of this portion of the art into the limits of one article, it will be necessary to abbreviate portions of this description considerably. The history of the art up to the development and adoption of the present chemical exhausting method will be passed over rapidly. The latter method will be considered as thoroughly as the allotted space will permit.

The first incandescent lamp of the modern type ever constructed was exhausted on a mercury pump. Mercury pumps were used for lamp exhausting for nearly twenty years before they were superceded by the present chemical process. These mercury pumps were of two general types. Each type had its advantages and disadvantages, but overshadowing all was the need for better brains than could be obtained for the attendance demanded by all mercury pumps.

Either type of pump required active, intelligent men of strong physique. Men with these three qualities were fitted for far more pleasant duties, so that the supply of such men was always far short of the demand. The result was that the pump rooms always contained many men who, while possessing some of these qualities, were not completely qualified for the exacting service. Many of those who were qualified, and who, for brief seasons, filled the hearts of the lamp manufacturers with joy and hope for the future, would be found after the first pay day to be confirmed drunkards. Drinking men seemed more numerous in the pump rooms than elsewhere. I can see, as I look back, that this was because we tolerated more of it in the pump rooms than elsewhere. We were thus obliged to put up with insufficient mental capacity on the part of strong, faithful workmen, accepting the widened voltage range, shortened life and decreased candle-hour performance of the lamps improperly exhausted, year after year, gradually improving our condition as we developed the processes. The changes and improvements did not essentially modify the general practice, which was as follows:

The mercury pumps used by all lamp manufacturers in this country, which commenced operation not later than about 1885, were of the Sprengel type. Many of the companies began about this date to change to the Geissler form of pumps. Companies starting at a later date without exception so far as the writer can learn, used the Geissler form. The reasons for this will appear as we discuss the faults of the Sprengel pumps.

The Sprengel pump consisted essentially of a stream of mercury falling through a glass tube. All systems of this class had the following good qualities and faults:

The pumps gave a good vacuum, were cheap, simple to construct and to repair. When a pump failed only one lamp was injured. Every lamp was individually exhausted, which insured its being exhausted at just the proper voltage, when conditions were uniform, providing the operator was competent. We were content to have a pump which would procure for us a good vacuum, when the business was young. It was some time before we awoke to the fact that there were other requirements.

As we discovered the various new requirements, we also discovered fundamental faults with our apparatus and methods. These faults were finally found to be so serious that so far as I can learn every company in the country but one abandoned the Sprengel form of pumps for the Geissler form before ultimately adopting the chemical exhausting process.

At least every third man in the pump room (the men worked in teams of three in the best developed system) had to be an expert. The men were much exposed to the poisonous fumes of the mercury. Their hands were almost always black with an amalgam of mercury and grease. Many men were incapacitated because of mercury poisoning, and as this became known it became more difficult to secure the requisite grade of intelligence.

The men were required to be on their feet all day, working almost constantly with their hands on a level with their shoulders, a blazing row of lamps in front of them and sometimes behind them. While every effort was made in summer to keep the pump rooms cool, air drafts were tabooed and there was no way of escaping the light and radiant heat from the lamps. Add to this the danger to health and it will be seen how difficult it was to obtain the kind of men required.

Pumps did not all work at the same speed. The glass tubes from which the pumps were made were of different diameters, which was one reason for the differing speeds. The cleanliness as well as the diameter of the principal glass tube of the pump affected its speed. The diameter of the hole in the glass tube attached to the lamp through which the air was exhausted also affected the speed. The differing speeds was a matter of much importance for the following reasons:

The completed lamp must not only be free from gases and vapors, but must also have had those parts capable of giving off gases and vapors, thoroughly freed from them. The only way we knew to accomplish this was to highly heat everything we wished to free from gas. We had three things to heat: the glass, the filaments and the joints between filaments and leading-in wires.

The glass was heated by an asbestos cone-shaped hood painted black on the inside. The heat from the lighted lamp furnished all the heat necessary. The lamps could be heated hot enough to cause the bulb to collapse if the hoods were made too thick. The filaments were also heated sufficiently by the current, but the joints were not heated sufficiently unless the current was passed through the lamps at a time when the gases were of just the right pressure to allow current to pass across the vacuous space from joint to joint. The current would not pass across this space, if the gas pressure was either too low or too high, and we had very little latitude in this respect. If we put sufficient voltage on the lamps to pass this current from joint to joint before the gas pressure in the lamps was sufficiently high, we burned the surface of the filaments. Filaments thus burned varied in color from light bronze to sooty black. If we waited too long and the gas pressure had been a little too much reduced, we could only pass this current from joint to joint by putting a destructively high voltage on the lamp, and if it had been too much reduced we could not heat the joints at all.

We found difficulty in making uniform filaments, which difficulty we still have, in a much reduced degree. This non-uniformity made it necessary for us to burn each lamp on these pumps at a different voltage, as at the same voltage a lower voltage lamp would get hotter than a higher voltage lamp and a hotter lamp would exhaust more quickly than one relatively cooler. Thus it will be seen, lamps were exhausted at various speeds for the reasons that (1) the pumps themselves were of different speeds; (2) the tubes through which we exhausted the lamps were contracted to slightly different diameters, and (3) the lamps were only exhausted at the same temperatures when the judgment of the operator was good.

The Geissler pump enabled us to get around these difficulties, but also introduced some of its own. The advantages were as follows:

1. The pumps were all of the same speed. 2. While the lamps were not exhausted through tubes any more uniform, the "slow" lamps being connected to the same reservoir as the "fast" lamps they balanced up fairly well, as we had twenty or more lamps on one reservoir. 3. We could not exhaust the lamps at so nearly the same filament temperature, but the conditions under which we exhausted made all the lamps of the same tempera-

ture of glass, and consequently of the same temperature and pressure of gas. This was because all the lamps on one Geissler pump were heated in one hood. This hood was raised to a high temperature by gas flames. We did not depend upon the filaments to produce the initial temperature which very much reduced the liability to burn the filaments.

In addition to these three important advantages we could keep all hoods at the same temperature, start all pumps simultaneously, give all pumps the same number of strokes, flash all lamps simultaneously, thoroughly protect the mercury from contact with the air, and we required only one high-grade man in the pump room where formerly one-third of the operators had to be high-grade men.

We now felt that a great stride had been made in the exhaustion of incandescent lamps, but additional experience with the Geissler pump brought to light faults which still left much to be hoped for. The faults were as follows:

1. They were more expensive to operate, for the following reasons: (*a*) If one lamp leaked, the whole lot of lamps on this pump could not be exhausted. If the leak was only a small one, we would damage all the lamps on the pump. (*b*) The pumps were fragile, and if a lamp was accidentally broken, or if in any other way air was admitted accidentally, the pump was liable to be ruined. Lamps had to be more carefully inspected for leaks and glass work had to be more carefully done.

2. We still were unable to make lamps of exactly the same voltage. The lamps on one pump would necessarily have to be handled as a unit, which would mean that lamps designed for the same voltage would all have to be exhausted at the same voltage.

It became increasingly apparent as the effort was made to improve quality and reduce cost, that it would be strongly advisable if some means be found for individually exhausting lamps which did not possess the prohibitive faults of the Sprengel pump system. Some of the companies went so far as to construct some very small Geissler pumps to take one lamp each. It is hard to say what the outcome of this would have been, had not the chemical process been developed about this time.

The mechanical pump systems came into use about this time. All of them were open to the objections which held with the Geissler. Pump makers did not seem to appreciate the fact that whether a pump used mercury or not, it was simply and solely a pump. Some very good mechanical pumps were made, but most of them had a capacity greater than that of any Geissler pump. In order to get a reasonable output for the money invested, it was necessary to exhaust an even larger number of lamps simultaneously. This offered no escape from the troubles of the Geissler pump systems, and hence came into only limited use.

The chemical process was brought to us by a lamp maker. He knew the drawbacks of the mercury systems. This process possessed the advantages of the Sprengel system, the advantages of the Geissler pump system, and also some advantages of its own, without the conspicuous disadvantages of any of the previous systems.

While the Sprengel pump system only required that every third operator should be an expert, the chemical system required that every operator should be an expert, but it made it possible for us to secure experts, by entirely removing the disadvantages which made it so difficult for us to get a good class of operators. We found we had no difficulty nor do we now have any difficulty in securing plenty of young women of good intelligence who find the chemical exhausting work rather pleasant than otherwise. Every operator sits down to her work, has only one lamp on the pump at a time and is able to exhaust every lamp according to its individual requirements.

Two articles of any kind differ in some slight degree. This is true of incandescent lamps with special reference to the manner in which they exhaust. It may be that in one the joints between the filament and the platinum wires are larger or the joints are a little closer to the glass stem, or that the lamp has not been heated quite so hot in the preliminary heater or perhaps the bulb is of slightly different internal dimensions. Be the causes what they may, the differences are sufficiently marked to be quite apparent to the operators. This was all fully realized during the closing days of the mercury pump systems, but the vital difference this made to the candle-hour performance of the lamps has never been so fully appreciated as since we began to use the chemical process of exhausting. The chemical process of exhausting consists roughly of mechanically exhausting a heated lamp to a pressure represented by a column of mercury about .125 mm. high. This is equivalent to about 1/6000 of an atmosphere. The lamp is sealed off from the pump and phosphorous is vaporized and passes into the lamp bulb while the filament is very hot and while an electric current is passing through the gaseous contents of the bulb. The vapors of this metal enter into an electrochemical combination with the gases, forming solid precipitates, if the conditions are proper.

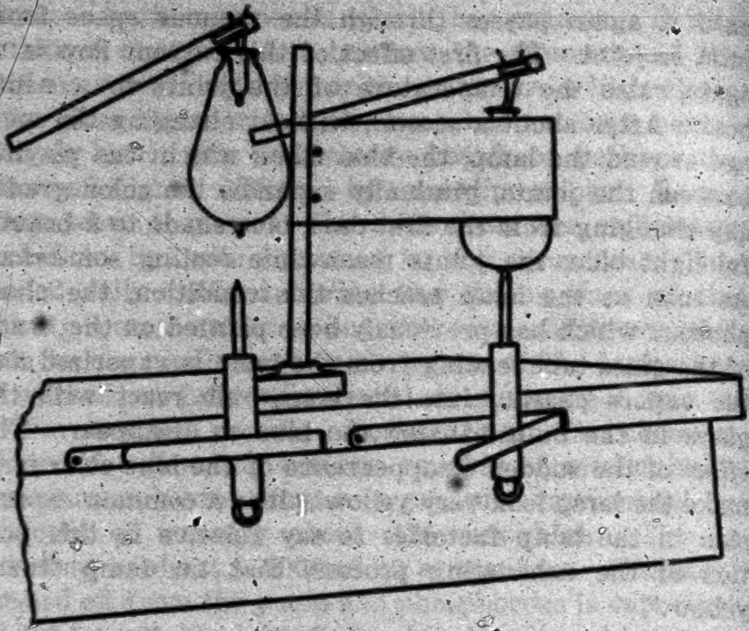
This whole operation from the time the lamp is first lighted up on the pump to the time it is completely exhausted requires approximately sixty seconds. During this time the following changes take place in the lamp bulb:

About one-half minute after the lamp is first placed upon the pump and before the lamp is shut off from the pump, current is passed through the filament. Current also passes from joint to joint across the vacuous space, heating both joints white hot. The joints are held at this temperature for a few seconds after which the current is reduced and the pump is given a few seconds to remove the gases which are dislodged by this heating. This takes about five seconds under usual conditions. The tube connecting the lamp to the pump is then closed very close to the lamp. The current is again increased until it again passes through the vacuous space from joint to joint. The first effect of this current flow is to again raise the temperature of the joints to a white heat. After about a second, without changing the voltage around the lamp, the blue flame which was playing between the joints, gradually expands, the color gradually changing from the first dark blue shade to a beautiful light blue, the joints meanwhile cooling somewhat. As soon as the lamp reaches this condition, the phosphorous which has previously been painted on the inside of the glass tube leading from the lamp is vaporized and the vapors passing into the lamp bulb react with the gases in the bulb, causing the blue to disappear. The effect of the sudden disappearance of the blue color is to make the lamp look very yellow. It is a common expression in the lamp factories to say relative to this portion of the exhausting process, that the lamp "turns yellow."

In order that the current may pass from joint to joint across the vacuous space the pump must necessarily produce a higher vacuum than is usual with mechanical pumps. The pump used in this work is of the ingenious variety which depends upon an oil-covered piston to displace all the air in the pump cylinder. The pump is so constructed that a little oil is always passing into the cylinder and is forced up through the exhaust valve with the gases which are being expelled. This oil is used over and over again. It is free from occluded gases, contains no volatile oils, and has a low surface tension. Care is taken to select an oil with these characteristics.

A mechanical pump of this description never produces a vacuum so high that there is any difficulty in passing current from joint to joint in the lamp being exhausted upon it. Care has to be taken with these pumps to be certain that they are always in such condition that they will produce a sufficient vacuum.

The present exhausting system has its faults. Any exhausting system will have faults, until a system is devised which automatically keeps itself in repair and



CHEMICAL EXHAUSTION OF LAMPS.

also automatically and perfectly exhausts lamps without the interposition of human judgment. The faults which concern us the most are as follows:

1. We must still have expert operators. 2. We still depend upon a system of pipes and valves which will occasionally develop leaks. 3. Pumps occasionally get out of order. 4. The chemical reactions which produce the vacuum are sensitive and atmospheric and chemical conditions occasionally give us new problems.

A better understanding of how this chemical exhausting is performed will be gained from the following description referring to the accompanying sketch. The operators are all seated in front of a long bench behind which are a number of little pumps. These pumps occupy about four feet of floor space and stand less than three feet high. They run continuously, being piped by the shortest possible connections to the face of the bench. Each operator utilizes one cylinder each of one of these pumps.

In the sketch the lamp on the left is exhausted and ready to be removed from its clip. The lamp on the right is shown thrust into a bit of rubber tubing. This tubing passes through a pinch cock on the edge of the bench.

In front of the lamp is a piece of metal that shields the eyes of the operator when the lamp is brightly lighted. The piece of metal can be swung around so that it can shield the operator from the light from either lamp.

While the lamp on the right is being exhausted, the lamp on the left is being removed from the clip which suspends it by the leading-in wires, another lamp is then thrust into the rubber tubing and connected to the clip. By this time the lamp on the right is sufficiently exhausted and current is passed through it by means of a rheostat on the left of the operator, and the process of exhausting is completed as indicated earlier in this article. After the exhausting is completed the tube through which the air is exhausted is sealed off by the blow pipe flame which much resembles the jeweler's blow pipe flame, familiar to every student.

Bits of glass, dust, moisture from the air, phosphorous, etc., collect in the pipes and interfere at times with the action of the pinch cock valve. It is necessary to watch very closely to see that the lamps are being exhausted under the desired conditions.

Each type of lamp behaves a little differently from another type.

The tubular lamp is difficult to exhaust because the phosphorous gases are heavy, the residual gases in the lamp are light; the phosphorous is in the form of gas at a high temperature only, and the lamps cool quickly from the high temperature of the heater in which it was heated before being placed upon the pump.

The space in this lamp is narrow and long and as the glass of the lamp is always somewhat cooler than the phosphorous vapors, this added to the other difficulties mentioned makes it necessary that the tubular lamps be handled by our most skilled operators.

Lamps with small bulbs are difficult to exhaust for the last-named reason and also because they are so small that it is difficult to avoid vaporizing too much phosphorous. If too much phosphorous is vaporized the bulb of the lamp is discolored. Each size of lamp and each shape of bulb behaves a little differently from any other size or shape of bulb. The two examples are given above as illustrations only.

As the tube, through which the lamp is exhausted, which also carries the phosphorous must necessarily be of a reasonable thickness, in order not to collapse when the blow pipe flame is applied to vaporize the phosphorous, it also must possess considerable heat capacity. As often only a very small amount of phosphorous vapor is required for the reaction there is every opportunity for an unskilled operator to use too much phosphorous, thereby making a lamp unsalable. An operator on a small lamp, or on a tubular lamp, or on a lamp in which the reaction is progressing freely, must be especially careful to withdraw the flame from the phosphorous-carrying tube long before the reaction is completed, as the phosphorous will continue to vaporize until the tube has cooled considerably. If an operator is sufficiently skilled, she can tell by watching the progress of the reaction in the lamp bulb as indicated by the changing color and form of the blue light which fills the bulb, when the reaction is about to be completed. A skilled operator will exhaust lamps with almost no rejections from one day to another. Such an operator is always very fast and always produces lamps of high quality. The contrary is true of one who is not skilled.

One reason that an operator who can always quickly vaporize just enough phosphorous and who does not vaporize too much phosphorous produces high-quality lamps is that the voltage at which it is necessary to operate these lamps in order to produce the temperature and the cross currents is such that if a lamp were burned at this temperature for many seconds the lamps would have passed much of its useful life. It is obvious that every second that can be saved when the lamp is being burned at this temperature adds hours to the life which the prospective customer will obtain from this lamp. This assurance that all the lamps exhausted by an expert operator will give practically the same life and candle-hours, other conditions being equal, is of great value.

Under the mercury pump régime the lamps burned not less than twenty minutes each at a voltage not less than 10 per cent. above normal. During only the last few minutes would the vacuum approximate that at which the lamps would ultimately burn. The lamps on the mercury pumps were also burned in addition to this at a voltage at least as high as that ever reached by the chemical methods and for a longer time.

Burning lamps at high incandescence before the vacuum becomes sufficiently good discolors the filaments. This raises the voltage at which the lamps deliver the candle-power for which they are designed, providing a good vacuum is ultimately produced in these lamps. When such lamps are shipped to the customer they are labeled to be operated at higher voltages than would have been the case had the lamps been exhausted by the modern process. In the days of the mercury pumps one of the principal causes for rejection of the lamps from some of the pump room operators was the blackened filaments resulting from this cause. In rejecting lamps for this cause, lamps with filaments only slightly burned were necessarily passed for shipment.

Such lamps would rise rapidly in candles at the beginning of their life and fall almost as rapidly after the first 50 or 100 hours. This condition has been almost entirely eliminated. Much of the improvement in lamp quality in recent years can be traced directly to better methods of exhaustion.

Lamps in which the gases have not been thoroughly eliminated from the joints between the filaments and the platinum wires will fall rapidly in candles when put into service. Much of the rapid decline in candles in the lamps exhausted on mercury pumps was due to the joints between the filament and the platinum discharging gases while in service.

The closer specifications to which modern lamps can be shipped can also be partly traced to this improvement in exhausting as indicated in the preceding paragraphs. When the history of the development of the incandescent lamp is written the most interesting chapters will be those which deal with this portion of the story. Only a very brief outline of the subject has been given above. Many hundreds of experiments and life tests and the expenditure of a great deal of money is summed up in this brief description.

DEFENDANT'S EXHIBIT No. 12

M. VON RECKLINGHAUSEN.
MEANS FOR EXHAUSTING INCLOSED RECEIVERS.
APPLICATION FILED JULY 30, 1904.

946,068. Patented Jan. 11, 1910

Fig. 1

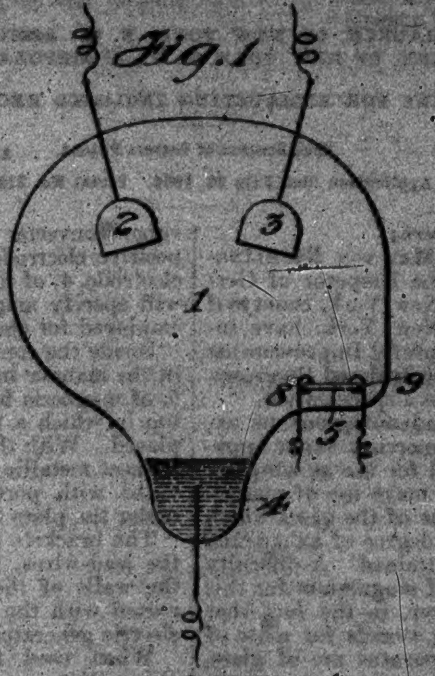
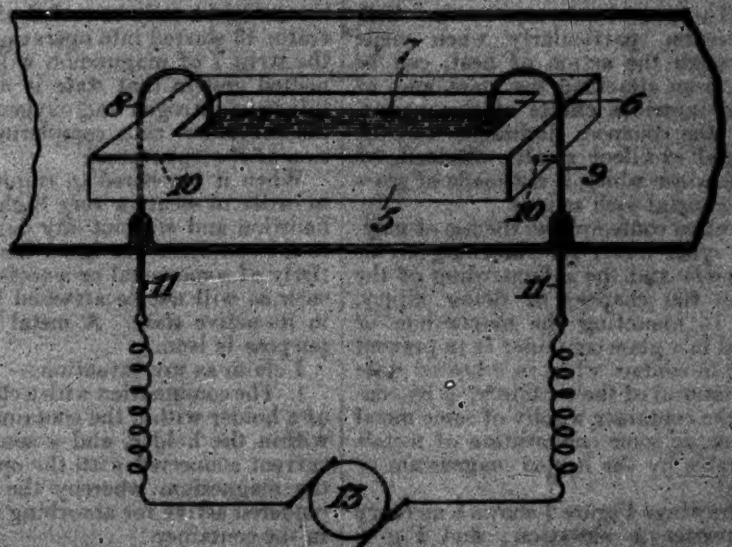


Fig. 2



Witnesses
Chas. F. Clagett
W. H. Capel

Inventor
Max von Recklinghausen
By his Attorney
Charles A. Terry

UNITED STATES PATENT OFFICE.

MAX VON RECKLINGHAUSEN, OF NEW YORK, N. Y., ASSIGNOR TO COOPER HEWITT ELECTRIC COMPANY, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

MEANS FOR EXHAUSTING INCLOSED RECEIVERS.

946,008. Specification of Letters Patent. Patented Jan. 11, 1910.

Application filed July 30, 1904. Serial No. 218,021.

To all whom it may concern:

Be it known that I, MAX VON RECKLINGHAUSEN, a subject of the Emperor of Germany, and resident of New York, county of New York, State of New York, have invented certain new and useful Improvements in Means for Exhausting Inclosed Receivers, of which the following is a specification.

It has been found advantageous in exhausting containers of mercury vapor apparatus, whether designed for use as lamps or as vapor converters, to make use of magnesium for absorbing some of the gases which remain after a certain degree of exhaustion by pumping has been attained. A difficulty with the employment of magnesium for this purpose resides, however, in the fact that whereas the containing vessels for most of the mercury vapor apparatus are of glass, yet the magnesium in its active state attacks glass and, therefore, is less adapted for use in assisting the exhaustion than it would otherwise be. There are, however, ways in which the magnesium, particularly when made active through the action of heat, can be prevented from attacking the glass, and, of course, the injurious effects of the magnesium for the purpose indicated can be avoided, and excellent results obtained, by using a container which is not made of glass but of some metal such as iron.

My invention contemplates the use of magnesium or other metal for absorbing air or other purposes and the safeguarding of the same from the chances of doing injury, either by so mounting the magnesium or other metal in a glass container as to prevent its coming in contact when in a heated state with the material of the container, or by constructing the container wholly of some metal such as iron or some composition of metals not attackable by the heated magnesium or other metal.

In the drawings Figure 1 shows a mercury vapor converter in elevation; and Fig. 2 shows a section of a portion of the mercury vapor apparatus illustrating in perspective certain details of the apparatus common to the structure of Fig. 1 and Fig. 2.

In the drawing, Fig. 1 shows a mercury vapor converter comprising a container, 1, positive electrodes, 2 and 3, and a negative electrode, 4, of mercury. For convenience I will specify magnesium as the metal to be employed for absorbing air.

Inside the container 1 I mount, somewhat in the manner indicated, a plate or support, 5, of magnesia having a depression, 6, at its top in which a portion, 7, of magnesium is placed. With the terminals of the strip 7, I connect metallic wires or brackets 8, 9, provided with portions 10, 10, which extend under the plate 5 and support it in position. The brackets 8 and 9 are connected with the lead-wires, 11, 11, which pass through the walls of the container 1 and are connected with the circuit wires leading to an electric generator, 13.

When used for the purpose indicated above, the apparatus is exhausted in the usual way. When, however, the exhaustion has been carried to a sufficiently high degree, the container may be sealed off and the generator 13 started into operation. Thereupon the strip 7 of magnesium will be heated or melted and in that state it will absorb the injurious nitrogen and oxygen remaining in the container, thus completing the exhaustion of the apparatus.

When it is desired to employ magnesium in order to secure a very high degree of exhaustion and without any danger of injury to the container, the latter may be made entirely of some metal or association of metals such as will not be attacked by magnesium in its active state. A metal suited for the purpose is iron.

I claim as my invention:—

1. The combination with a closed container, of a holder within the container, magnesium within the holder, and a source of electric current connected with the opposite ends of the magnesium whereby the same may be rendered active for absorbing injurious gases in the container.

2. The combination with a closed container, of an insulating holder inside the container, magnesium in the holder, and a source of electric current connected with the magnesium at points of different potential.

3. The combination with a closed container, of an insulating vessel inside the container adapted to hold a conducting liquid and a material in said vessel adapted to remove gases from the container, together with means for heating and melting said material.

Signed at New York, in the county of New York, and State of New York, this 22nd day of July A. D. 1904.

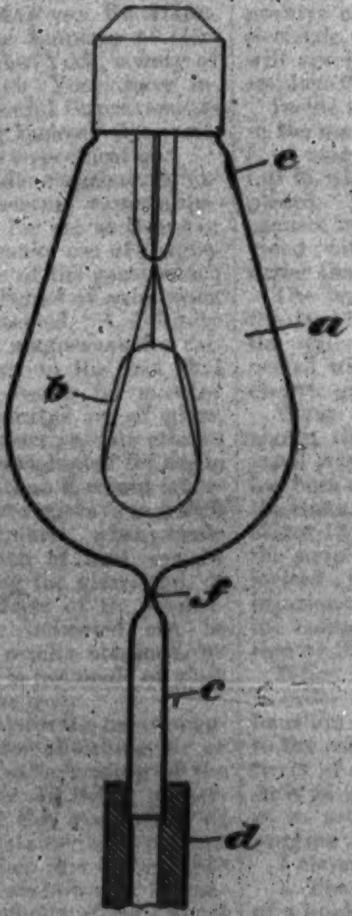
MAX VON RECKLINGHAUSEN.

Witnesses:
Wm. H. Capel,
George H. Stockbridge.

DEFENDANT'S EXHIBIT No. 13.

M. M. MERRITT.
PROCESS FOR EXHAUSTING LAMPS.
APPLICATION FILED JAN. 27, 1906.

909,811. Patented Jan. 12, 1909.



Witnesses:
Horace A. Crossman
Emmett J. Emery

Inventor:
Matthew M. Merritt
by Emery, Booth & Powell
Attys

UNITED STATES PATENT OFFICE.

MATTHEW M. MERRITT, OF MIDDLETON, MASSACHUSETTS, ASSIGNOR TO BOSTON INCANDESCENT LAMP COMPANY, OF DANVERS, MASSACHUSETTS, A CORPORATION OF MASSACHUSETTS.

PROCESS FOR EXHAUSTING LAMPS.

No. 909,211. Specification of Letters Patent. Patented Jan. 12, 1909.

Application filed January 27, 1908. Serial No. [illegible].

To all whom it may concern:

Be it known that I, MATTHEW M. MERRITT, a citizen of the United States, residing at Middleton, in the county of Essex and State of Massachusetts, have invented an Improvement in Processes for Exhausting Lamps, of which the following description, in connection with the accompanying drawings, is a specification, like letters on the drawings representing like parts.

My invention relates to the manufacture of incandescent lamps, and consists more particularly in a new process of employing a chemical assistant in the exhaustion of the bulb.

The process of lamp exhaustion, as heretofore carried out, has consisted generally in exhausting the bulb to some selected point by means of a vacuum pump. The pump is then cut off from the bulb and the filament brought to a state of high incandescence by the passage of an abnormal current therethrough to expel the gases absorbed in the filament and the joints thereof and at the same time suitable chemical substances are permitted to act upon the deleterious gases, and particularly the oxygen, remaining within the bulb. The object of this is the conversion into harmless compounds of those gases which remain after mechanical exhaustion in the highly rarified atmosphere of the bulb and would be injurious to the life or efficiency of the filament. This process of chemical exhaustion has been well-known in the art for many years. More recently, this process has been practiced by inserting the chemical agent in the open ended tubulature which it is customary to secure to the tip of the bulb about to be exhausted. This tubulature having been connected with the pump and exhaustion carried to the required degree, which is naturally short of the final vacuum, communication is interrupted between the pump and the tubulature below the chemical. The lamp filament is then brought to intensive incandescence and simultaneously the chemical in the tubulature (if, as usual, a volatile chemical is employed) is heated to cause it to unite with the occluded gases of the bulb and the deleterious gases driven from the carbon of the filament and the joints. As soon as chemical union has taken place, which is determined by the visual disappearance of an intensely blue or violet colored glow within the bulb, the latter is sealed off from the tubulature above the chemical, the lamp then being in a practically finished state.

The process of introducing a chemical agent into the tubulature has material defects. The procedure involves starting the chemical action by a violent heating of the tubulature before the sealing off of the bulb. It is difficult even for an experienced operator satisfactorily to volatilize the chemical in the tubulature without occasionally so overheating the walls thereof, and particularly at its slender neck where it is joined to the bulb, as to form a slight crack or fissure with the consequent admission of air. It has been found that if even a slight amount of air is admitted before the chemical action is completed, the vacuum is not only destroyed or impaired, but the chemical action is accompanied by the production of a brownish yellow deposit on the interior of the bulb which makes the lamp defective and unsalable. It is a frequent occurrence in carrying out the process described, to overheat the tubulature while volatilizing the chemical and permanently discolor the bulb. This procedure also involves the somewhat hurried sealing off of the bulb from the tubulature while the chemical action is at its height. This hasty sealing of the bulb is often accompanied by the formation of a slight crack at the seal, or the admission of a small amount of air before the seal is perfected, which results as above in spoiling the lamp and in impairing or destroying the vacuum. After completion of mechanical exhaustion and before the chemical action takes place, much of the remnant gaseous matter is in the form of moisture. This becomes apparent to the eye in the form of an illuminated fog-like haze before the filament is brought to intensive incandescence, which haze hovers about the narrow opening between the tubulature and the bulb. Under the process referred to, it is extremely difficult to properly extract this moisture. For some reason, it tends to seal the narrow opening of the tubulature and prevent the entrance of the volatilized chemical into the bulb, while at the same time the volatilized chemical tends to prevent the moisture from leaving the bulb. Even if the pump is kept in communication with the bulb during a preliminary heating of the chemical and filament, the pump tends to suck the chemical out of the tubulature while extracting the moisture in the bulb only with the greatest difficulty. This trouble is also enhanced by the fact that the tubulature through which or into which the moisture should pass, is raised to a high heat tending to drive back the moisture into the bulb. The final sealing of the lamp which is performed after interrupting communication with the pump also tends to drive any attracted or absorbed moisture in the tubulature out of it and into the rapidly cooling and relatively cooler bulb.

Prior to the exhaustion process the bulb is customarily heated in an oven to drive off the absorbed moisture and gases. Unless the exhaustion is effected rapidly, however, the subsequent cooling of the bulb causes a material re-absorption of those gases. Again, if the filament is raised to intensive incandescence without the presence of the volatilized chemical the expelled gases tend to unite with the hot filament greatly to its detriment. It is difficult to perform the present process rapidly enough to prevent a material cooling of the bulb, and, owing to the remoteness of the chemical from the filament and the check which the expelled moisture puts upon the entrance of the chemical into the bulb when the filament is raised to intensive incandescence, a large portion of the expelled gases undoubtedly combine with the highly heated filament, burning and blackening the same.

My process provides an entirely novel and different mode of performing the exhaustion of the lamp, whereby it can be completed with fewer steps and in less time than with the present process, being at the same time free from the defects above pointed out.

My process will be best understood by reference to the following description, wherein, for illustrative purposes, there is given in detail the preferred mode of performing it, while its scope will be more particularly pointed out in the appended claims.

The drawing shows diagrammatically a lamp bulb *a* with its contained filament *b* and the attached tubulature *c*, all of which are typical of a lamp of the usual construction. The end of the tubulature is shown inserted in a rubber socket connection *d*, which is in communication with an air pump (not shown). The latter may be of any description capable of exhausting to the degree required as a preliminary for the chemical action.

Preferably within the normal bulb space, instead of in the tubulature as before, and preferably, although not necessarily, upon the inner walls of the bulb itself, as at *e*, there is deposited a small and preferably definite amount of some one of the well-known agents suitable for chemical exhaustion, such, for example, as red amorphous phosphorus. The location of the chemical shown in the drawing, is particularly advantageous, for it is in immediate proximity to the porous pasted joints of the filament wherein are absorbed the major portion of the deleterious gases finally expelled. The insertion of this chemical (which in the drawing is shown greatly exaggerated in amount) is affected at some prior stage in the process of the lamp manufacture and may be conveniently accomplished before the tubulature is joined to the bulb. The lamp having been previously warmed or heated, as in an oven, to drive out as large a portion as possible of the absorbed gases, its tubulature is connected with the pump, as shown in the drawing, and there remains for a few moments until mechanical exhaustion to the required degree has been accomplished. Meanwhile the filament may be made to glow slightly by the passage therethrough of a current of normal or somewhat less than normal strength. This point having been reached, I then preferably bring the filament to intensive incandescence and at the same time heat the glass bulb, and particularly at the point *e* where lies a deposit of chemical, the connection with the pump, however, preferably remaining uninterrupted. This volatilizes a portion of the chemical already within the bulb, causing it to act, not only upon the residual gases of the bulb space, but also upon the expelled gases from the filament and the joints thereof and the gases driven out from the pores of the bulb, these gases, however, being freed in the immediate presence of the volatilized chemical and having no opportunity to unite chemically with the filament. The heat applied to the bulb to volatilize the chemical also materially assists in expelling the absorbed gases. During this operation the pump easily withdraws the moisture discharged from the filament and the bulb through the free open passage of the tubulature which is obstructed by neither volatilized nor unvolatilized chemical. As soon as the moisture has been withdrawn and before the chemical has been completely volatilized, the lamp is sealed between the bulb and the tubulature at *f*, such sealing hermetically closing both the bulb and the tubulature, which latter remains in the socket. The chemical remaining within the bulb, which latter is now in its complete, hermetically-sealed state, is then again heated to complete its volatilization and the filament simultaneously brought to intensive incandescence. This operation will be accompanied first by the appearance and then the disappearance of the blue glow referred to, which will indicate the completion of the exhaustion of the lamp. The severed and sealed tubulature may remain in its socket until a fresh lamp is to be exhausted, when it may be replaced by the tubulature attached thereto. It will be seen that the final step of this process of exhaustion, as here performed, is the chemical action upon the atmosphere of the bulb after the latter is hermetically sealed in its completed state and after every step which can in any way affect the vacuum therein has been performed. This absolutely avoids the possibility of any air or gases entering into the bulb during the final chemical action. It also permits this final chemical exhaustion to be carried on carefully and, if desired, leisurely. In fact, any desired interval may elapse between the time of sealing of the bulb and the time of volatilizing the remaining chemical in the presence of the incandescent filament.

The present process requires the placing of an amount of chemical in the tubulature largely in excess of what is required for the actual chemical action which takes place. This is not only detrimental because the chemical absorbs and retains a considerable quantity of moisture, but more particularly because it is difficult or impossible for the operator to volatilize just the precise amount needed for the required chemical reaction. This required amount is a definite quantity and if exceeded will result in a discoloration of the bulb similar to that produced when air is admitted in excess through an accidental crack or fissure, as above described. The use of an excess amount of chemical, however, is a necessary consequence of its volatilization in the tubulature, for it is volatilized at a point comparatively remote from where it is needed and an indeterminate portion of it undoubtedly fails to enter the bulb at all. By my process, the amount of chemical can be reduced to substantially that which is required for the chemical action, this being a definite proportion which can be easily determined in each case. When this is volatilized it may be known that the action is complete and it is impossible for the operator to discolor the bulb by the volatilization of an excess amount of chemical as is the case in the present process.

It is to be observed that in my process the restricted entrance to the tubulature and the tubulature itself may be maintained in free communication with the pump up to the moment of sealing the bulb, so that all moisture and gaseous matter which it is possible for the pump to withdraw will be withdrawn without interference or opposition on the part of the volatilized chemical.

The manipulation in my process is so simplified that it can be performed with greater rapidity, and with less opportunity for the cooling of the bulb. As has been observed, however, the latter is no serious defect in my process for the heating of the chemical is accompanied by a heating of the bulb and the expulsion of the contained gases in the immediate presence of the chemical.

Other advantages, many of which will be apparent to those skilled in the art, follow from the use of my process but these, as well as the many modifications thereof and the many variations in the detailed steps thereof are unnecessary to mention; it being understood that my invention is not limited to the details here described but only to the broad principles claimed.

Claims:

1. The process of exhausting lamp bulbs which consists in inserting a volatile chemical agent within the bulb, placing the latter in communication with a pump, exhausting to the required degree, raising the filament to a state of incandescence and partially volatilizing the said chemical while said bulb is still in communication with the pump, sealing off the bulb and thereafter completing the volatilization of the chemical in the presence of the incandescent filament.

2. The process of exhausting a lamp bulb which consists in placing the latter in communication with a pump, exhausting to the required degree, raising the filament to a state of incandescence, acting upon the residual gases by a volatilized chemical agent while the bulb is still in communication with the pump, sealing off the bulb and thereafter acting upon the residual gases by a volatilized chemical agent in the presence of the incandescent filament.

In testimony whereof I have signed my name to this specification in the presence of two subscribing witnesses.

MATTHEW M. MERRITT.

Witnesses:
CHARLES E. PIERCE,
THOMAS B. BOOTH.

DEFENDANT'S EXHIBIT No. 14

PROCEEDINGS OF THE ROYAL SOCIETY
Vol. 74 (1905)

CONVERSION OF ELECTRIC OSCILLATIONS INTO CONTINUOUS CURRENTS BY MEANS OF A VACUUM VALVE.

by

J. A. FLEMING

PP. 476-487.

"On the Conversion of Electric Oscillations into Continuous Currents by means of a Vacuum Valve." By J. A. Fleming, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received January 24,—Read February 9, 1905.

An electric oscillation being an alternating current of very high frequency, cannot directly affect an ordinary movable coil or movable needle galvanometer.

Appliances generally used for detecting electric waves or electric oscillations are, therefore, in fact, alternating current instruments, and must depend for their action upon some property which is independent of the direction of the current, such as the heating effect or magnetizing force. The coherer used in Hertzian wave research is not metrical, since the action is merely catastrophic or accidental, and bears no very definite relation to the energy of the oscillation which starts it. Even the demagnetising action of electric oscillations, though more definite in operation than the contact action at loose joints, is far from being all that is required for quantitative research. It is obvious it would be an advantage if we could utilise the direct current mirror galvanometer for the detection and measurement of feeble electric oscillations. This can be done if we can discover a medium with perfect unilateral conductivity.

Some time ago, I considered the use of the aluminium-carbon electrolytic cell with this object. It is well known that a cell containing a plate of aluminium and carbon, immersed in some electrolyte which yields oxygen, such as dilute sulphuric acid or an aqueous solution of any caustic alkali, or salt yielding oxygen, has a unilateral conductivity within limits. An electric current under a certain electromotive force can pass through the cell from the carbon to the aluminium, but not in the reverse direction.

This action has been much studied and is the basis of many technical devices, such as the Nodon electric valve.

The electrochemical action by which this unilateral conductivity is produced involves, however, a time element, and after much experimenting I found that it did not operate with high frequency currents. My thoughts then turned to an old observation made by me in 1889, communicated to the Royal Society, amongst other facts, in a Paper in 1889, and also exhibited experimentally at the Royal Institution in 1890.[*] This was the discovery: that if a carbon filament electric glow lamp contains a pair of carbon filaments or a single filament and a metallic plate sealed into the bulb, the vacuous space between possesses a unilateral conductivity of a particular kind when the carbon filament, or one of the two filaments, is made incandescent. I have quite lately returned to this matter, and have found that this unilateral conductivity exists even with alternating currents of high frequency and is independent of the frequency. Hence, in a suitable form, it seemed possible that such a device would provide us with a means of rectifying electric oscillations and making them measurable on an ordinary galvanometer. The following experiments were, therefore, tried:—

---

[*] See 'Roy. Soc. Proc.,' vol. 47, p. 122, 1890, "On Electric Discharge between Electrodes at different Temperatures in Air and High Vacua," by J. A. Fleming, communicated December 16, 1889; see also 'Proceedings of the Royal Institution,'

Into a glass bulb, made like an incandescent lamp, are sealed in the ordinary way two carbon filaments, or there may be many filaments. On the other hand, one carbon filament may be used and a platinum wire may be sealed into the bulb terminating in a plate or cylinder of platinum, aluminium or other metal surrounding the filament. It is preferable to use a metal plate carried on a platinum wire sealed into the glass bulb, the plate being bent into a cylinder which surrounds both the legs of the carbon loop. The diagrams in fig. 1 show various forms of the arrangement. Diagram *a* shows a bulb with a single carbon filament surrounded by a metal cylinder, *b* shows one with two carbon filaments, and *c* a carbon filament and two insulated metal plates. The ends of the carbon filament which is rendered incandescent are marked + and − and the terminal of the other electrode of the valve is marked *t*. The bulb must be highly exhausted to about the pressure usual in the case of carbon filament incandescent lamps, and the metal cylinder or plate must be freed from occluded air.

Suppose that we employ such a bulb containing one carbon filament surrounded by a metal cylinder (see *a*, fig. 1). The filament may be of any voltage, but I find it most convenient to employ filaments of such a length and section that they are brought to bright incandescence by an E.M.F. of 12 volts. The voltage and section of the filament should be so arranged that the temperature of the filament corresponds with an "efficiency," as a lamp-maker would say, of 2·75 or 3 watts per candle. The filament is conveniently brought to incandescence by a small insulated battery of secondary cells. A circuit is then completed through the vacuous space in the bulb between the cylinder and the filament by another wire which joins the external terminal *t* of the metal cylinder and that terminal of the carbon filament which is in connection with the negative pole of the heating battery. In this last circuit is placed a sensitive mirror galvanometer of the movable needle or movable coil type, and also a coil which may

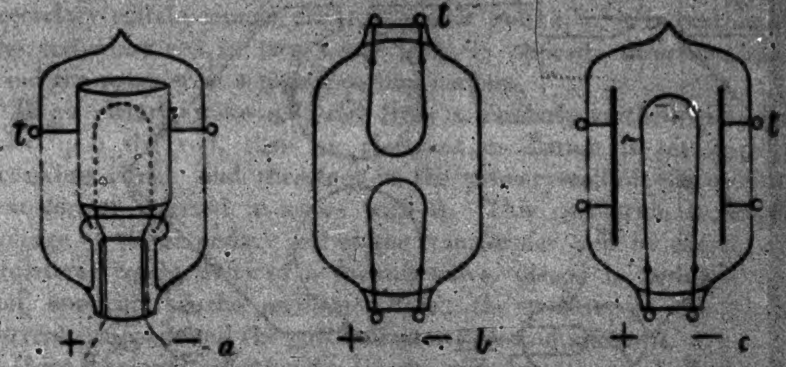
---

vol. 13, Part LXXXIV, p. 45, Friday evening discourse on February 14, 1890, "Problems on the Physics of an Electric Lamp," when this unilateral conductivity was experimentally shown.

be the secondary circuit of an air core transformer in which electric oscillations are set up. As is now well known, the vacuous space in the bulb permits negative electricity to move in it from the hot filament or cathode through the vacuous space to the cylinder or anode and back through the galvanometer and coil, but not in the reverse direction, as long as the cylinder is cool and the carbon filament not at a temperature much above the melting point of platinum. To illustrate the action of the bulb as an electrical valve, the following experiments can be shown:—

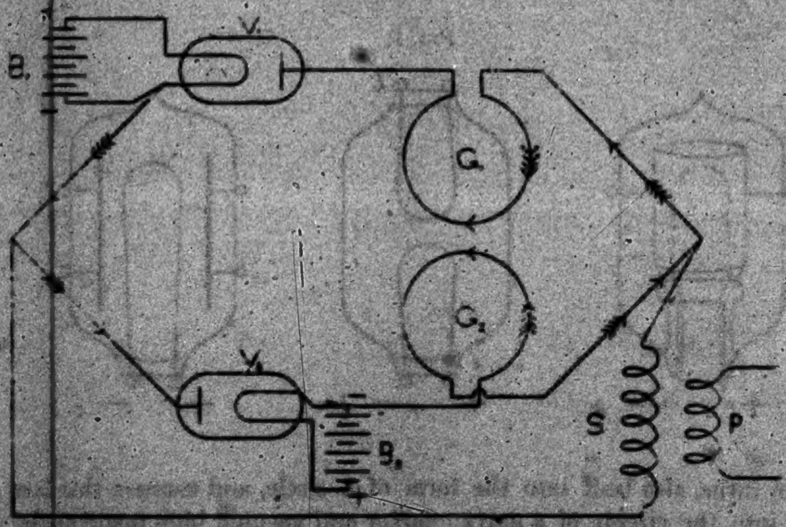
Electric oscillations are set up in a metal wire circuit by the discharge of a Leyden jar, as usual. This circuit takes the form of a thick wire of one or more turns, bent into the form of a circle or square. Some distance from this, we place another wire, of several, say eight or ten turns, also bent into the form of a circle, and connect this last wire into the circuit of a galvanometer and vacuum bulb made as described, so that it is a circuit having unilateral conductivity. On exciting the oscillations in the primary circuit by an induction coil we have an alternating high frequency magnetic field produced, which affects the secondary circuit at a distance. The oscillations in this last are, however, able to flow only in one direction. Hence, the galvanometer is acted upon by a series of intermittent but unidirectional electromotive forces, and its needle or coil deflects. Since the field is a high frequency field, we can show the screening effect of a sheet of tin foil or silver paper in a very simple and effective manner by the effect it produces in cutting down the galvanometer deflection when the metal sheet is interposed between the primary secondary circuits. Also, if we move the secondary coil away from the primary coil or turn the two coils with their planes at right angles to one another, then the galvanometer deflection diminishes or falls to zero because the induction is decreased. Accordingly, we have in this vacuum valve and

Fig. 1.



associated mirror galvanometer a means of detecting feeble alternating electric currents or oscillations. Another method is to employ a differential galvanometer and two vacuum valves. These must then be arranged, as shown in fig. 2, one circuit G_1 of the differential galvanometer is in series with one valve V_1 and the other circuit G_2 with the other valve V_2, but so joined up that currents flowing through the valves in opposite directions pass round the two galvanometer wires in the same direction as regards the needle and, therefore, their effects are added together on the galvanometer needle. Each valve must then have its own separate insulated battery to ignite the filament. Also, it is necessary that the connection with the oscillatory circuit must be made in both cases to the hot filament by that terminal which is in connection with the negative pole of the local battery used to ignite the filament (see fig. 2).

Fig. 2.



This arrangement of a differential galvanometer and two valves transforms, of course, more of the alternating oscillation into direct current than when one valve alone is used. It provides us with a means of detecting electrical oscillations not merely in closed circuits but in open electrical circuits.

When so using it, it is necessary to associate with the oscillation valve and galvanometer an oscillation transformer for raising the voltage. The resistance of these valves, when in operation, may be anything from a few hundred ohms up to some megohms, depending on the state of incandescence of the filament and upon the electromotive force employed to drive the current through the vacuous space, as well as upon the size of the filament and the plate.[1] This resistance does not obey Ohm's law, but the current increases to a maximum and then slightly decreases as the voltage progressively increases. The form of oscillation transformer employed with the device is as follows: A small air-core induction coil has a primary circuit, which consists of 52 turns of gutta-percha covered wire, wound in a helical groove cut on an ebonite rod 0·5 inch in diameter and 6 inches in length. The primary circuit is made of a No. 20 or No. 22 S.W.G. copper wire. The secondary circuit consists of 36,000 turns of fine silk-covered wire, No. 36, wound in six coils, each having about 6000 turns, and all joined in series. This secondary circuit has one terminal connected to one common terminal of the galvanometer and the other to the common terminal of the two oscillation valves (see fig. 4). The primary coil of this oscillation transformer has one terminal connected to earth and the other to a long insulated rod which acts as an aerial or electric wave collector. To prevent the direct action of the transmitter upon the secondary coil by simple electromagnetic induction, it is best to wind the secondary coil in two equal parts in opposite directions and to wind the primary in a corresponding manner.

If an electric wave sent out from a similarly earthed transmitter falls upon the rod, then an electrical oscillation is set up in the receiving circuit and therefore in the primary coil of the oscillation transformer inserted in series with it. This oscillation is raised in voltage by the secondary coil of the transformer, and by reason of the unilateral conductivity of a vacuum valve, placed in series with the coil, one part of the oscillation, viz., the positive or the negative current, passes round the galvanometer coils and affects it.

If we employ a sensitive dead-beat galvanometer of the type called by cable engineers a "Speaking Galvanometer," then intelligible signals can be sent by making small and larger deflections of the galvanometer corresponding to the dot and dash of the Morse alphabet; anyone who can "read mirror" can read off the signals as quickly as they can be sent on an ordinary short submarine cable with this arrangement.

The arrangement, although not as sensitive as a coherer or magnetic detector, is much more simple to use. Also it has one great advantage, viz., that it enables us to examine the behaviour of any particular form of oscillation producer. By means of it we can detect changes in the wave-making power or uniformity of operation of the transmitting arrangement, by the variation of the deflection of the galvanometer. Thus, for instance, if a spark-ball transmitter is being employed and the deflection of the galvanometer in association with the receiving aerial is steady, if we put the slightest touch of oil upon the spark-balls of the transmitter, their wave-making power is increased and the deflection of the galvanometer at once increases. Since the current through the galvanometer is the result of the groups of oscillations which are created in the receiving circuit, and since in the ordinary transmitter these oscillation groups are separated by wide intervals of silence, it is obvious that we can increase the sensitiveness of the above described arrangement by employing a very rapid break or interruptor with the induction coil. If, for instance, we employ a Wehnelt break with the induction coil or a high speed mercury break or alternating current transformer, we get a far better result as indicated by the deflection of the galvanometer than when employing the ordinary low frequency spring or hammer break.

The point of scientific interest in connection with the device, however, is the question how far such unilateral conductivity as is possessed by the vacuous space is complete. The electrical properties of these vacuum valves have accordingly been studied.

A bulb containing a 12-volt carbon filament rendered brightly incandescent by a current of about 2·7 to 3·7 ampères was employed. The filament was surrounded by an aluminium cylinder. The length of the carbon filament was 4·5 cm., its diameter 0·5 mm., and surface 70 square mm.

The aluminium cylinder had a diameter of 2 cms., a height of 2 cms., and a surface of 12·5 square cms. The filament was shaped like a horse-shoe, the distance between the legs being 5 mm. This filament was rendered incandescent to various degrees by applying to its terminals 8, 9, 10, and 11 volts respectively. Another insulated battery of secondary cells was employed to send a current through the vacuous space from the cylinder to the filament, connection being made with the negative terminal of the latter. The current through the vacuous space and the potential difference of the cylinder and negative end of the hot carbon filament were measured by a potentiometer. The effective resistance of the vacuous space is then taken to be the ratio of the so observed potential difference (valve P.D.) to the current (valve current) through the vacuum.

The following table records the observations. The column headed P.D. gives the potential difference between the hot filament and the cylinder, that headed A gives the current through the vacuous space in milliampères, that headed R the resistance of the space in ohms, and that headed $K10^5$ is 100,000 times the conductivity.

The result is to show that the vacuous space does not possess a constant resistance, but its conductivity increases rapidly up to a maximum and then decreases as the valve potential difference progressively increases. If we plot the current values as ordinates and potential difference of the valve electrodes as abscissæ, we find that the current curve quickly rises to a maximum value and then falls again slightly as the potential difference increases steadily. The conductivity curve also rises to a maximum and then decreases (see fig. 3).

The facts so exhibited are well-known characteristics of gaseous

Table I.—Variation of Current through, and Conductivity of, a Vacuum Valve with varying Electromotive Force, the Electrodes being an Incandescent Carbon Cathode and Cool Aluminium Anode.

Carbon filament at 11 volts, 3·77 amp., 41·47 watts.				Carbon filament at 10 volts, 3·44 amps., 34·13 watts.			
Vacuum Space.				*Vacuum Space.*			
P.D.	A.	R.	K10^5.	P.D.	A.	R.	K10^5.
0·6	0·024	25,000	4·0	0·7	0·014	50,000	2·0
5·4	0·264	20,550	4·86	2·8	0·073	38,360	2·6
8·8	0·480	18,330	5·45	8·2	0·392	20,920	4·78
18·2	3·880	4,691	21·4	12·8	0·824	15,530	6·44
22·9	26·790	855	118·1	16·2	1·739	9,316	10·70
29·1	28·02	1,038	96·1	20·1	5·352	3,756	26·6
37·1	28·426	1,305	76·6	23·3	9·68	2,407	41·4
40·0	23·30	1,719	58·0	35·9	10·037	3,577	28·0
70·2	26·87	2,613	38·3	49·7	9·794	5,075	20·0
100·0	24·36	4,106	25·0	71·6	8·920	8,027	12·5
				100·08	8·331	12,010	8·32

Carbon filament at 9 volts, 3·112 amps., 28·0 watts.							
Vacuum Space.							
P.D.	A.	R.	K10^5.	P.D.	A.	R.	K10^5.
0·5	0·005	100,000	1·0	24·2	2·389	10,130	10·0
2·5	0·049	50,020	2·0	28·2	2·437	11,650	8·6
5·2	0·128	40,625	2·46	36·6	2·508	14,590	6·86
8·3	0·324	25,620	4·0	48·6	2·535	19,170	5·0
8·8	0·361	24,380	4·1	58·5	2·374	24,640	4·0
12·6	0·70	17,970	5·5	72·5	2·253	32,180	3·0
16·4	1·735	9,452	10·5	102·0	2·067	49,350	2·0
20·4	2·351	8,677	11·2				

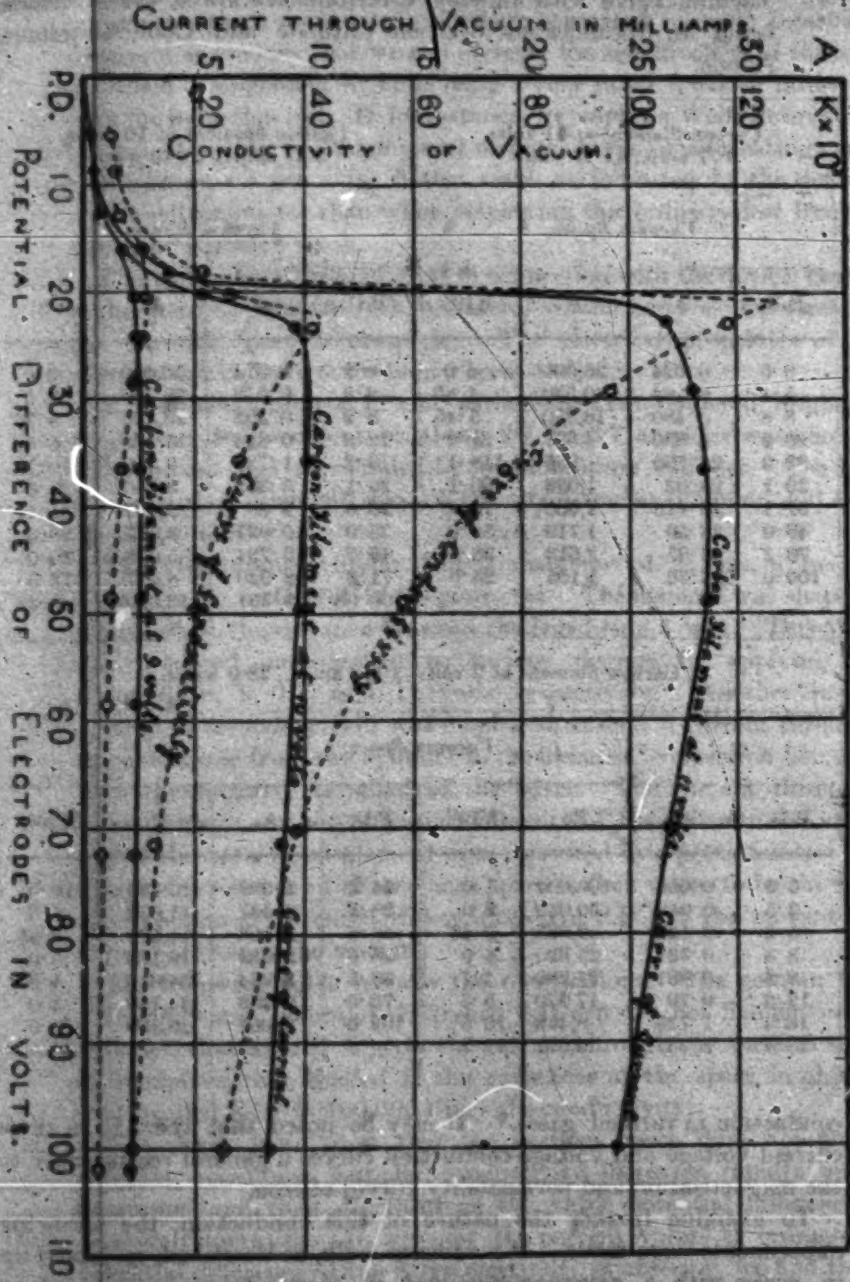
conduction in rarified gases.* It may be noted that there is in these current-voltage and voltage-conduction curves a general resemblance to the magnetisation and permeability curves of iron.

To examine further the nature of this conduction, the following experiments were made. If a vacuum bulb, as described, is joined up in series with a galvanometer and an electrodynamometer and an alternating electromotive force applied to the circuit, the two instruments will both be affected. The galvanometer is, however, affected only by

---

* See J. J. Thomson, 'Conduction of Electricity through Gases,' Chap. VIII.

FIG. 3.



the resultant flux of electricity in one direction. It measures the unidirectional current. The dynamometer is affected by the bilateral flux of electricity and it measures the total or alternating current. If, therefore, the vacuous space is totally non-conducting in one direction, one half of the alternating current will be cut out. The galvanometer will read the true mean (T.M.) value of the remanent unidirectional current, and the dynamometer will read the root-mean-square (R.M.S.) value. If the conductivity in one direction is not zero, then the galvanometer will read the T.M. value of the difference of the positive and negative currents, but the dynamometer will read the R.M.S. value of their sum.*

In the last case, the current through the valve may be considered to be a continuous current superimposed upon an alternating current.

If we call I the maximum value of the nearly sinoidal current in one direction, and I′ the maximum in the opposite direction, then we may say that the dynamometer reading (D) expressed in true current value is equal to $g\,(I+I')$ where g is the *amplitude factor*, and also that the galvanometer reading (G) in true current value is equal to $g/f\,(I-I')$ where f is the *form factor* of the current.† Hence—

$$\frac{D}{G} = f\frac{I+I'}{I-I'}, \text{ or } \frac{D/G+f}{2f} = \frac{I}{I-I'}.$$

The fraction $\frac{2f}{D/G+f}$, say β, expressed as a percentage may be called the *rectifying power* of the valve, for it expresses the percentage which the actual unilateral electric flow or continuous current through the valve is of that continuous current which would flow if the unilateral conductivity were perfect.

Perfect rectifying power, however, does not exist. There is not an infinite resistance to movement of negative electricity from the metal cylinder to the hot filament through the vacuum, although this resistance is immensely greater than that which opposes the movement of negative electricity in the opposite direction. This point was examined, as follows: A very sensitive electrodynamometer was skilfully constructed by my assistant, Mr. G. B. Dyke, the fixed coil having 2000 turns of No. 47 silk-covered copper wire and the movable coil 1000 turns. The suspension of the movable coil was by a fine flat phosphor-bronze wire at top and bottom. The deflection was observed by a mirror and scale.

---

* If i is the instantaneous value of a periodically varying current with maximum value I and periodic time T, then the root-mean-square value (R.M.S. value) of i is defined to be $\left(\frac{1}{T}\int_0^T i^2 dt\right)^{\frac{1}{2}}$ and the true mean value (T.M. value) of i is defined to be $\frac{2}{T}\int_0^{\frac{1}{2}T} i\,dt$.

† The *form factor f* and *amplitude factor g* are the names given by the author (see 'Alternating Current Transformer,' J. A. *Fleming*, vol. 1, p. 585, 3rd edit.) to the ratio of the R.M.S. to the T.M. value of the ordinates of a single valued periodic curve, and to the ratio of the R.M.S. value of the ordinates to the maximum value during the period.

This dynamometer was placed in series with a shunted movable coil galvanometer of Holden-Pitkin pattern, and the two together placed in series with a variable section of an inductionless coil through which an alternating current was passing. A vacuum valve as above described was in series also with the galvanometer and dynamometer. The alternating current was derived from an alternator giving a nearly true sinoidal electromotive force. The form factor of the electromotive force curve of this alternator was determined and found to be 1·115, that for a true sine curve being 1·111.

The vacuum valve sifted out the alternating current flow and allowed the currents in one direction to pass, but nearly stopped those in the opposite direction. The indications of the electrodynamometer were proportional to the root-mean-square (R.M.S.) value of the sum of the two opposite currents, and that of the galvanometer to the true mean value (T.M.) of their difference. The galvanometer and dynamometer were both calibrated by a potentiometer by means of continuous current, and curves constructed to convert their scale readings to milliampères. Then with various alternating current electromotive forces, their readings were taken when in series with a vacuum valve and recorded in the following tables. The letter D denotes current in milliampères as read by the so calibrated dynamometer and G that read by the galvanometer. The ratio D/G is denoted by z, and the rectifying power, viz., $2/z+1$ by β.

The table shows that the value of z is not constant, but for each state of incandescence of the filament reaches a maximum which, however, does not greatly differ from the mean value for the range of currents used. If we set out the mean values of β in a curve (see fig. 4), in terms of the power expended in heating the carbon filament, we see that the rectification is less complete in proportion as the temperature of the carbon filament increases. This is probably due to the fact that as the filament gets hotter, it heats the enclosing cylinder to a higher temperature and enables negative electricity to escape from the latter.

Hence, I feel convinced that if the metal cylinder could be kept quite cool by water circulation the rectification would reach 100 per cent. or be complete.

An ideal and perfect rectifier for electric oscillations may, therefore, be found by enclosing a hot carbon filament and a perfectly cold metal anode in a very perfect vacuum. With a bulb such as that used for the above experiments all we can say is that the current passed through the vacuum is from 80 to 90 per cent. continuous, 100 per cent. implying that the vacuum is perfectly non-conducting in one direction and permits the flow of negative electricity only from the hot to the cold electrode. The necessity for keeping the cathode cold is shown by the following experiment:—An alternating-current arc was

Table II.—Ratio of Electrodynamometer (D) to Galvanometer (G) Readings in Milliampères. Form Factor of E.M.F. Curve = 1·115 = f.

Carbon filament at 11 volts, 3·77 amps., 41·7 watts.

D.	G.	$D/G = a$.	$2f/a+f = \delta$.	
0·85	0·57	1·49	0·86	Mean = 0·82.
1·33	0·85	1·56	0·83	
1·87	1·16	1·61	0·82	
2·30	1·40	1·64	0·81	
3·20	1·88	1·73	0·78	
3·52	2·10	1·68	0·80	
4·54	2·81	1·62	0·82	

Carbon filament at 10 volts, 3·44 amps., 34·43 watts.

D.	G.	$D/G = a$.	$2f/a+f = \delta$.	
0·50	0·34	1·47	0·86	Mean = 0·83.
1·34	0·86	1·56	0·83	
2·28	1·48	1·54	0·84	
2·72	1·68	1·62	0·82	
2·78	1·71	1·63	0·81	
3·02	1·87	1·62	0·82	
3·53	2·17	1·63	0·81	
4·30	2·92	1·47	0·86	
4·25	2·88	1·48	0·86	

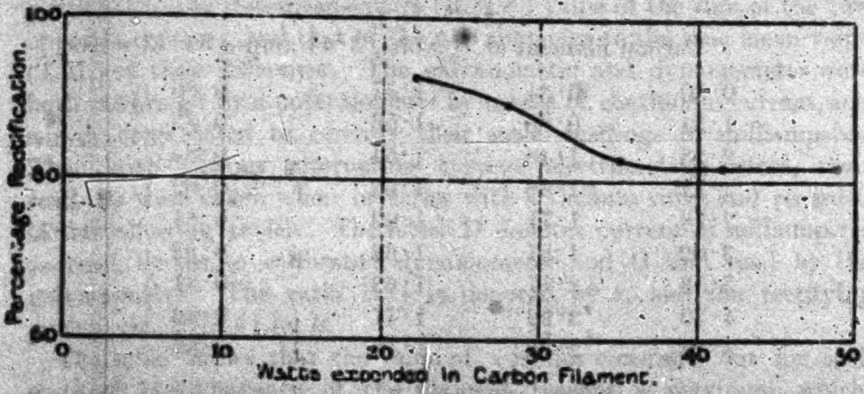
Carbon filament at 9 volts, 3·112 amps., 28·0 watts.

D.	G.	$D/G = a$.	$2f/a+f = \delta$.	
0·40	0·31	1·29	0·93	Mean = 0·89.
0·73	0·50	1·46	0·87	
1·28	0·83	1·54	0·84	
1·65	1·15	1·43	0·88	
1·82	1·26	1·44	0·87	
1·78	1·26	1·41	0·88	
1·93	1·35	1·43	0·88	
1·94	1·41	1·38	0·89	
1·87	1·41	1·38	0·91	
1·83	1·39	1·32	0·92	
1·73	1·37	1·26	0·94	

formed between carbon rods, and an iron rod was placed so that its end dipped into the arc. An ammeter was connected in between either carbon and the iron rod, and indicated a continuous current of negative electricity flowing through the ammeter from the iron rod to the carbon pole. This current was, however, greatly increased by making the iron rod of a piece of iron pipe closed at the end and kept cool by a jet of water playing in the interior. In this manner I have been able to draw off a continuous current of 3 or 4 amperes from an alternating-current arc using 15 alternating-current ampères.

Returning, then, to the vacuum valve, we may note that the curves in fig. 3 show that the vacuous space possesses a maximum conductivity corresponding to a potential difference of about 20 volts between the electrodes, for the particular valve used. The interpretation of this fact may, perhaps, be as follows:—In the incandescent carbon there is a continual production of electrons or negative ions by atomic dissociation. Corresponding to every temperature there is a certain electronic tension or percentage of free electrons. If the carbon is made the negative electrode in a high vacuum these negative ions are expelled from it, but they cannot be expelled at a greater rate than they are produced. Therefore, there is a maximum value for the outgoing current and a maximum value for the ratio of current to electromotive force, that is for the conductivity.

Fig. 4.



This fact, therefore, fixes a limit to the utility of the device. The current through the vacuous space is, to a very large extent, independent of the electromotive force creating it, and is at no stage proportional to it, or at least only within a narrow range of electromotive force near to the maximum conductivity.

Whilst, therefore, the device is useful as a simple means of detecting electric oscillations, it has not that uniformity of conductivity which would make it useful as a strictly metrical device for measuring them. It can, however, perform the useful service of showing us how far any device for producing electric oscillations or electric waves produces a uniform or very irregular train of electric oscillations, and what changes conduce to an improvement or reduction in the efficiency of the transmitting device.

A.D. 1904. Nov. 16. N° 24,850.
FLEMING'S COMPLETE SPECIFICATION.

(1 SHEET)

(3rd Edition)

[This Drawing is a reproduction of the Original on a reduced scale.]

Fig. 1.

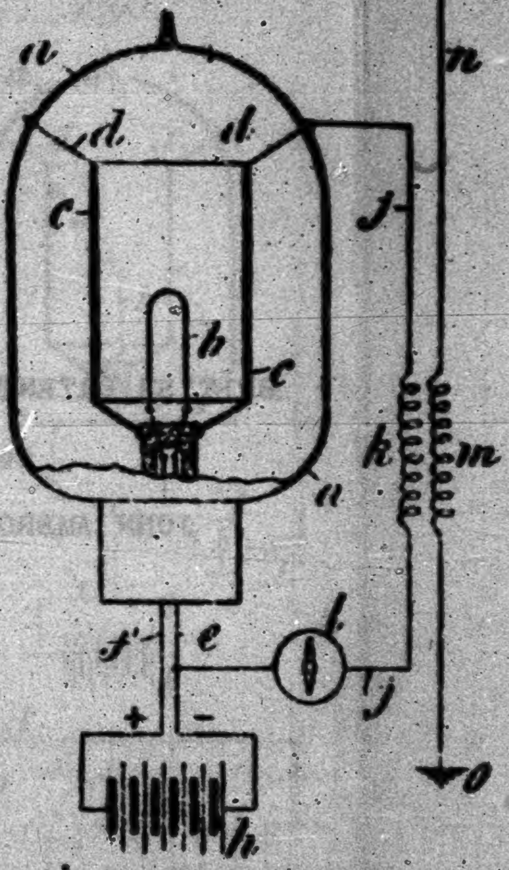

a
d
d
n
c
j
h
c
k
m
a
f
e
l
j
+
-
o
h

Fig. 2.

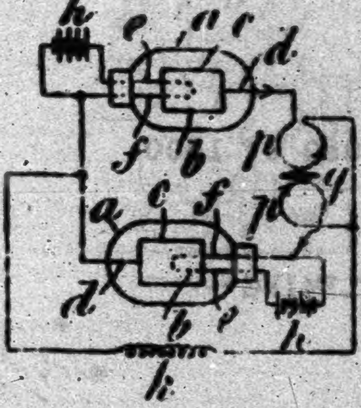
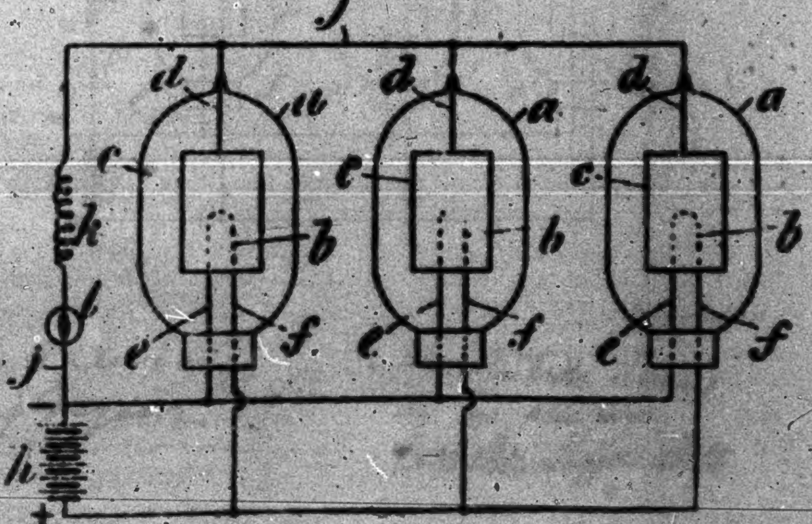

h
e
a
c
d
f
b
p
g
p
a
c
f
d
b
e
h
h

Fig. 3.


j
d
a
c
b
e
f
d
a
c
b
e
f
d
a
c
b
e
f
k
l
j
-
h
+

BRITISH PATENT 24,850 of 1900

to

JOHN AMBROSE FLEMING

DEFENDANT'S EXHIBIT No. 15.

No. 803,684. PATENTED NOV. 7, 1905.

J. A. FLEMING.

INSTRUMENT FOR CONVERTING ALTERNATING ELECTRIC CURRENTS INTO CONTINUOUS CURRENTS.

APPLICATION FILED APR. 19, 1905.

Fig. 1.

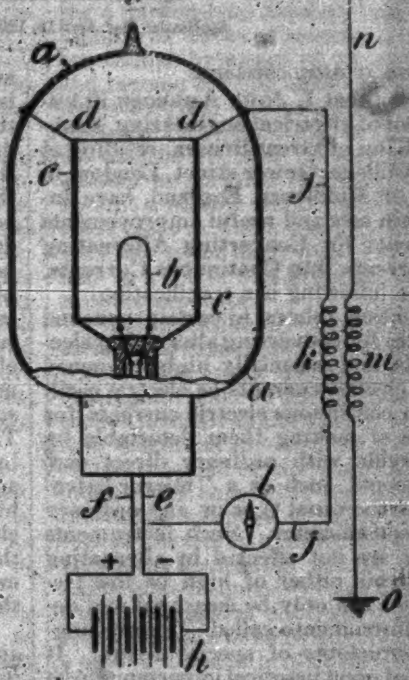

a
d
d
c
j
n
b
c
k
m
a
f
e
l
j
o
+
-
h

Fig. 2.

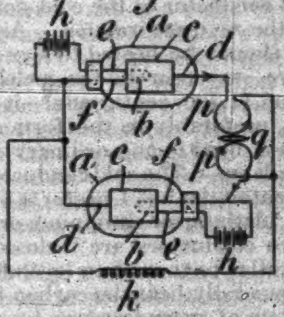
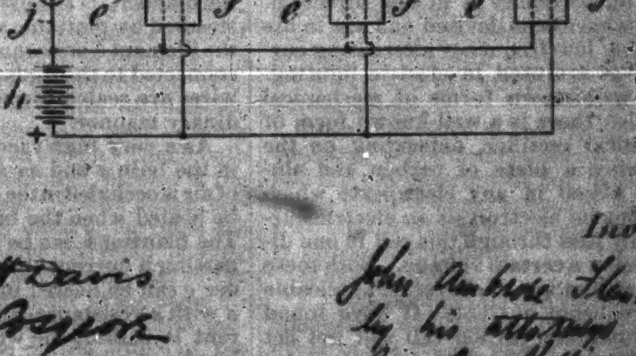

h
e
a
c
d
f
b
p
q
p
a
c
f
d
b
e
h
k

Fig. 3.


j
d
a
d
a
d
a
c
c
c
k
b
b
b
l
e
f
e
f
e
f
j
-
h
+

Witnesses

William H Davis

James J Gaynor

Inventor

John Ambrose Fleming

by his attorneys

Betts Betts Sheffield Betts

UNITED STATES PATENT OFFICE.

JOHN AMBROSE FLEMING, OF LONDON, ENGLAND, ASSIGNOR TO MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA, A CORPORATION OF NEW JERSEY.

INSTRUMENT FOR CONVERTING ALTERNATING-ELECTRIC CURRENTS INTO CONTINUOUS CURRENTS.

No. 803,684. Specification of Letters Patent. Patented Nov. 7, 1905.

Application filed April 19, 1905. Serial No. 256,488.

To all whom it may concern:

Be it known that I, JOHN AMBROSE FLEMING, professor of electrical engineering, a subject of the King of Great Britain, residing at University College, Gower street, London, in the county of Middlesex, England, have invented certain new and useful Improvements in Instruments for Converting Alternating Electric Currents into Continuous Currents, of which the following is a specification.

This invention relates to certain new and useful devices for converting alternating electric currents, and especially high-frequency alternating electric currents or electric oscillations, into continuous electric currents for the purpose of making them detectable by and measurable with ordinary direct-current instruments, such as a "mirror-galvanometer" of the usual type or any ordinary direct-current ammeter. Such instruments as the latter are not affected by alternating electric currents either of high or low frequency, which can only be measured and detected by instruments called "alternating-current" instruments of special design. It is, however, of great practical importance to be able to detect feeble electric oscillations, such as are employed in Hertzian-wave telegraphy by an ordinary movable coil or movable needle mirror-galvanometer. This can be done if the alternating current can be "rectified"—that is, either suppressing all the constituent electric currents in one direction and preserving the others or else by changing the direction of one of the sets of currents which compose the alternating current so that the whole movement of electricity is in one direction. Many means have been devised and are in use for rectifying low frequency alternating currents, such as are used in electric lighting. There are well-known forms of mechanical rectifier; also, there is a well-known form of electrochemical rectifier, depending on the fact that when a plate of carbon and aluminium is placed in any electrolyte which yields oxygen on electrolysis an electric current can only pass through this cell in one direction if below a certain voltage. Both these forms of rectifier are, however, inapplicable for high-frequency currents. I have found that the aluminium-carbon cell will not act with high-frequency currents.

I have discovered that if two conductors are inclosed in a vessel in which a good vacuum is made, one being heated to a high temperature, the space between the hot and cold conductors possesses a unilateral electric conductivity, and negative electricity can pass from the hot conductor to the cold conductor, but not in the reverse direction. As the hot conductor should be heated to a very high temperature—say near to the melting-point of platinum, (1,700° centigrade)—it should be of carbon, preferably in the form of a filament such as is used in any ordinary incandescent electric lamp. The cold conductor may be of many materials; but I prefer a bright metal, such as platinum or aluminium or else carbon. The two conductors are inclosed in a glass bulb similar to that of an incandescent lamp, and I generally heat the carbon filament to a high state of incandescence by a continuous electric current, the electrical connection to the filament and the cold conductor being made by platinum wires, sealed air-tight through the glass.

Figure 1 is a full-size sectional elevation of an instrument constructed according to this invention, the electrical connections being shown diagrammatically. This figure illustrates the application of the invention to wireless telegraphy. Figs. 2 and 3 show modifications to smaller scales.

In Fig. 1, *a* is a glass bulb, and *b* is a carbon filament like the carbon filament of an incandescent lamp, suitable, say, for taking a current of six to eight volts and two to four amperes. *c* is a cylinder of aluminium, open at the top and bottom, which surrounds but does not touch the filament. The cylinder *c* is suspended and steadied by platinum wires *d*, and the ends of the filament *b* are connected to platinum wires connected to the leads *e* and *f*. The platinum wires are sealed through the glass in the ordinary manner.

As a very high vacuum should be obtained in the bulb *a* and as a considerable quantity of air is occluded in the conductors, these should be heated when the bulb is being exhausted. The filament *b* can be conveniently heated by passing a current through it, while the cylinder *c* can be heated by surrounding the bulb *a* with a resistance-coil through which a current is passed, the whole being inclosed in a box lined with asbestos or the like. When, as hereinafter described, the cylinder *c* is replaced by any form of conductor which can be heated by passing a current through it, this method is usually more convenient than that just described.

The carbon filament is made highly incandescent in the usual way by a continuous electric current produced by the battery *h*, the negative pole of which is connected to the wire *e* and the positive to the wire *f*. The wires *d* and *e* are connected together by a wire *j*, which completes the circuit through the secondary winding *k* of an induction-coil (such as is ordinarily used in wireless telegraphy) and a galvanometer *l*.

m is the primary winding of the induction-coil, having one end connected, as is usual, to an aerial wire *n* and the other to earth *o*. The arrangement described above operates as an electric valve and permits negative electricity to flow from the hot carbon *b* to the metal cylinder *c*, but not in the reverse direction, so that the alternations induced in the coil *k* by the Hertzian waves received by the aerial wire *n* are rectified or transformed into a more or less continuous current capable of actuating the galvanometer *l* by which the signals can be read.

Although Fig. 1 shows the application of the instrument to wireless telegraphy, it will be understood that the aerial wire *n* may be replaced by any circuit in which there is an alternating electromotive force, whether of low frequency or of high frequency.

I may increase the effect in the following manner: I employ two bulbs arranged as shown in Fig. 2, each being similar to that shown in Fig. 1. *p p* are the two coils of a differential galvanometer connected to the bulbs in such fashion that currents flowing in opposite directions through the two bulbs flow in the same direction round the two coils of the galvanometer as regards the needle *q* of the galvanometer itself. For this purpose the hot conductor of each bulb is connected to the cold conductor of the other. Hence one bulb permits negative electricity to flow only in one direction and the other bulb permits only negative electricity to flow in the opposite direction through it. The common terminal of the two galvanometer-coils *p* is connected to the coil *k* or any source of alternating electromotive force or of electrical oscillations, the other terminal of the said source being connected to the bulbs, as shown. Each bulb has its own separate insulated battery *h* for heating its hot filament. Under these circumstances alternating electric currents are split into two continuous currents passing through the two bulbs in opposite and in the two coils of the galvanometer in the same directions. By thus using a differential galvanometer I make use of the whole of the energy of the alternating current instead of discarding half of it. In this manner very feeble electrical oscillations can make themselves apparent by the indication which they give on a sensitive mirror-galvanometer. A number of these valves may be associated together in parallel, as shown in Fig. 3, so that alternating currents rectified by them separately may produce continuous currents which are added together.

In place of using a metal cylinder surrounding a carbon-loop filament I sometimes use a number of carbon filaments. Some of these are heated by means of an electric current and become the hot conductor of the oscillation-valve and the others remain cold and form the cold conductor, or the metal cylinder may be replaced by a cylinder of meerschaum or the like having wound helically upon it a narrow ribbon of metallic foil. In those cases in which a larger alternating current has to be dealt with the hot conductor may be a rod of soft graphitic carbon held in suitable supports.

I find it possible by means of the device described above to rectify an alternating current without the use of any auxiliary continuous heating-current. Thus if I pass through the carbon filament an alternating current to bring it to bright incandescence I find if I connect either terminal of the filament by a circuit outside the bulb with the terminal of the embracing cylinder or other cold-conductor then in this circuit a continuous current flows. Hence the device may be used for rectifying either high-frequency or low-frequency alternating currents of electrical oscillations, provided these are of sufficient strength to render a carbon filament brilliantly incandescent.

It will be understood that when an alternating current is impressed upon a circuit including one of my improved rectifiers, as in Fig. 1, the alternating impulses in one direction will be suppressed and the alternating pulsations in the other direction will pass through the circuit in the form of a pulsating unidirectional current. This pulsating unidirectional current actuates the galvanometer or other continuous-current-indicating instrument *l*. When two rectifiers are used oppositely connected, as in Fig. 2, there will result two unidirectional pulsating currents flowing in opposite directions, and both of these currents are utilized in the differential galvanometer.

When I specify in my claims "means for detecting a continuous current" I intend to include any instrument for detecting such a single unidirectional pulsating current or two such unidirectional pulsating currents flowing in opposite directions.

What I claim is—

1. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for heating one of the conductors, and a circuit outside the vessel connecting the two conductors.

2. The combination of a vacuous vessel, two

conductors adjacent to but not touching each other in the vessel, means for passing an electric current through one of the conductors, and a circuit outside the vessel connecting the two conductors.

3. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for heating one of the conductors, a circuit outside the vessel connecting the two conductors, means tending to produce an alternating current in the circuit, and means for detecting a continuous current in it.

4. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for passing an electric current through one of the conductors, a circuit outside the vessel connecting the two conductors, means tending to produce an alternating current in the circuit, and means for detecting a continuous current in it.

5. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for passing a continuous electric current through one of the conductors, and a circuit outside the vessel connecting the two conductors.

6. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for passing a continuous electric current through one of the conductors, a circuit outside the vessel connecting the two conductors, means tending to produce an alternating current in the circuit, and means for detecting a continuous current in it.

7. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for heating one of the conductors, a circuit outside the vessel connecting the two conductors, an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth, and means for detecting a continuous current in the circuit.

8. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for passing an electric current through one of the conductors, a circuit outside the vessel connecting the two conductors, an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth, and means for detecting a continuous current in the circuit.

9. The combination of a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for passing a continuous electric current through one of the conductors, a circuit outside the vessel connecting the two conductors, an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth, and means for detecting a continuous current in the circuit.

10. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for heating the filament, and a circuit outside the vessel connecting the filament to the cylinder.

11. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for passing an electric current through the filament, and a circuit outside the vessel connecting the filament to the cylinder.

12. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surroupding but not touching the filament, means for heating the filament, a circuit outside the vessel connecting the filament to the cylinder, means tending to produce an alternating current in the circuit, and means for detecting a continuous current in it.

13. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for passing an electric current through the filament, a circuit outside the vessel connecting the filament to the cylinder, means tending to produce an alternating current in the circuit, and means for detecting a continuous current in it.

14. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for passing a continuous electric current through the filament, and a circuit outside the vessel connecting the filament to the cylinder.

15. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for passing a continuous electric current through the filament, a circuit outside the vessel connecting the filament to the cylinder, means tending to produce an alternating current in the circuit, and means for detecting a continuous current in it.

16. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for heating the filament, a circuit outside the vessel connecting the filament to the cylinder, an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth, and means for detecting a continuous current in the circuit.

17. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for passing an electric current through the filament, a circuit outside the vessel connecting the filament to the cylinder, an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth, and means for detecting a continuous current in the circuit.

18. The combination of a vacuous vessel, a carbon filament in the vessel, a metallic cylinder surrounding but not touching the filament, means for passing a continuous electric current through the filament, a circuit outside the vessel connecting the filament to the cylinder, an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth, and means for detecting a continuous current in the circuit.

19. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, and a circuit connecting the two latter connections.

20. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for passing an electric current through and so heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, and a circuit connecting the two latter connections.

21. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for passing a continuous electric current through and so heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, and a circuit connecting the two latter connections.

22. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, a circuit connecting the two latter connections, and means tending to produce an alternating current in the circuit.

23. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for passing an electric current through and so heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, a circuit connecting the two latter connections, and means tending to produce an alternating current in the circuit.

24. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for passing a continuous electric current through and so heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, a circuit connecting the two latter connections, and means tending to produce an alternating current in the circuit.

25. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for heating the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, and a circuit connecting the two latter connections.

26. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for passing an electric current through the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, and a circuit connecting the two latter connections.

27. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for passing a continuous electric current through the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, and a circuit connecting the two latter connections.

28. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for heating the filaments, two coils of a differential galva-

nometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, a circuit connecting the two latter connections, and means tending to produce an alternating current in the circuit.

29. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for passing an electric current through the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, a circuit connecting the two latter connections, and means tending to produce an alternating current in the circuit.

30. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for passing a continuous electric current through the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel, and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, a circuit connecting the two latter connections, and means tending to produce an alternating current in the circuit.

31. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, a circuit connecting the two latter connections, and an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth.

32. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for passing an electric current through and so heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, a circuit connecting the two latter connections, and an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth.

33. The combination of two vacuous vessels, two conductors adjacent to but not touching each other in each vessel, means for passing a continuous electric current through and so heating one of the conductors in each vessel, two coils of a differential galvanometer, one coil being connected to the heated conductor in one vessel and the other coil being connected to the unheated conductor in the other vessel, a connection between the other pair of conductors, a connection between the coils, a circuit connecting the two latter connections, and an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth.

34. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for heating the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, a circuit connecting the two latter connections, and an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth.

35. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for passing an electric current through the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, a circuit connecting the two latter connections, and an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth.

36. The combination of two vacuous vessels, a carbon filament in each vessel, a metallic cylinder in each vessel, surrounding but not touching the filament, means for passing a continuous electric current through the filaments, two coils of a differential galvanometer one coil being connected to the filament in one vessel and the other coil being connected to the cylinder in the other vessel, a connection between the other cylinder and filament, a connection between the coils, a circuit connecting the two latter connections, and an induction-coil having its secondary winding in the circuit and its primary winding connected to an aerial wire and earth.

37. At a receiving-station in a system of wireless telegraphy employing electrical os-

cillations of high frequency a detector comprising a vacuous vessel, two conductors adjacent to but not touching each other in the vessel, means for heating one of the conductors, a circuit outside of the vessel connecting the two conductors, means for detecting a continuous current in the circuit, and means for impressing upon the circuit the received oscillations.

JOHN AMBROSE FLEMING.

Witnesses:
H. D. JAMESON,
A. NUTTING.

Disclaimer in Letters Patent No. 803,684.

DISCLAIMER.

803,684.—*John Ambrose Fleming*, London, England. INSTRUMENT FOR CONVERTING ALTERNATING ELECTRIC CURRENTS INTO CONTINUOUS CURRENTS. Patent dated November 7, 1905. Disclaimer filed November 17, 1915, by the assignee, *Marconi Wireless Telegraph Company of America.*

Enters this disclaimer—

"To the combinations of elements set forth in claims 1 to 6, inclusive, and 10 to 15, inclusive, respectively, of said Letters Patent, except as the same are used in connection with high frequency alternating electric currents or electric oscillations of the order employed in Hertzian wave transmission, and to the words in the specification: 'whether of low frequency or,' at page 2, lines 32 and 33; 'either,' at page 2, line 98; and 'or low-frequency alternating currents of,' at page 2, lines 98 and 99."

[*Official Gazette, November 23, 1915.*]

DEFENDANT'S EXHIBIT No. 16.

Scientific American Supplement, No. 1568, January 20, 1906, pp. 25129-25131.

ON THE ELECTRIC CONDUCTIVITY OF A VACUUM.*

By J. A. FLEMING, M.A., D.Sc., F.R.S.

In the thirteenth series of his Experimental Researches on Electricity, Faraday discusses the question whether a vacuum should be considered to be a conductor or a non-conductor of electricity. The subject may seem, to some people, to be of purely academic interest, and devoid of any technical value. Since, however, any increase in knowledge concerning the manner in which electricity is moved from place to place, and its relation to atoms of matter, is extremely practical, the consideration of the conductivity of a so-called vacuum is not an unimportant matter. Since the time of Faraday we have been able to make vacua far more complete than any attained by him. Nevertheless, any vacuum we can make can only be so called by courtesy. In air at ordinary pressure there are about 10^{20} molecules per cubic centimeter; hence, even

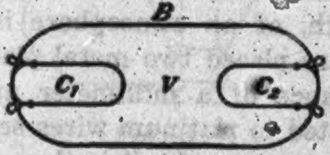


FIG. 1.

B. Bulb containing high vacuum. C_1, C_2, Carbon filaments sealed in, like an incandescent lamp.

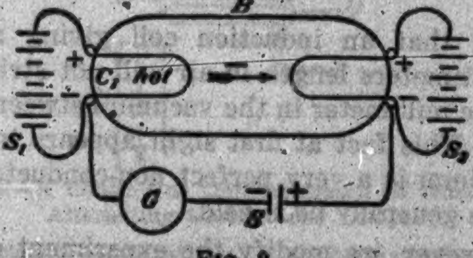


FIG. 2.

B. Vacuum bulb. C_1. Carbon filament to be rendered incandescent by insulated battery S_1. *G.* Galvanometer. *S.* A single cell sending negative electricity from hot filament to the cold one.

---

* Technics.

if we can take out from any space all but one hundred-millionth of the original gas at atmospheric pressure, the molecular population of that space must still be very large. Sir James Dewar has shown that extremely high vacua can be most rapidly produced by condensing the residual air in an ordinary vacuum by cocoanut charcoal, cooled by liquid hydrogen, and it may be possible in this way to remove from any space all but a very small proportion of the gaseous matter present.

Let us assume that we make a high vacuum of one hundred-millionth, of an atmosphere in a glass vessel and that in it are placed two metal plates, say of platinum, at a distance of a millimeter apart. Let these plates be connected to platinum wires sealed through the glass. If the plates are cold, it is then possible to create between them a difference of potential of 100,000 volts or so, and yet not cause any discharge or the slightest measurable current across the space. A vacuum can be made such that an induction coil giving a spark of several centimeters length in air will not strike across a space of one millimeter in the vacuum between cold metal terminals. This fact at first sight appears to show that a high vacuum is a very perfect non-conductor, and this opinion has generally been held.

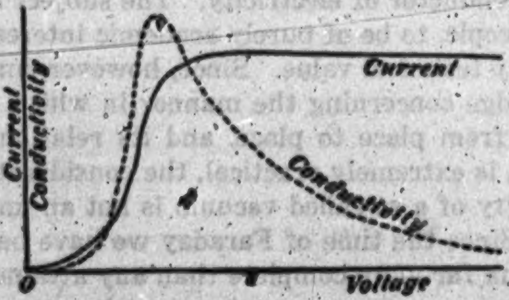


Fig. 8.—Curve Showing the Variation of Current and Conductivity through the Vacuum Valve, with Increasing Potential Difference between the Electrodes.

If, however, we modify the experiment slightly, we shall be able to show that the highest vacuum we can produce may, under other conditions, be a very good conductor.

Imagine a bulb of glass, made as in Fig. 1, containing two loops of platinum wire, or better still, two carbon filaments. Let this bulb be exhausted as completely as possible, so that in it the highest attainable vacuum is made. To achieve this, the filaments must be heated to bright incandescence while the exhaustion is going on. Having done this, if the secondary terminals of an induction coil are connected to the two separate filaments when cold, no discharge will take place across the vacuum be-

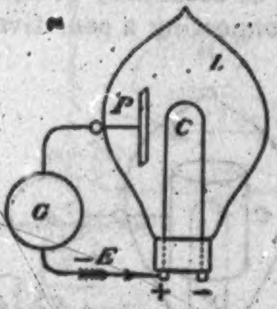


FIG. 4.

L. An ordinary carbon filament incandescent lamp. *C*. The carbon filament, rendered incandescent by a continuous current. *P*. A metal plate, sealed through the glass. *G*. Galvanometer through which flow negative electrons from the plate *P* when the other terminal of the galvanometer is connected to the positive of the filament.

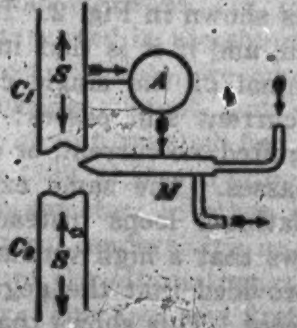


Fig. 5.—A Continuous Current drawn off from an Alternating Current Arc Lamp.

C_1, C_2. Carbons of the alternating arc. *A*. Continuous current ammeter. *M*. Hollow iron pole kept cold by circulating water. Negative electricity flows through the ammeter from one carbon to the metal pole.

tween them, thus apparently showing that the space is a very perfect non-conductor. Suppose, however, that we render one or both of these filaments incandescent by passing electric currents through them by means of two insulated batteries of secondary cells, S^1, S^2 (Fig. 2), it will be found, on connecting a sensitive galvanometer, *G*,

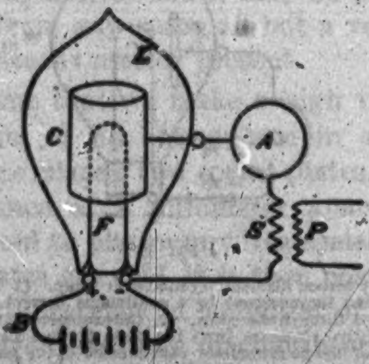


Fig. 6.—Vacuum Valve for Rectifying Electrical Oscillations.

L. A glass bulb highly exhausted. *F*. Carbon filament. *B*. Insulated battery. *C*. Cylinder surrounding filament. *A*. Ammeter or galvanometer. *S*. Coil in which secondary oscillations are induced by a primary coil *P*.

and a single cell, *S*, as a shunt to the two negative terminals of the two separate filaments, that a current of several milliamperes will pass across the vacuum under the electromotive force of this single cell. The arrangements should be as shown in Fig. 2. If only one of the filaments is ignited, and if it is that in connection with the negative terminal of the single cell in the shunt circuit, then the current still passes; but if the other filament alone is ignited, no current, or only a very much smaller current passes. The same experiment can be repeated using platinum loops instead of carbon filaments, and it shows that a high vacuum may be a very good conductor, provided that the negative electrode is rendered incandescent. This shows that the obstruction which a high vacuum offers to the passage of electricity is not due to the mere reduction of the matter in the space (that is, to the rarefaction of the gas), but is, in

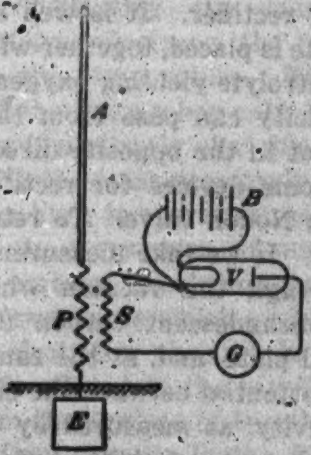


Fig. 7.—Vacuum Valve Used as Receiver in Wireless Telegraphy.

A. Aerial wire. P, S. Oscillation transformer. V. Vacuum valve. B. Battery. G. Galvanometer.

some way or other, largely dependent upon the temperature of the electrodes; the resistance to the passage of electricity through a vacuum can be rendered very small by intensely heating the negative electrode. Hence, such a bulb containing two carbon filaments forming the two electrodes, one of which can be rendered incandescent, will act as a *vacuum-valve*, allowing the electricity to pass in one direction, but not in the other. It permits negative electricity to pass out of the hot electrode, but not out of the cold electrode. If, in place of a single secondary cell (arranged in the shunt circuit, as in Fig. 2, to give a direct current), we employ an alternator, giving an alternating current, but still keep the galvanometer in the circuit, we shall find, as was first shown by the writer in 1889, that a continuous current passes through the gavanometer; in other words, the vacuum possesses a unilateral conductivity, and separates out the two constituents of the alternating current, passing one but not the other. This fact was first demonstrated and described in a paper by the author of this article, presented to the Royal Society in 1889.

In this respect, such a vacuum valve resembles an aluminium-carbon rectifier. It is well known that, if a carbon or iron plate is placed, together with an aluminium plate, in some electrolyte yielding oxygen, then a current of positive electricity can pass from the carbon to the aluminium, but not in the opposite direction. This fact is the basis of some devices for rectifying alternating current, such as a Nodon valve. To return, however, to the vacuum valve. If we take measurements of the current passing through the vacuum when the negative electrode is an incandescent carbon filament and the other a cold metal plate, and, at the same time, measure the difference of potential between the electrodes, we find that the conductivity, as measured by the ratio of current to voltage, is not constant, but varies with the electromotive force. In other words, the resistance of the vacuous space does not follow Ohm's law. As the electromotive force is steadily increased, the current gradually increases up to a certain maximum, and then slightly falls again. The firm line curve in Fig. 3 shows the general relation between current and voltage up to 100 volts; and it will be noticed that the curve is something like a magnetization curve of iron. It follows that the curve of conductivity, represented by the dotted line, is a curve rising rapidly to a maximum, and resembling to some extent the curve of permeability of iron.

For an explanation of these facts we must fall back upon the electronic hypothesis of matter and electricity. According to this view, atoms of matter are built up of electrons, which are point-charges of electricity; and an atom is considered to be made up either of a collocation of positive and negative electrons in orbital motion round one another, or else of negative electrons, or simply of electrons scattered throughout a space, which in some way or other, not yet understood, constitutes a sphere of positive electricity. In any case, facts connected with electro-chemistry and radio-activity show that atoms can break up, by giving off electrons, or can part with one or more electrons. Hence, in any mass of matter, such as a metal, there must be, in addition to the complete atoms or molecules constituting the mass, a distribution throughout it of free electrons, the percentage of these increasing with the temperature. These electrons cannot escape from the mass when cold, because if they did they would leave it positively electrified. If, on the other hand, we electrify the mass negatively to a high potential and raise it to a high temperature, electrons can escape freely from it. In every mass of matter there is what we may call a certain "electronic pressure"; hence, it follows that the resistance which a high vacuum offers to the passage of electricity through it is, in fact, the resistance which is offered to the ejection or drawing out of electrons from the surface of the electrodes.

In an interesting paper in the Philosophical Magazine for October, 1904, Lord Kelvin sums up the position as follows: "The labors of many experimenters during the last fifty years, and the comparatively modern atomic theory of electricity have thoroughly confirmed the view that the space of our best modern vacua, interstellar and interplanetary space, and generally, space occupied only by the luminiferous æther, is a very perfect non-resister of electricity passing through it. Hence, we see that the insulation of electricity in a vacuum is to be explained, not by any resistance of vacant space or of æther, but by a resistance of glass or metal or other solid or liquid against the extraction of electrions* from it, or against the tearing away of electrions or fragments of its own substance."

Lord Kelvin enters into some calculations of a very interesting kind, estimating the force required to extract an electron from the negative electrode. He considers an atom to consist of a sphere of positive electricity (it may be of positive electrons distributed through a spherical space), and he calculates the force necessary to tear a negative electron out of this environment. The force required to displace the negative electron whose charge is

---

* Lord Kelvin uses the term *electrion* for an infinitely small point-charge or atom of negative electricity. Most other writers, following the suggestion orginally made by Professor Johnstone Stoney, call these point-charges of electricity *electrons*.

e by a distance, x, from its position at the center of an atom whose radius is r, is equal to ex/r^2 electrostatic units. Now, the charge carried by one electron is known to be 3.4×10^{-10} electrostatic units, and the radius of an atom is known to be of the order of 10^{-8} centimeter. Hence, the force required to make $x/r = 1/9$ or to move an electron from the center of the atom only one-ninth part of the way to the atomic surface, is 320,000 electrostatic units, or equal to 96 million volts per centimeter; and the force required to extract the electron altogether would be equal to 384 million volts per centimeter.

This, as Lord Kelvin shows, means a strain equal to 66.4 tons per square centimeter, and would rupture or pull apart the strongest steel.

It seems, therefore, clearly impossible for any electrostatic force which we can create, to directly break up atoms or draw out electrons from them. On the other hand, it is a cardinal principle in the electronic theory of electricity, that the only way in which an electric current can be produced is by the movement of electrons. Since, therefore, we can produce currents of electricity in conductors by feeble electromotive forces, it follows that free electrons must exist within the metal. We picture to ourselves, therefore, a mass of metal as follows:

It is composed of atoms, each one of which is a complex structure of electrons in motion and vibration. Owing to collisions and mutual reactions, electrons are detached from some atoms, and constitute free point-charges of negative electricity, which remain mixed up with the atoms. The remainder of the atom from which the electron is detached is therefore positively charged, and may be called a positive ion. The free electrons are continually being set free from atoms, and taken up again by others. Hence, at any one moment there is a certain percentage of complete atoms and a certain corresponding percentage of free electrons and positive ions. The equilibrium is dynamic, and no doubt determined by temperature. The free electrons can move about between the atoms and comport themselves like molecules of gas in a vessel. They cannot leave the metal, because, if they did, it would be positively electrified. Hence, any attempt of an electron to remove itself from the conductor is strongly resisted. On the other hand, the electrons diffuse from one place to another in the same mass, if by any reason the concentration of electrons is different at the two places.

Creating an electromotive force in a metallic mass merely means that we make a difference in concentration or density of free electrons between different places, or that the number per cubic centimeter is greater at one place than at the other. Then there is a tendency for electrons to migrate or diffuse from the place where they are most numerous to places where they are less numerous. This diffusion of electrons constitutes an electric current. Electronic movement under variation of concentration follows the same laws as the diffusion of solids in solutions. This law, moreover, when mathematically considered, leads at once to the well-known law of Ohm defining the current under various electromotive forces in a conductor.

Suppose, then, that we seal two platinum wires into the opposite ends of a glass tube, and connect these two wires to a battery, or induction coil, or transformer. These appliances are virtually electron pumps, and force an excess of electrons into one piece of platinum and make a deficit in the other. The one which has an excess of electrons is the negative electrode. If the pressure is great enough, electrons may be projected from the negative electrode. If, however, the electrode is surrounded by air molecules at normal air pressure, the electrons projected from the metal never attain a very high velocity.

Imagine, now, the gas molecules greatly reduced in number—in other words, the air in the bulb rarefied and a "vacuum" made.

We have three broadly marked conditions to consider. We may have the "vacuum" low or high. We may have the electrodes cold or incandescent. We may have the electronic pressure difference, or voltage between, them, small or large.

Let us define these conditions more closely.. The vacuum is said to be low when the original normal air pressure in it is reduced to one-thousandth of an atmosphere, or it may be only to one three-hundredth. It is said to be high when it is reduced to one hundred-millionth of an atmosphere. The electrodes are said to be cold when not in any way specially heated. They are incandescent when brought to a bright white heat by some external means. The voltage is said to be small when the difference of potential between the electrodes is only a volt or two. It is said to be large when it is some hundreds or thousands of volts.

The phenomena which take place when the "vacuum" is not very high (that is, when the residual gas pressure is only about one-thousandths of an atmosphere), and the electrodes are cold, are very complicated. In this case we have an enormous number of gaseous atoms per cubic centimeter still left, and we have all the beautiful but complex phenomena shown by an ordinary *vacuum tube,* provided the potential difference of the electrodes is made sufficiently great (that is, provided it amounts to some hundreds or thousands of volts). The study of these phenomena has given occupation to a large number of the most distinguished physicists, and it has taken them at least have a century to unravel them. When the vacuum is very high (that is, if the residual gas pressure is something less than one ten-millionth of an atmosphere) the phenomena becomes simplified. We then observe the well-known effects of the Crookes or Röntgen tube. The electrons in the negative electrodes are projected from it, owing to the great electric force, with very high velocities; and as their path is not sensibly disturbed by the sparsely distributed molecules of the remanent gas, we have all the phosphorescent and other remarkable effects due to the bombardment of these electrodes, and their impact gainst the glass walls of the vessel or objects placed in the tube. This state makes itself evident by the apple-green phosphorescence of the glass vessel.

We may have a third set of conditions. If the negative electrode is heated to a very high temperature, then even if the electric potential of this electrode is low (that is, if there is only a volt or less difference of potential between the two electrodes) we have a very considerable current of electricity passing across a very highly vacuous space.

This can only be accounted for by the fact that the incandescent carbon or metal which forms the negative electrode is emitting vast numbers of these electrons or point-changes of negative electricity. These are flung out of the heated metal by the high velocities which they attain. Just as it would be possible to impart to a projectile such a velocity as would carry it beyond the earth's attraction, so the electrons present in the metal, when its temperature is high enough, are flung out of the mass; and if that mass is kept at a high potential this torrent of negatively charged electrons is a current of electricity.

We have in these facts an explanation of many well-known phenomena. One effect in the case of incandescent electric lamps has been much studied by the author; as it was first noticed by Mr. Edison, it is usually called the Edison effect. A plate of platinum or other metal, *P*, is attached to a platinum wire, and this last is sealed into the bulb of an incandescent lamp, *L*. The plate is placed as shown in Fig. 4. If then, the filament is rendered incandescent by a continuous current, and if we connect a sensitive galvanometer, *G*, between the positive terminal of the filament and the terminal of the plate, we find a current of several milliamperes passing through it. If, however, we connect the galvanometer between the negative terminal and the plate, no current flows. Again, if we render the filament incandescent by an alternating current, we can draw off a continuous current by connecting a galvanometer between the plate terminal and either of the terminals of the filament. These phenomena are susceptible of explanation by the fact that negative electricity (that is, electrons) can escape freely from the hot carbon filament, and hence move across the high vacuum and enter the positively electrified plate. The same thing can be shown with an electric arc. The writer showed many years ago, that if a thin carbon rod (or better still, an iron tube, *M*, closed and made chisel-shaped at one end, and cooled by water led into the interior) is placed with its sharp end just dipping into the electric arc, then a continuous current can be drawn off by a wire connecting this third pole with the positive carbon of the arc, and rendered evident on an ammeter, *A* (see Fig. 5).

On the other hand, no current, or very little current, passes through a wire connecting the negative carbon and this middle pole; or, if the arc is formed with an alternating current of electricity, in a wire which connects either carbon to a cool middle pole dipping into the arc.

These things are all consequences of the fact that incandescent carbon and metals send out vast numbers of electrons. In other words, an incandescent mass of carbon is flinging negative electricity out of itself. If it is surrounded by air at ordinary pressure the effects of this are not very marked, because the presence of vast numbers of air molecules round the metal keeps the electrons from making their way very far. They must, however, exercise an immense physical effect, and the everyday phenomena of a coal fire and the combustion of carbon by oxygen is without doubt intimately connected with it. Let us see what account the electronic theory can give of such a familiar fact as the combustion of a piece of coal or carbon.

To begin the combustion, the carbon must be raised to a high temperature. As already explained, this is accompanied by a dissociation of carbon atoms. We have present in the mass of carbon not only complete carbon atoms, but free electrons or point-charges of negative electricity. Therefore there must also be the residues called "carbon positive ions," which are the result of depriving the carbon atom of one or more electrons. The carbon atom is with good reason supposed to be built up of about 12,000 electrons, and of these it can lose four negatives at most. For every four free negative electrons which have escaped, or been flung out from a carbon atom, there will be left one positive carbon ion containing 12,000 or so, *less* four negative electrons. Outside the carbon there are the atoms of oxygen and nitrogen composing the air. Various atoms can, with different degrees of facility, either lose or take up additional electrons. Electro-chemical facts indicate that the oxygen atom can acquire or take up two additional negative electrons over and above the 16,000 or so which are its normal constituent number.

Hence, we may consider that, of the electrons projected from the hot carbon, some at least find their way into oxygen atoms, giving them a negative charge of electricity and converting them into negative oxygen ions.

There will, therefore, be a strong electric attraction between the positive carbon ions near the surface of the glowing carbon, which have lost four electrons, and the negative oxygen ions hard by, which have each gained two electrons. This electric attraction will be satisfied if two oxygen ions draw near to one carbon ion and form a closely united ionic group, or carbonic dioxide molecule represented by the chemical symbol CO_2. These groups being electrically neutral, remove themselves out of the sphere of action, and are the product of combustion of the carbon. As fast as the carbon ions and free electrons are removed from the glowing carbon, fresh ones are formed to keep up the number, and so the process goes on.

The temperature of the burning carbon is kept up by the conversion of potential energy of the oxygen ions and the carbon ions into atomic kinetic energy. The electrons in each ion are set in rapid vibration, and this in turn creates waves in the æther, which are the radiated heat and light. The process is therefore continuous and self-supporting. The combination of the carbon and oxygen ions maintains that temperature which is necessary for the continual production of the electrons in the carbon, and when it is begun at one point in the mass it speedily spreads all over it.

The nitrogen atoms take little part in the process. They do not quite so easily take up electrons as do the oxygen atoms. Hence, they are not in a condition to combine with the carbon ions.

The above process is typical, and proceeds when any metal is heated in air and oxidized or burned. Returning, then, to the vacuum valve, the writer of this article has recently discovered, and announced to the Royal Society, an important property possessed by a high vacuum when the electrodes are at very different temperatures.

A glass bulb contains a carbon filament, such as would be used for an incandescent lamp, and is surrounded by a metal cylinder not touching the filament, the said cylinder being connected to a platinum wire sealed through the glass. Such an arrangement possesses the property that when the filament is rendered incandescent, negative electricity can pass from the hot carbon to the cold cylinder, but not in the opposite direction. This arrangement may act as a vacuum valve if used in the following manner: Let the filament be, for example, a 12-volt carbon filament. It must be rendered incandescent by a small insulated secondary battery, *B*. To the negative terminal of this filament is connected one end of a circuit which includes a sensitive galvanometer, *A*, and the other end of the same circuit is connected to the terminal of the metal cylinder, *C*. This circuit may include the secondary coil of a small transformer or air core induction coil, *S.P* (see Fig. 6). If, then, electric oscillations are created in the primary circuit of this transformer by the discharge of a Leyden jar or any other method, these very high frequency alternating currents produce other high frequency currents in the circuit which includes the galvanometer and the high vacuum. Only one of these sets of currents, however, can pass round the circuit, viz., that which is due to a movement of negative electricity from the hot filament to the cold cylinder. The movement of electricity in the opposite direction is prevented, hence the galvanometer gives a deflection and is traversed by a continuous current. This enables us to employ a sensitive mirror galvanometer for detecting electric oscillations.

We may modify the experiment and make use of the apparatus to show many interesting effects. We may, for instance, set up an electric oscillation by the discharge of a condenser in one circuit. This discharge produces, as is well known, a rapid alternating current dying away in intensity; the current flows first in one direction and then in the other, the interval of time between them being exceedingly small, perhaps of the order of a millionth of a second. Then at a distance several feet or several yards away, we may set up another circuit including a galvanometer and a vacuum valve, and we may produce, as above described, a deflection in the galvanometer showing it is traversed by a continuous current when we set up an alternating current in the primary circuit by the discharge of the condenser. We can then show that the high-frequency magnetic field which is producing this effect is entirely arrested by thin sheets of metal; for if we hold a sheet of tinfoil between the primary and secondary coils, the deflection of the galvanometer at once ceases. We can also make use of such an arrangement as a receiver for wireless telegraphy; it is not so sensitive, however, as the coherer or the magnetic detector, but is very useful for many purposes. It would then be used in the following way: Between the aerial wire, *A*, and the earth plate is inserted one circuit, *P*, of an oscillation transformer or induction coil, the other circuit, *S*, including a vacuum valve, *V*, and galvanometer, *G*, as already described (see Fig. 7.). If, then, electric waves from a distance fall on the aerial wire, they set up in it rapid electric oscillations, and these induce other oscillations in the circuit of the vacuum valve.

If the vacuum valve has its carbon filament ignited by a small battery, it will permit only one of the constituent currents of the electric oscillation to pass, viz., that for which the movement of negative electricity is from the hot carbon to the cool surrounding cylinder. Hence the galvanometer will give a steady deflection all the time the electric waves are falling on the wire, and if the galvanometer is that type of instrument called a "speaking galvanometer" (or one which responds very quickly to the rise and fall of current through it), it will give deflections larger or smaller in proportion as the wave trains falling upon the aerial are longer or shorter, and in this manner signals in accordance with the Morse alphabet may be transmitted and rendered visible by the deflections of the galvanometer.

A galvanometer of the above kind is used in submarine cable telegraphy, and we can employ precisely the same instrument by the aid of a vacuum valve in connection with wireless telegraphy.

These, then, are some of the practical problems to which we are led by the study of the electric conductivity of a vacuum.

DEFENDANT'S EXHIBIT No. 17.

No. 859,021. PATENTED JULY 2, 1907.

F. SODDY.

MEANS AND APPARATUS FOR PRODUCING HIGH VACUUMS.

APPLICATION FILED JULY 12, 1906.

2 SHEETS—SHEET 1.

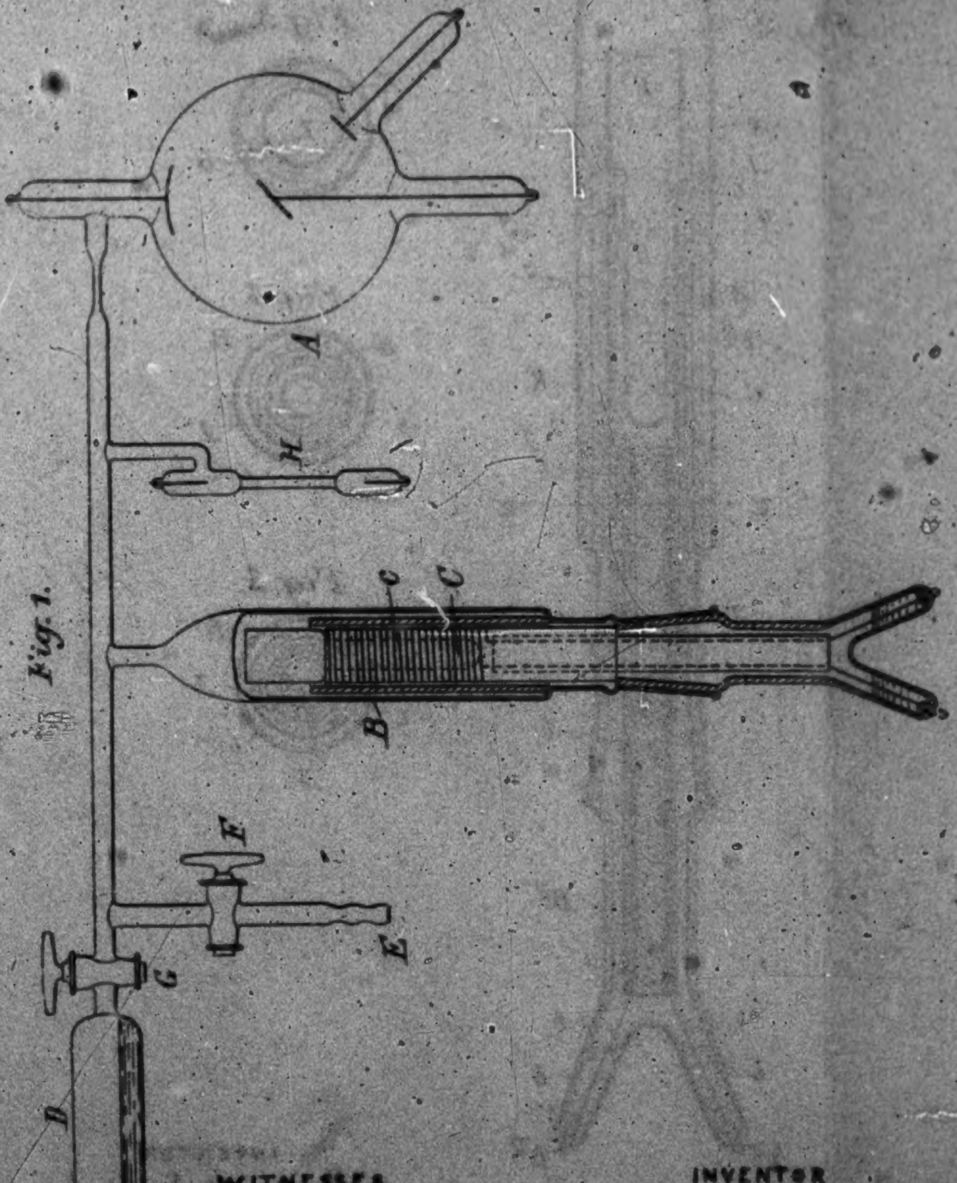


Fig. 1.

WITNESSES
William Abbt
E. W. Collins

INVENTOR
Frederick Soddy
by Howson and Howson
Attys.

No. 858,921. PATENTED JULY 2, 1907.

F. SODDY.

MEANS AND APPARATUS FOR PRODUCING HIGH VACUUMS.

APPLICATION FILED JULY 13, 1906.

2 SHEETS—SHEET 1.

Fig. 2

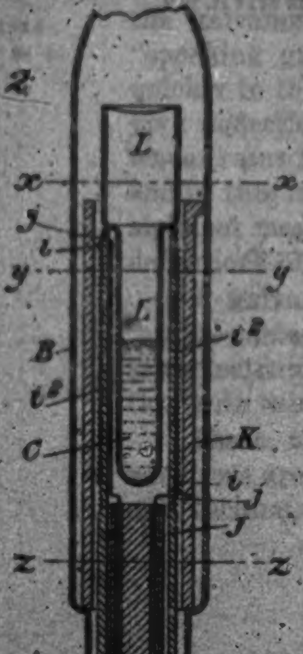

L
x
x
J
i
y
y
L
i²
B
i²
C
K
i
J
J
z
z
i
i
I
B²
i
i
b
b
b²
b²

Fig. 3.

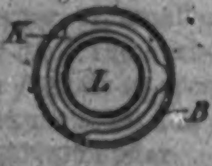


Fig. 4.

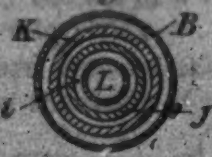
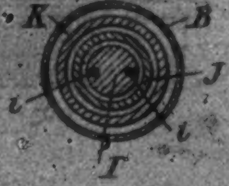


Fig. 5.



WITNESSES

William Abb

E. W. Collins

INVENTOR

Frederick Soddy

by Howson and Howson

Attys

No. 859,021. PATENTED JULY 2, 1907.

F. SODDY.

MEANS AND APPARATUS FOR PRODUCING HIGH VACUUMS.

APPLICATION FILED JULY 13, 1906.

4 SHEETS—SHEET 3.

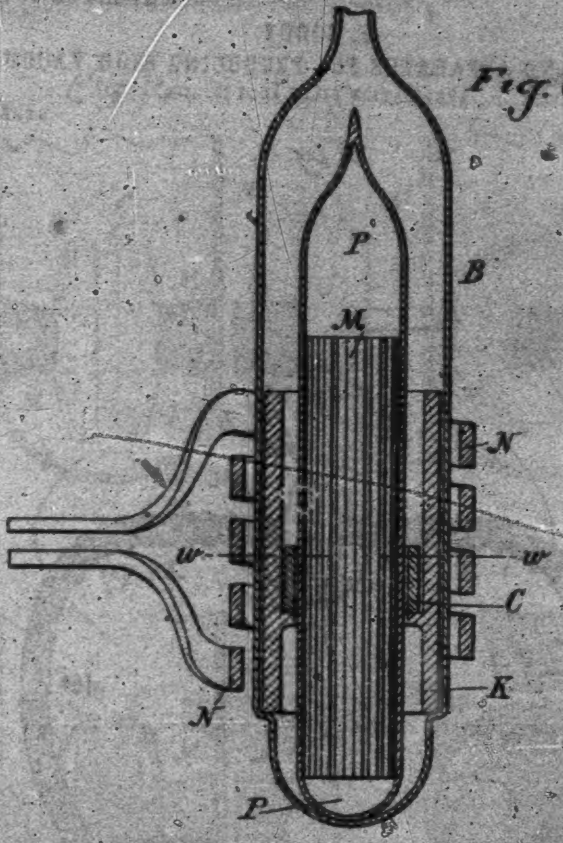
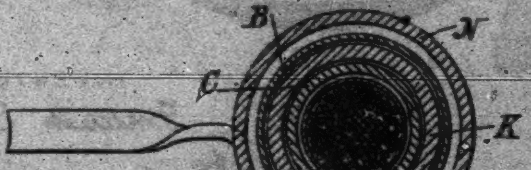


Fig. 6

Fig. 7



WITNESSES
William Abbe
E.W. Collins

INVENTOR
Frederick Soddy
by Howson and Howson
Attys

No. 859,021. PATENTED JULY 2, 1907

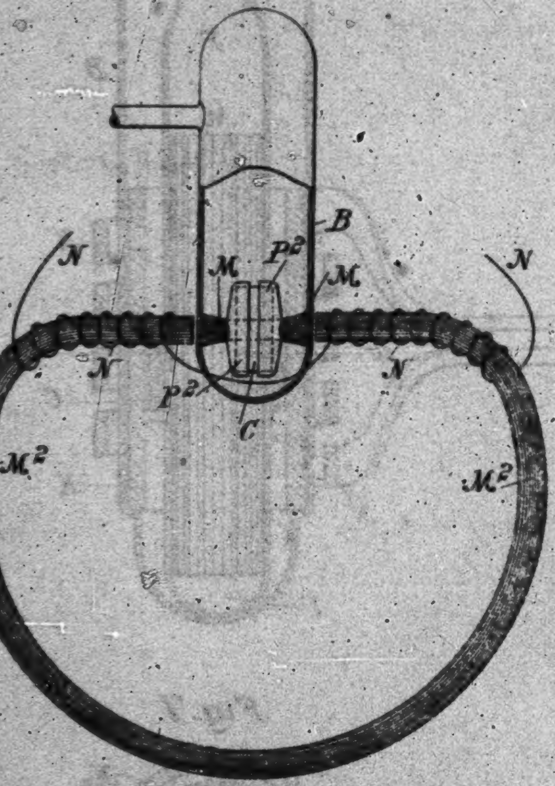
F. SODDY,

MEANS AND APPARATUS FOR PRODUCING HIGH VACUUMS.

APPLICATION FILED JULY 13, 1906.

5 SHEETS—SHEET 4

Fig. 8.



WITNESSES

William Abt

E.W. Collins

INVENTOR

Frederick Soddy

by Howson and Howson

Attys

No. 859,02[illegible]. PATENTED JULY 2, 1907.

F. SODDY.

MEANS AND APPARATUS FOR PRODUCING HIGH VACUUMS.

APPLICATION FILED JULY 13, 1906.

[illegible] SHEETS—SHEET [illegible]

Fig. 9.

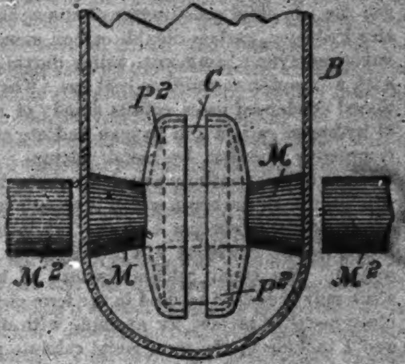

B
P²
C
M
M²
M
P²
M²

Fig. 10.

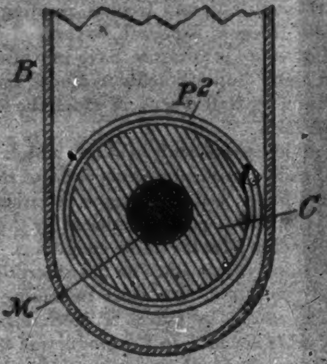


Fig. 11.

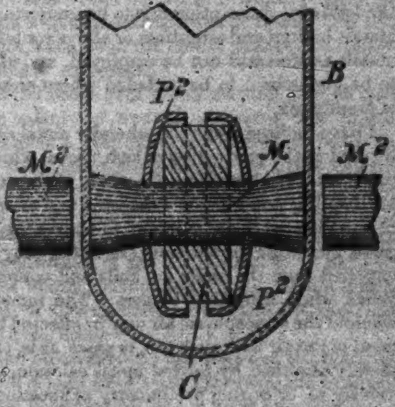
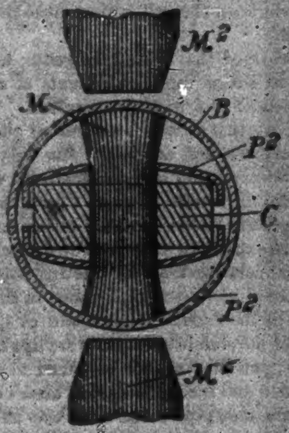

B
P²
M²
M
M²
P²
C

Fig. 12.


M²
M
B
P²
C
P²
M²

WITNESSES

William Abbe

E W Collins

INVENTOR

Frederick Soddy

by Howson and Howson

Attys

UNITED STATES PATENT OFFICE.

FREDERICK SODDY, OF GLASGOW, SCOTLAND.

MEANS AND APPARATUS FOR PRODUCING HIGH VACUUMS.

No. 859,02[illegible]. Specification of Letters Patent. Patented July 9, 1907.
Application filed July 13, 1906. Serial No. 326,152.

To all whom it may concern:

Be it known that I, FREDERICK SODDY, a subject of the King of Great Britain and Ireland, residing at 46 Kersland street, Glasgow, Scotland, lecturer of chemistry in the University of Glasgow, have invented certain new and useful Improvements in Means and Apparatus for Producing High Vacua, of which the following is a specification.

The object of this invention is to obtain a high vacuum in a rapid and economical manner without the use of the mercury pump, but of a degree of rarefaction fully equal to that which can be produced by the mercury pump under the most favorable conditions.

The process employed depends on the absorption by highly heated reagents of the gases remaining after preliminary exhaustion by means of mechanical air pumps or any other means. In the prodiction of high vacua not only has the air to be removed but also the gases occluded or condensed on the walls of the vessel being exhausted and on the contained electrodes or filaments or other contents of the said vessel, which condensed gases are given up slowly after exhaustion and if not removed during the exhaustion cause the vacuum to deteriorate.

I have discovered that certain reagents, hereinafter described, will act as rapid absorbents of almost all gases when heated to a high temperature. This temperature is above that at which exhausted glass vessels soften and collapse, and as glass is the only material that can be economically and satisfactorily employed for the containing vessels in cases where the highest vacuum is desired, I have invented means for heating the reagents in exhausted vessels made entirely of glass to a higher temperature than the melting point of glass for the purpose of producing high vacua in the manner before described. Vessels of porcelain or quartz are expensive and unreliable since they are apt to become porous in use, and they cannot be joined to the vessel to be exhausted and sealed therefrom after exhaustion by means of the blowpipe in the same way as glass vessels, and metal wires for carrying an electric current cannot be sealed air tightly into any othermaterial except glass. Metal vessels cannot be employed in the production of high vacua for even if these are constructed entirely without joints or flaws of any kind, and are perfectly air-tight the gases condensed in the metal and evolved from it in vacuo prevent a high vacuum being readily obtained therein. By my invention I have overcome the difficulty of the glass vessel collapsing at the high temperature employed, and by the use of glass vessels I can produce high vacua in a practical manner by means of reagents which do not act as absorbents of gases below the softening temperature of glass.

One of the reagents I may employ is the metal calcium. I have discovered that the metal calcium under suitable conditions absorbs rapidly and completely nearly all gases, including not only oxygen and nitrogen the two chief constituents of atmospheric air but also hydrogen, carbon dioxid, carbon monoxid, water vapor, acetylene, ammonia, sulfur dioxid, and even such a complex mixture as coal gas. The aforementioned condensed gases consist chiefly of compounds of hydrogen carbon and oxygen and are readily and completely absorbed by metal calcium. But metal calcium will not entirely absorb atmospheric air, for it will not absorb the argon which is present in air to the extent of about one per cent, nor while it is in the highly heated condition will it completely retain hydrogen. The metal calcium instead of being used alone may if desired be used in the form of alloys with other metal or metals, for example with magnesium, and I include in the term metal calcium alloys containing this metal. I have also discovered that the metals barium and strontium, which are in many respects the chemical equivalents of the metal calcium, may be used instead of, but in a similar manner to metal calcium in the production of high vacua, and in the following description it is to be understood that the metals barium and strontium or alloys containing these metals as aforesaid can be employed, and all these are to be understood to be included where metal calcium is mentioned.

I have devised a method whereby metal calcium can be used in the production of high vacua, which method consists in first removing the whole of the atmospheric air from the vessel being exhausted and afterwards employing heated metal calcium, to absorb the remaining gases, including the aforesaid gases after they have been expelled from the walls, or walls and contents, of the vessel while subjected to heat. The removal of the whole of the atmospheric air may be effected by replacement of the air with such gas, or gases, as is, or are, completely absorbed by heated metal calcium, either previously to, or during preliminary exhaustion.

The heating and expelling of the condensed and occluded gases may be effected in any usual, or suitable, manner of expelling condensed and occluded gases from the walls and contents of vessels being exhausted. The usual manner of effecting such an operation is to heat the vessel while it and its contents are subjected to the same treatment as they are subjected to in after use. In incandescent electric lamps for example an electric current is passed through the filament, and in X ray bulbs an electric discharge is passed between the electrodes during the continuation of the exhaustion.

The economical and rapid production of high vacua according to my invention can be effected as follows:— In communication with the vessel to be exhausted I place a receptacle for metal calcium, the said receptacle being provided with means for heating such metal calcium sufficiently to volatilize it, in the manner hereinafter to be described, means being also provided for placing the said vessel and receptacle in communication with a mechanical, or other, exhauster, and with a receptacle containing a substance which will generate gas capable of being entirely absorbed by heated metal calcium, and I first put the exhauster in communication with the vessel and receptacles and exhaust, as far as is possible by this means, air from the vessel and receptacles, and then I shut off the exhauster and generate the gas capable of being entirely absorbed by heated metal calcium as aforesaid, and I again exhaust by means of the exhauster, repeating this supply of such gas and exhaustion as may be necessary to replace and remove all the air, and consequently all the argon. I then shut off the vessel being exhausted and the receptacle containing the metal calcium from the exhauster and the receptacle containing the gas generating substance and keep the vessel and its contents heated and subjected to such treatment as hereinbefore indicated as will expel all condensed, and occluded, gases from the walls and contents of the said vessel, and I heat to the temperature at which it commences to volatilise the metal calcium which then absorbs all remaining gases and also the gases expelled as aforesaid. Instead of using a special substance to generate a gas, as aforesaid, for use in removing the air remaining after the preliminary exhaustion, the preliminary exhaustion may be continued while the vessel and its contents are subjected to such treatment as hereinbefore indicated as will expel the condensed and occluded gases, and the gases expelled from the vessels and contents of the said vessel be utilized instead of gases generated from a special substance as aforesaid, this being possible, for instance in the case of vessels and contents not previously exhausted.

Commercial samples of metal calcium give off gases, consisting mainly of hydrogen, carbon, and oxygen, when heated in a vacuum to a temperature below that at which these gases are absorbed by metal calcium, but these gases are reabsorbed on raising the temperature of the metal calcium. Use may be made of the gases evolved from metal calcium, in this way to assist in the replacement of the air remaining in the apparatus in the manner before described. This is possible in the case of a new charge of calcium not previously heated in a vacuum.

When the metal calcium has absorbed the remainder of the gases which have been expelled, the exhausted vessel may be sealed off and a very high and permanent vacuum has been obtained in a rapid and economical manner. Towards the end of the process of absorption of the gases by the metal calcium the temperature of the metal calcium can, with advantage, be reduced, for I have found that certain of the compounds formed by the combination of metal calcium with the gases it absorbs (and particularly the compounds with hydrogen and with carbon) possess an appreciable tension of dissociation at high temperature, but that on sufficiently lowering the temperature the gaseous products of dissociation are completely reabsorbed by the metal calcium, and the vacuum resulting is improved.

Figure 1 of the accompanying drawings illustrates diagrammatically means I may employ in carrying out the process according to my invention. A is the vessel to be exhausted, for example, an X ray bulb, B is the receptacle in which is [illegible] container of the metal calcium C, means being provided as at c, for heating it electrically to a high temperature as hereinafter described. D is the receptacle containing a substance which will furnish gas, or gases, capable of being entirely absorbed by metal calcium. This receptacle D may be, for example, a glass tube containing a mixture of, say, potassium chlorate and manganese dioxid furnishing oxygen on warming. E is the glass tube connected to the exhauster, not shown. F is a tap to open and close communication with the exhauster, and G is a tap to open and close communication with the receptacle D. H is a spectrum tube which may be of the usual kind and is a convenience for determining by means of the spectroscope the nature of the residual gases in the vessel undergoing exhaustion.

I will now describe constructions of apparatus suitable for use in carrying out that part of my invention which relates to the heating of the reagent to a high temperature in a glass containing vessel, for the purpose of causing it to absorb the remaining gases and so produce a high vacuum. For this purpose I employ, in combination with electrical means, as hereinafter described, for supplying heat to the reagent within the glass vessel, means for protecting the walls of the glass vessel from softening, or melting.

As the glass vessel is partially, or completely, exhausted, the conduction of heat from within outward to the walls is much diminished and in some cases I also interpose a shield, or shields, of refractory material between the reagent being heated in the said vessel and the walls of the said vessel to intercept heat radiated. The electrical heating is obtained by conduction of an electric current through a separate resistance circuit placed within the said exhausted glass vessel, or by electrical means situated outside the said glass vessel and causing induced electrical effect through the walls of the said glass vessel, either in a circuit composed of the reagent to be heated or in a separate circuit within the said exhausted glass vessel in close proximity to the reagent. For example, in one modification of my apparatus I employ a combination of an exhausted glass vessel with an electrical resistance circuit within the said glass vessel and surrounding the reagent to be heated and a shield, or shields, of refractory material placed between the said resistance circuit and the walls of the glass vessel, and in another modification I employ a combination of an exhausted glass vessel with a core of iron wires, or strips, inside the said vessel, and I dispose around the outside of the vessel a coil traversed by an alternating, or intermittent, current of high periodicity, and I place around the core a ring, or tube, composed of a good conductor of electricity in which the heating current is induced. This ring, or tube, may, in some cases for example in the case of metal calcium, be made of the reagent to be heated, or of a separate substance on, or in, which the reagent to be heated is placed. In addition I may use with this combination a shield, or shields, of refractory material which, in this case, must be an insulator of electricity, between the substance heated and the walls of the glass vessel, and also I may use a shield between the substance heated and the iron core. When the heating current is induced directly in the substance to be heated, this substance is hotter than its surroundings, so that less heat is required than for any other mode of heating and the glass vessel needs less protection in this case and the shield, or shields, of refractory material may, in certain cases, be dispensed with.

Figs. 2 to 5 represent a form of the apparatus according to the first mentioned modification, Figs. 3, 4, and 5 being respectively sections on the lines *x*, *y* and *z*, Fig. 2. Figs. 6 and 7 show a form of the apparatus according to the second mentioned modification. Figs. 8 to 12 represent another modification as hereinafter described.

Referring first to Figs. 2 to 5. The glass vessel B is closed by a glass tube B^2 ground into the vessel B, and having two hollow legs, or pockets, *b*, filled with mercury into which penetrate the platinum conductors b^2 from the respective poles of any suitable source of electricity. I is a porcelain insulator through longitudinal holes in which pass the conductors *i i*, the lower ends of which dip into the mercury in the legs, or pockets, *b* and passing within the porcelain tube J and out through holes *j j* therein, and to the said conductors is joined an electrical resistance wire i^2 (of platinum, or other suitable material,) coiled round a helical groove on the porcelain tube J which is surrounded by a porcelain shield-tube K. Inside the tube J is carried the porcelain container L for the reagent C, which is to be heated. The upper enlarged part is employed when a reagent such as metal calcium is used which gives off a vapor which it is desirable to condense this enlarged part constituting a surface upon which the vaporized reagent will deposit. The shield-tube K serves to protect the glass of the vessel B from the heat radiated from the resistance wire i^2. If desired there may be more than one shield-tube of refractory and insulating material between the substance to be heated and the glass vessel B, or the glass vessel may be formed into a bulb at the part where the greatest heat is developed.

Referring to the modification shown in Figs. 6 and 7, this shows an arrangement adapted for use when the reagent, for example, metal calcium, is itself a conductor of electricity and can be made into suitable form. The substance to be heated is made into the form of a ring, or tube, C which may be supported in a tube K constituting a shield of refractory and insulating material, in the glass vessel B. Within the substance C and this tube K are iron wires, or strips, M arranged after the manner of the core of an induction coil and contained in the tube P of thin glass, or porcelain. The ring, or tube, C is heated by an electric current induced in it either by a bobbin of insulated wire, or by spiral strips, as shown at N, traversed by an alternating, or intermittent, current of high periodicity and coiled outside the glass vessel B and therefore surrounding the iron core within it. This heating arrangement constitutes an alternate, or intermittent, current transformer of which the outside coilings N constitute the primary, the ring, or tube, C the single short-circuited winding of the secondary, and the iron wires, or strips, M the core. It may be convenient to obtain the alternating, or intermittent, current from a step-down transformer (not shown) of which N is the secondary and C is the tertiary. If necessary, in this case also, more than one shield K, may be used, or the shield K, (or shields), may, in some cases, be dispensed with as explained, and the outer glass tube at this part be expanded into a bulb, and the core M be made longer and the spiral N be placed above, or below, the bulb. The ring C in this case is conveniently supported on a projection on the tube K. When it is desirable to protect or inclose the core M the said core may, as shown, be contained in a sealed tube P of difficultly fusible glass, which, if necessary, may be protected externally by wrapping round it a sheet of mica, or other refractory material, or by placing round it a concentric shield of porcelain. With this method of heating, the limitation of temperature is fixed mainly by the loss of the magnetic properties of the iron core above a certain temperature, so that for very high temperatures the iron as well as the glass walls must be shielded. For the purpose of charging and cleaning the apparatus, the glass vessel B may, if desired, be made in two, or more, parts ground to fit together accurately without leakage when the ground joint is lubricated with rubber grease in the usual manner.

Fig. 8 represents a ½ scale modification of the apparatus for use in the inductive method of heating upon the same principle as that last described. Fig. 9 is a section actual size of a part of the apparatus. Fig. 10 is a central transverse section; Fig. 11 a section at right angles thereto and Fig. 12 a horizontal section. The reagent, for example, metal calcium, is in the form of a disk C with a central hole through which a magnetic material such as a bundle of iron wires, or strips, M, passes the said wires, or strips, supporting the disk C, centrally, in the glass vessel B. Outside the glass vessel B is a magnetic material such as a bundle of iron wires, or strips, M^3, bent into approximately ring form and so arranged that it forms, with the iron wires, or strips, M, or the equivalent, inside the glass vessel B a magnetic circuit with two air gaps in which part of the walls of the glass vessel B are situated. A conductor N, of copper, or other suitable metal, is coiled around the outer wires, or strips, M^3, and through this is passed a rapidly alternating, or intermittent, electric current so as to induce a magnetic flux in the magnetic ring and consequently in the bundle of wires, or strips, M, or the equivalent, within the glass vessel B, and so heat the disk C. The disk C may if desired be made of a good conductor, for example, copper, and the reagent heated in a cavity in the same. Or, two disks of copper and a disk of the reagent placed between the other two disks may be employed. The drawing shows two caps, or shields, P^2 of porcelain, or other sufficiently refractory material which is a bad conductor of heat, these caps, or shields, being used to protect the walls of the glass vessel B from the heat generated in the disk C.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The process of producing high vacuum which consists in bringing a heated alkaline earth metal capable of absorbing gas into the presence of a rarefied atmosphere whereby the remaining gases are absorbed.

2. The process of producing high vacuum which consists in subjecting a vessel to preliminary exhaustion, expelling the condensed and occluded gases from the walls of the vessel and bringing said gases into the presence of a heated alkaline earth metal capable of absorbing gas.

3. The process of producing high vacuum which consists in subjecting a vessel to preliminary exhaustion, expelling the condensed and occluded gases from the walls and contents of the vessel, and bringing said gases into the presence of a heated alkaline earth metal capable of absorbing gas.

4. The process of producing high vacuum which consists in subjecting a vessel to preliminary exhaustion, expelling the condensed and occluded gases from the walls of said vessel, bringing said gases into the presence of a heated alkaline earth metal capable of absorbing gas and permitting said metal to cool, substantially as described.

5. Apparatus for the purpose of producing high vacuum by heating in an exhausted glass vessel to a temperature above the softening point of glass any reagent which becomes an absorbent of gases at high temperature, the said apparatus consisting of the combination of a glass vessel adapted to be exhausted, means for supporting therein the reagent and means for electrically heating such reagent within the vacuum and means for preventing the intense hea. being conveyed to th walls of the said glass vessel, substantially as hereinbefore described.

6. Apparatus for the purpose of producing high vacuum by heating in an exhausted glass vessel to a temperature above the softening point of glass any reagent which becomes an absorbent of gases at high temperature, the said apparatus consisting of the combination of a glass vessel adapted to be exhausted, means for supporting therein the reagent to be heated and means for heating such reagent within the vacuum by means of an electric current passing through a conductor external to the glass vessel and inductively heating the aforesaid reagent by current, and means for preventing the intense heat being conveyed to the walls of the glass vessel, substantially as hereinbefore described.

In testimony whereof I have signed this specification in the presence of two subscribing witnesses.

FREDERICK SODDY.

Witnesses:

THOMAS D. MACKENZIE,
ARTHUR J. REDDY.

DEFENDANT'S EXHIBIT No. 18.

surveyors and astronomers. The examples are mostly taken from actual observations, and the necessary calculations are given in considerable detail. In the earlier chapters a knowledge of determinants is not assumed, and the explanations given ought to make the method intelligible to readers of quite moderate mathematical ability. For the more difficult and controversial points of the theory, reference is made to the treatise of Czuber; at the same time, a very good example of the unavoidably empirical nature of the whole subject is given by working out the same elementary problem according to each of three different laws of error. Now that the measurements of physics and chemistry are approaching, not to say surpassing, in exactness those of astronomy and geodesy, a practical work of this kind is likely to assist a larger and larger body of experimenters.

Die Purpurbakterien. Eine mikrobiologische Studie. By Prof. Hans Molisch. Pp. 92. (Jena: Gustav Fischer, 1907.) Price 5 marks.

THIS memoir deals with an interesting group of chromogenic microorganisms, *viz.* those producing brilliant pigments ranging in tint from pink, through rose and deep red to reddish-purple. They are probably more nearly allied to the coloured algæ (Phycochromaceæ) than to the bacteria proper, and one of the earliest descriptions of a member of the group was given by Sir Ray Lankester in 1873 under the title of a "peach-coloured bacterium." The author first discusses the occurrence in nature of these organisms. Sometimes they are met with in great abundance on the sea-coast, in river estuaries, and in hot and sulphur springs. Directions are given for obtaining growths in various organic mixtures, for the preparation of suitable culture media, and for obtaining pure cultures in the latter. The biological and physiological properties are next considered; while light has an inhibitory, or a germicidal, action on most bacteria, the "purple" bacteria develop best in its presence. They are sensitive to all light rays, but in particular to the ultra-violet ones; they do not, however, evolve oxygen in the presence of light, and their need for oxygen varies much, some species being almost anaërobic.

The colouring matter produced by the "purple" bacteria is a mixture of two pigments—a green, "bacteriochlorin," and a red, "bacteriopurpurin." The chemical and other properties of these are described fully.

As regards classification, the organisms are grouped in a special order, the Rhodobacteria. This is divided into two families, distinguished by the presence or absence of sulphur granules, and several new species isolated by the author are described. Altogether the book forms a very useful summary of our knowledge of an interesting and peculiar group of micro-organisms.

R. T. HEWLETT.

The Case of Existence. By Norman Alliston. Pp. xiii+262. (London: Kegan Paul, Trench, Trübner and Co., Ltd., 1907.) Price 5s. net.

"OF the enigmas of life," says Mr. Alliston in his introduction, "all speak; but nobody acts as if there were an enigma." It is his object to remove this inconsistency by exposing the confusions of thought of those who "want life speculatively to be a mystery." The book has three parts. The first contains a good account of the nature of Explanation and some not ineffective criticisms of Knowledge, Nature, &c., mingled, it must be admitted, with much rather ill-informed dogmatism. The second, in the course of a review of man's "obstinate questionings" about existence, develops the author's peculiar egoistic optimism. The third, in which he draws his ethical corollaries, unfortunately contains some chapters which many readers will find offensive both in matter and in tone. The book contains little to engage the attention of the practical student of philosophy, but, being written with obvious conviction and enthusiasm, may here and there attract a useful recruit to the study of first principles. At a later stage the student may not unprofitably return to these pages to detect and analyse the crudities and ambiguities which abound under a surface of apparent lucidity.

Science German Course. By C. W. P. Moffatt. Pp. xii+228. (London: W. B. Clive.) Price 3s. 6d.

THE portion of this book devoted to grammatical construction and word formation occupies about eighty pages, and is followed by extracts for translation from the German. These selections deal with various scientific subjects, and can be commenced after the student has made himself familiar with the first few pages of the grammar that precedes them. Short vocabularies are given of technical terms in mathematics, physics, chemistry, geology, botany, and zoology. The book thus provides a convenient means of obtaining sufficient acquaintance with the German language to read simply scientific descriptions in it with intelligence.

LETTERS TO THE EDITOR.

[The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.]*

The Wehnelt Kathode in a High Vacuum.

THAT a good vacuum can be made into a good conductor by the use of an incandescent kathode is known since the discovery of the Edison effect, and has been investigated with great thoroughness by O. W. Richardson (Trans. Roy. Soc., 1903, 201 A, 497). Wehnelt has shown (*Ann. d. Physik*, 1904, iv., 14, 425) that if the incandescent kathode is coated with one of the alkaline earths, surprising results can be obtained. From a platinum foil kathode at 1300° C. to 1400° C. coated with lime, two to three amperes per sq. cm. of surface can be passed through a good vacuum, the kathode fall being practically negligible, and the total voltage across the vacuum tube being below 30 volts. This result is so very remarkable that I have repeated it in the following way to test whether, as is commonly supposed, the phenomenon is really independent of the perfection of the vacuum.

In a tube provided with a Wehnelt kathode of about 2 sq. cm. area was mounted an anode of the metal calcium. I have recently shown (Proc. Roy. Soc., 1907, 78 A, 429) that calcium at its volatilising temperature (700° C. to 800° C.) absorbs practically instantaneously and very perfectly all known gases and vapours except the chemically inert gases of the argon family, and have described a form of vacuum furnace suitable for this operation. The tube was prepared in the usual way by preliminary exhaustion and washing out with oxygen to remove argon, and then subjected to the action of calcium heated in a furnace attached to the apparatus. When a good vacuum had been obtained, current from the 250-volt supply was passed through the tube between the heated Wehnelt kathode and the calcium anode in order to heat the latter.

The gases evolved from the anode and tube under this treatment were absorbed by the calcium in the furnace. The current was regulated by a resistance to about 1·2 amperes, and was interrupted at intervals to give the evolved gases time to flow out of the apparatus. When the gases had been for the most part removed the current was passed continuously, heating the calcium anode up to its volatilising point. Quite suddenly and completely the current through the tube stopped, and at the same moment a copious mirror of calcium was volatilised from the anode. In a little while a very feeble glow started and passed intermittently from time to time, but it was not enough to move the ammeter needle, and was most likely due to a further slow evolution of gas from the still heated surfaces. A current could be passed by a coil from the hot kathode to a third electrode as anode without causing any appreciable resumption of the flow in the 230-volt circuit.

More gas was then generated within the apparatus by heating the third electrode with the coil discharge, and the current in the main circuit resumed its original intensity, again heating up the calcium anode. The original phenomenon was repeated, a sudden cessation of current taking place when the calcium volatilised. Just before stopping, the glow of the tube changed to that characteristic of argon, so probably a trace of air had not been removed. The whole phenomenon could be repeated by admitting oxygen to the apparatus and proceeding as before.

This experiment shows that in a sufficiently high vacuum the Wehnelt electrode ceases to be effective. In the experiments so far recorded the saturation current has increased with the improvement of the vacuum, and the phenomenon has been supposed to be in the first place independent of the residual trace of gas present. Wehnelt (*loc. cit.*, p. 446) remarks:—"Für Drucke unter 0·1 mm. ist die für eine bestimmte Temperatur ausgesandte Zahl von negativen Ionen unabhängig vom Druck," and (p. 456) "die Grenzstromstärken um so höher sein . . . je tiefer die Druck ist." In his description of his modification of the Braun tube (*Phys. Zeit.*, 1905, vi., 732) he says the vacuum in the tube must be as perfect as possible.

Richardson, whose mathematical theory of the general phenomenon has received quantitative experimental confirmation, and has been accepted by Wehnelt in the case of his electrode, regarded the action as purely electronic. Commenting on the magnitude of the current and the smallness of the residual gas—in one experiment 2 amperes per sq. cm. at a measured pressure of 0·0016 mm. from a carbon lamp-filament—he says (*loc. cit.*, p. 546):—"This (the current) is twenty-five times the maximum value obtained by supposing each molecule to produce one ion; so that it is highly improbable that any considerable part of the conductivity investigated is due to ions produced in this way. . . . Both these points of view lead to the conclusion that the corpuscles are not produced by a dynamical action between the molecules of the surrounding gas and the surface of the metal. In fact, all the experimental results seem to point to the view that the corpuscles are produced from the metal by a process similar to evaporation."

These isolated quotations, of course, may not fairly express the opinions of the authors about what is a very complex phenomenon; but the general impression their results has conveyed, I think, has been that the large currents dealt with were wholly conveyed by the expelled electrons, and therefore should pass through any vacuum, however perfect. I do not think the electronic emission can account for more than a negligible fraction of the total current, which is carried almost wholly by the residual gas.

The results here given bear out the general view I have from time to time advocated since my experience with the use of calcium, that degrees of vacuum are in practice apt to be overrated, and really high degrees of vacuum are not so readily obtained as is commonly supposed.

Frederick Soddy.

Physical Chemistry Laboratory, The University,
Glasgow.

The Interpretation of Mendelian Phenomena.

I am strongly inclined to agree with Dr. Archdall Reid that Mendelian investigations throw no light on many of the most important problems of biology, such as the causes of variation, the evolution of adaptations, and many others. On the other hand, it is difficult to understand what Dr. Archdall Reid means by the statement that Mendelism is the investigation of sex. In one of his letters he describes Mendelian phenomena as "abnormalities of sexual reproduction which occur under conditions of artificial selection." If this means peculiarities of heredity in sexual reproduction observed in cultivated varieties, it may be allowed to pass; but in an appendix to the second edition of his "Principles of Heredity," Dr. Reid states that the inheritance of Mendelian characters is probably sexual. He proceeds as follows:—"Nature has evolved alternative inheritance to create and perpetuate sexual differentiation, but, just as blending of sexual characters sometimes occurs, so on the other hand the inheritance of non-sexual characters is sometimes alternative. As we have seen, whenever the latter happens, the non-sexual differences are, like the sexual differences, usually considerable. Nature makes the mistake, so to speak, of treating them as sexual. Of course, however, the alternative inheritance of large non-sexual differences is not certain, not so 'clean' as that of sexual differences, the alternative inheritance of which has been established by a long course of selection."

According to this, the alternative inheritance of non-sexual characters is of the same nature as sexual dimorphism. It seems to me that Dr. Reid has not sufficiently studied the inheritance of secondary sexual characters. It is admitted by almost all evolutionists from Darwin himself downwards that selection cannot have been the cause of the alternative inheritance of sexual differences. The female in selecting a particular male cannot prevent the transmission of his peculiarities to her daughters. The male characters must be limited to the male sex from their first origin as variations, because otherwise the selection of the individual male would merely ensure their transmission to both sexes.

The essential peculiarity of secondary sexual characters is their physiological connection with the primary, *i.e.* with the male or female gonads. It is not merely a question of alternative inheritance; both male and female characters are inherited by each individual, but normally only one set is developed. When, however, the male gonads are removed, the male characters are usually not normally developed, but suppressed. In Mendelian cases the development of alternative characters is usually entirely independent, both in theory and fact, of the sex or condition of the gonads.

The contrast of male and female corresponds to alternative dominance in a heterozygote; male characters are dominant in male, female in female, but either can and does transmit both. In Mendelian cases alternative inheritance is segregative; a recessive transmits only recessive characters, a pure dominant only the dominant. In other passages which I could quote Dr. Reid has shown that he has failed to appreciate this fundamental distinction between dominance and segregation, between the heterozygote and the homozygote, between the first generation of a Mendelian cross and the second.

Excepting parthenogenesis, the heredity of all characters is sexual in that it is connected with fertilisation, but I do not see that Mendelian characters are sexual in any other sense. The theory that the inheritance of sexual characters is Mendelian is one which has a definite meaning and can be investigated. Dr. Archdall Reid's statement that Mendelian inheritance is sexual is in one sense a truism, in another seems to me to have no real meaning at all, for to say that nature has evolved alternative inheritance to perpetuate sexual differentiation explains nothing.

J. T. Cunningham.

Highgate, November 3.

I am very willing, and, like most people with theories, I believe I am able to maintain the correctness of the views to which Mr. Cunningham refers; but to discuss my speculations now would be to confuse the issue. I may say, however, that the appendix to the second edition of my work, from which Mr. Cunningham quotes, is a mere sketch hastily thrown together to meet the objections of critics who had advised the lay and scientific public that a book, which I fondly hoped contained a little that was new, and which certainly contained more than a little of which Mendelians seem profoundly unaware, was antiquated and worthless, not because there were no new facts or inferences in it, nor because its facts and inferences were invalid, but simply and solely because I had not adopted "the new method" nor accepted the

DEFENDANT'S EXHIBIT No. 18-A.

Proceedings of The Royal Society. (1907).
Vol. 78-A, pp. 429-458.

Calcium as an Absorbent of Gases for the Production of High Vacua and Spectroscopic Research.

By Frederick Soddy, M.A., Lecturer in Physical Chemistry in the University of Glasgow.

(Communicated by Professor J. Larmor, Sec. R.S. Received September 13,—Read November 15, 1906. Notes added November 20, 1906.)

CONTENTS.

PAGE
I.—Introductory 429
II.—Historical 430
III.—Electric Furnace for Strongly Heating Reagents in Glass Vessels 433
IV.—Absorption of Gases by Calcium 436
V.—Behaviour of Barium and Strontium 438
VI.—Production of High Vacua by means of Calcium 439
VII.—An Induction Method of Electrically Heating Calcium in Glass Vessels ... 441
VIII.—Practical Considerations in the Use of Calcium as an Absorbent for the Production of High Vacua 444
IX.—Quantity of Argon detectable by the Spectroscope 446
X.—Misapprehensions regarding High Vacua 447
XI.—Quantity of Pure Helium detectable by the Spectroscope 451
XII.—Most Favourable Conditions for the Detection of Infinitesimal Quantities of Helium 452

I.—*Introductory.*

This paper contains an account of researches carried out by the aid of an electric furnace designed to heat reagents in soft glass tubes up to temperatures far above the softening point of glass, and has special reference to the use of calcium under these conditions as a valuable absorbent of gases. Recent work on the generation of helium from the radio-elements has shown the necessity for more simple, certain, and powerful means of absorbing other gases and in particular nitrogen. The usual practice of Sir W. Ramsay and the writer when working together was to make provision for the removal of compounds of hydrogen, oxygen, and carbon, but to take the utmost precautions against the admission of air into the apparatus in the first place. If nitrogen was present in spite of the precautions taken, it was often possible, by gently running the spectrum-tube, to absorb it by the hot electrodes of aluminium, the lines of helium, if present, appearing as the nitrogen spectrum faded.

The difficulty in absorbing nitrogen is that the usual absorbents, for example, a mixture of lime and magnesium, only react above the softening temperature of an exhausted soft glass tube, and the present researches had their origin in an attempt to enable higher temperatures and more powerful absorbents of gases to be used within soft glass apparatus. Lithium, it is true, absorbs nitrogen at a very low temperature, but its use introduces hydrogen. A good example of a very perfect train of absorbents, able to absorb all known gases with the exception of those of the argon family, is to be found in the recent researches of Debierne* on the production of helium from radium and actinium. "Oxygen is absorbed by heated copper; the absorption of hydrogen is secured by the action of heated copper oxide and phosphorus pentoxide, at the same time the copper oxide transforms gaseous carbon compounds into carbon dioxide, which is absorbed by potash, and finally nitrogen is absorbed by pure lithium."

Now such an apparatus serves but one experiment, and has to be built up afresh for each, because it is necessary to fill it after the absorption with mercury in order to compress the helium sufficiently to detect it. The labour involved during a lengthy investigation may be imagined. It is, therefore, very satisfactory to be able to state that I have found that a single reagent, namely, calcium, at the high temperature attainable by the use of my furnace, would serve instead of all the reagents employed by Debierne, and do the work far more effectively and rapidly. Calcium, under the conditions mentioned, is a universal absorbent of all gases with the exception of the argon group.

II.—*Historical.*

Till recently calcium has been a very uncommon metal, while barium and strontium still belong to the category of chemical curiosities. Maquenne† found that when amalgams of these three metals were heated in nitrogen, the mercury was volatilised and nitrides of the metals were formed. The absorption took place at a lower temperature than in the case of the metals magnesium and aluminium. Barium was stated to lend itself best to the experiment. None of the alkaline-earth metals were investigated by Lord Rayleigh and Sir W. Ramsay in their examination of the known absorbents of nitrogen,* on account of the difficulties in obtaining large quantities of these metals at that time. After the discovery of argon, Maquenne† showed that a mixture of calcium oxide and magnesium rapidly absorbed the oxygen and nitrogen of the air when heated in a hard glass tube, and attributed this reaction to the production of calcium in an extremely divided state. He states that a manometer attached to the apparatus showed a diminution of pressure from the atmospheric equal to 70 and even 73 cm. of mercury. This mixture is now commonly employed in the preparation of argon, and it is customary to accept Maquenne's explanation of its absorbing power. It is, however, quite certain that the commercial calcium in the form of compact metal bars, produced by electrolysis, behaves in a manner entirely different from the "nascent calcium," if such it be, produced by heating a magnesium and lime mixture, for the former, heated in a tube filled with air at atmospheric pressure, produces no noticeable absorption, even at the highest temperatures.

---

* 'Comptes Rendus,' 1905, vol. 141, p. 383.

† 'Comptes Rendus,' 1892, vol. 114, p. 220.

Moissan first succeeded in preparing calcium in quantity sufficient to make an accurate study of its properties.‡ His calcium was in finely divided crystalline condition, and was obtained by acting upon calcium iodide with excess of sodium. The calcium is deposited out from the sodium on solidification, and the latter is removed by the action of absolute alcohol, which does not attack calcium. He showed that at a dull red heat this calcium absorbs both hydrogen and nitrogen with incandescence, forming nitride and hydride respectively. The hydride heated to the softening temperature of a Bohemian glass tube in an atmosphere of hydrogen neither absorbed nor evolved gas. In a determination of its melting point the calcium was heated in a vacuum obtained by the use of a mercury pump. Moissan noted the evolution of small quantities of gas which were pumped off, "but as soon as the metal became dull red hot the last traces of gas are absorbed, and the vacuum stood at 1 mm." This inconsistency might have been due to sticktion of the mercury in the gauge, or to an error in its reading, for, as Moissan himself remarks, the last traces of gas are absorbed under these conditions.

---

* 'Phil. Trans.,' A, 1895, vol. 186, p. 187.

† 'Comptes Rendus,' 1895, vol. 121, p. 1147.

‡ 'Comptes Rendus,' 1898, vol. 126, p. 1753; and vol. 127, pp. 29, 497, and 584.

Calcium, electrolytically produced in the form of compact bars, free from mercury and oil, has been available for over two years, and has been the subject of much interest. Those who have examined it must have been more struck with its apparent disinclination to react than with any exceptional reactivity. Thus the attempts to replace the magnesium or magnesium-lime mixture by this calcium in the preparation of argon have never succeeded in my experience. Even when heated to 1200° C. in an electric oven it refuses, after a very slight initial action, to absorb nitrogen. It must be heated to a very high temperature in the blow-pipe before it ignites in the air, and then readily goes out. In one experiment a powerful arc was caused to pass between calcium points in air without inducing combustion.* Negative results of this character could be multiplied.

Arndt† undertook a research on the melting point of commercial calcium, in which the metal was heated, as in Moissan's experiment, in a vacuum of 1 mm. pressure to avoid chemical action. He noticed that the calcium began to volatilise below its melting point, and that the vapour reacted energetically with the residual air, so that the pressure on the manometer sank to an unreadable value. Absorption commenced at 700° C., was rapid and accompanied by visible volatilisation at 730°, whereas the melting point was found to be 800°. When a Plücker spectrum-tube was included, it was found that "the nitrogen spectrum faded rapidly, while the lines of hydrogen (from a trace of water present) remained behind with the lines of argon." He found that the vapour of magnesium did not exhibit nearly the absorptive power of calcium.

With the use of the apparatus to be described I arrived independently at and have confirmed, the observation of Arndt on the extreme rapidity of absorption of the oxygen and nitrogen of air by the vapour of calcium. In addition I have found that all the common gases can be absorbed equally well, although in some cases, as the above quotation from Arndt's paper shows for hydrogen, complete absorption is not effected by simple heating alone.

III.—*Electric Furnace for Strongly Heating Reagents in Glass Vessels.*

The apparatus usually employed depends upon the internal heating of the reagent by an electric resistance circuit and the protection of the glass walls by a screen of porcelain placed between it and the enclosed furnace. It is shown to the scale of 6 inches to the foot, in section, in fig. 1. Figs. 2, 3, 4 are transverse sections on the lines *x*, *y*, *z* respectively. The outer containing

---

* This, however, is partly due to the extraordinarily slight heating which electrodes of calcium experience when a discharge is passed through a gas between them. Of all metals calcium heats the least, and is in this respect far superior to aluminium. But for other difficulties it might be used to replace aluminium, with advantage, as the electrodes of vacuum tubes in the case of the inert gases. A steady arc can be maintained between calcium points in air with a very small amperage.

† 'Ber. d. D. Chem. Ges.,' 1904, vol. 37, p. 4723.

Fig. 1.

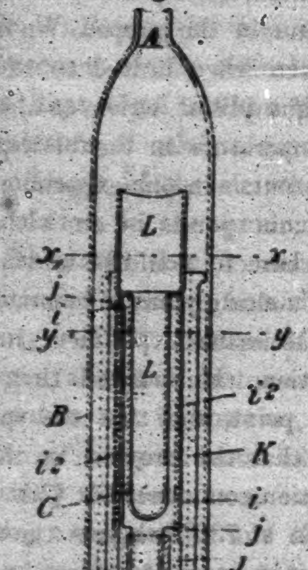


Fig. 2

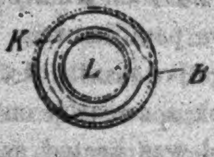


Fig. 3.

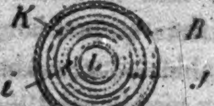


Fig. 4.

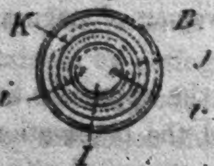
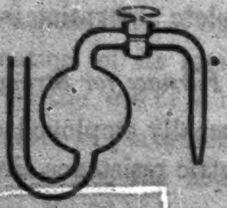


Fig. 5.



vessel is made out of soft glass tubing, and is in two parts, the upper *B* and the lower B_2, which are ground to fit together accurately at *D*. The lower part B_2 has two mercury cups with platinum wires b_2 sealed through the glass. The upper part *B* widens at the shoulder *d*, on which rests the porcelain shield-tube *K*. This is slipped into the tube, which is then constricted at *A* and joined to a narrow piece of tubing for connecting to other apparatus. The furnace-tube *J*, which carries the heating wire, slides through the ground-joint of *B* and passes inside the shield-tube *K*. For the upper part of its length it is grooved with an external screw thread of about 1 mm. pitch, and wound with a platinum wire *ii* of 0·25 mm. diameter. It passes through the holes *jj* into the inside of the tube, and is joined to stouter leads of nickel, copper, or platinum, or is simply doubled on itself. The leads pass through the doubly-bored porcelain insulator *I*, which slips within the lower half of the furnace tube and the upper part of B_2, and are finally taken into the mercury cups. The lower end of the furnace-tube *J* rests on, and is supported by, the upper end of B_2, and itself surrounds and supports at its upper end a porcelain test-tube *L*, in which the reagent to be heated is placed, at *C*.

The whole arrangement is readily taken to pieces at the ground-joint *D* for recharging, cleaning, or repairs. The end B_2 usually carries between the two mercury cups a narrow tube, shown by dotted lines, to which is attached a bulb and tap, shown in fig. 5, for the purpose of admitting mercury into the apparatus without introducing air, and also for conveniently filling the mercury cups and other purposes. An oil or mercury seal may surround the ground-joint, but is not necessary if it is of good workmanship.

For special work, where the possibility of leaks or the presence of vapour of grease is to be avoided, it is easy to dispense with the ground-joint *D* and to make the apparatus in one piece. In this case *B* is made long, so that it can be repeatedly opened and sealed, and the various parts are introduced through the upper end by suitable tongs. But these refinements are usually quite unnecessary if the ground-joint is of good workmanship, and is well lubricated, and if the leads are of sufficient conductivity not to heat the joint. In special work, too, the mercury cups may be dispensed with and the wires continued through the glass seal if the presence of mercury vapour is to be avoided.

[*Added*.—An improved and thoroughly satisfactory method of working, applicable whether the ground-joint is used or not, is to dispense with the porcelain insulator *I*, and to bore two holes opposite each other at the lower end of the furnace-tube *J*, twisting one end of the doubled platinum heating wire through each hole, together with a length of "flexible" copper wire, and continuing the two flexibles, insulated if necessary in little glass tubes, into the cups *bb*, where they make good touching contact with the platinum, without the use of mercury. In this way a mechanically strong joint with the fine heating wire is secured, the presence of mercury inside the vacuum is altogether avoided, and the formation prevented of a mercury arc between the two cups when a high-tension discharge is passed through the vacuum, which in the first form of apparatus constituted an occasional source of annoyance and damage.]

With this apparatus reagents may be safely heated to temperatures far above the melting point of glass without injuring the apparatus. After nearly two years' use of these furnaces I do not recall a single case where the heat has caused the glass to crack or break while in use, although, of course, the glass tends to get brittle and to break when being cleaned more readily after use than before. If required for prolonged heating at high temperature, it is an advantage to blow a bulb on the tube at the hottest part of the furnace, otherwise, when the porcelain shield-tube has become heated through, the glass is apt to melt. These shield-tubes never break. The furnace-tubes are more fragile, but stand extremely well, while, of course, the test-tubes containing the reagents require the most frequent replacement. Tubes made of thin iron would for many purposes have very many advantages over porcelain. But they must be gas-tight at the lower end, for the vapour of calcium would ruin the platinum wire if it came in contact with it.

The limit of temperature attainable in this apparatus is fixed mainly by the volatility of the heating wire in the high vacuum usually maintained within the apparatus, and for this reason platinum or one of its alloys must be used. Iron or nickel volatilise and the wire is destroyed in a few minutes. Even with platinum the volatilisation of the metal is serious at a bright-red heat. In addition, a certain tendency to become brittle with loss of metallic qualities, which is noticeable in ordinary platinum resistance furnaces, thermometers, and thermocouples, and which prevents their prolonged use at temperatures above 1200° C., appears to be far more marked and to take place at lower temperatures in the high vacuum, rendering occasional rewindings of the furnace necessary. The cause of this has not been fully explained. An examination of somewhat analogous phenomena in the case of nickel has been recently made by Dr. H. C. H. Carpenter in a paper read before Section G of the British Association this year, and attributed by him to gases in the nickel.* I am inclined to connect the phenomenon in the case of platinum with the vaporisation of the metal. If tantalum wire could be obtained, no doubt it would prove far more suitable than platinum. Naturally, a high vacuum within the apparatus tends greatly to conserve the heat and to diminish convection, and the risk of the outer vessel melting. In this respect the apparatus is the antithesis of the Dewar vessel for storing liquid air.

---

* 'Engineering,' August 17, 1906, p. 222.

IV.—*Absorption of Gases by Calcium.*

If the apparatus described, charged with a small piece of calcium, and furnished with a Plücker spectrum-tube, is exhausted by a Fleuss pump, and the furnace heated, gases, consisting of compounds of hydrogen, carbon, and oxygen are given out by the calcium. If connection with the pump is then shut off and the heating continued, absorption of the remaining gases, accompanied by volatilisation of the calcium, takes place, and the vacuum rises almost instantly to a point at which no discharge can be passed through the spectrum-tube. By a non-conducting vacuum is to be understood one of greater resistance than an alternative spark gap in air of 2 to 3 cm., unless the length of the gap is given.

If air is introduced into the apparatus, all but argon is rapidly absorbed, and quantities up to 10 or 20 c.c. can be thus dealt with. These experiments with air are, however, of interest from so many points of view that they will be dealt with in detail later.

In a similar way it was shown that carbon monoxide, carbon dioxide, water vapour, hydrogen, acetylene, sulphur dioxide, ammonia, and the oxides of nitrogen (nitric oxide, with deflagration of the calcium) are all as readily and completely absorbed as in the case of the oxygen and nitrogen of the air. Quantities of several cubic centimetres disappear within a minute after introduction, and the vacuum-tube becomes non-conducting.

Finally, in order to put the power of the calcium to as severe a test as possible, several successive quantities of coal gas, each of several cubic centimetres, were introduced into the apparatus after the absorption temperature had been attained. Within a minute after each addition the spectrum-tube became non-conducting to the discharge. Calcium thus acts as a universal absorber of chemically valent gases.

The case of hydrogen and its compounds alone calls for fuller treatment, for at too high temperature calcium hydride possesses an appreciable tension of dissociation. The same is of course true of calcium carbonate, but this compound does not appear to be formed when only small amounts of carbon dioxide are absorbed by the calcium. If hydrogen or its compounds are present in a gas in large quantity, the spectrum-tube, after the absorption of the other gases, shows still the hydrogen lines, and refuses to become non-conducting as long as the temperature of the furnace is maintained. But if the heat is reduced, the non-conducting stage is reached at once. In one experiment 1 c.c. of hydrogen was introduced, and the heat reduced. The spectrum-tube became non-conducting in 40 seconds.

Careful experiments have shown that even after cooling an infinitesimal quantity of hydrogen remains unabsorbed. Thus if, after cooling, mercury is allowed to fill the apparatus and compress the residual gas many hundred times into a tiny spectrum-tube, a very faint hydrogen spectrum can be seen, although the spectrum-tube, even after this concentration of the gas, is still of high resistance and fluoresces brilliantly under the discharge. This residual trace will be shown to be of great value in certain experiments.

A point of very great practical importance arises out of the dissociation phenomena of calcium hydride. Different commercial specimens of electrolytic calcium exhibit differences in their behaviour which I have traced to the presence of hydride in some specimens and not in others. The presence of this hydride quite alters the characteristics of the absorption process, and although with sufficient experience it is possible to get good results in spite of the presence of hydride, this experience is apt to be dearly bought. When hydrogen is present the real absorption temperature is apt to be overstepped, for instead of a non-conducting vacuum being obtained, as it should be almost instantly with a proper specimen of metal, the dissociation tension of the hydrogen is sufficient to enable the discharge to pass. An inexperienced operator, or one accustomed only to the character of the purer metal, will, in consequence, continually increase the temperature, and the tension of the hydrogen of course increases, and may ultimately become quite measurable on a gauge. Before it is realised that the proper temperature has been far overstepped, the metal may have melted, subsequently to crack the crucible on cooling, the platinum wire may fuse or volatilise, and even the glass envelope may soften. Whereas, if instead of increasing the temperature the heat had been cut off, the non-conducting stage would have been reached in a few seconds. It was noticeable that of two specimens, one excellent and the other containing hydrogen and unsuitable, the latter was by far the more malleable and could be always detected by this test after it had accidentally got mixed with the other specimen. But this difference of properties may not have been due to the presence of the hydride. No one would use metal containing hydride wittingly, but it is well to know that by cutting off the heat, when the spectrum of the gas becomes that of hydrogen, quite satisfactory results are attainable. But the sacrifice of time and apparatus, destroyed by excessive temperature, was considerable before the differences between the specimens of metal were suspected, and the differences of behaviour understood.

Experiments were tried to see if calcium which had been strongly heated and allowed to cool in an atmosphere of helium and argon, respectively, re-evolved any trace of these gases when reheated *in vacuo*, but in each case with negative results.

V.—*Behaviour of Barium and Strontium.*

Tested under the same conditions, barium and strontium show very analogous behaviour to calcium. The specimen of barium employed had been preserved under oil, and was in the form of a granular powder. It had been prepared from the amalgam and still contained mercury. It was given a preliminary heating *in vacuo* to remove oil and some of the mercury. It commenced to absorb gases without appreciable volatilisation at a temperature notably below that required in the case of calcium. A non-conducting vacuum was usually not obtained before the metal had been allowed to cool. In the work with both barium and strontium the hydrocarbon spectrum, reminiscent of the argon gases, was very frequently observed, and was probably due to traces of the oil in which the metals had been preserved. This spectrum usually appeared when the metal was hot, and disappeared on lowering the temperature, the vacuum becoming non-conducting. Coal gas was admitted to the heated barium to a pressure of 2 to 3 mm., and was rapidly absorbed, and a non-conducting vacuum obtained without difficulty. Air introduced to about 7 mm. pressure was rapidly absorbed, except for argon, exactly as with calcium.

Barium *can* be heated to its absorbing temperature in a hard glass tube by a Bunsen burner, but the tube collapses and cracks on cooling. Under similar circumstances calcium requires a blowpipe to induce volatilisation and absorption, and the tube is completely melted and flows round the calcium in the process.

Experiments with strontium were less complete on account of the difficulty of obtaining the real metal, and on account of the small quantities that had to be used. The first sample bought as strontium proved to be potassium amalgam simply, without sufficient strontium to give a precipitate with sulphuric acid. The metal, when it was obtained, proved to be similar in properties to barium and calcium. On account of the cost only a decigramme at a time could be used, and it is very probable that its behaviour, as observed, was partly due to presence of alkali metals, oil, and mercury, and that electrolytic strontium in compact form, free from these contaminations, would exhibit a behaviour even more nearly allied to calcium. So far it has not been possible to procure this. Absorption with the sample employed seemed to start at a slightly higher temperature than with calcium, and at a high temperature some volatilisation of the metal appeared to occur. This was due probably to a trace of alkali metal. It showed to a very marked extent the phenomenon of not giving a good vacuum until it had been cooled down, and of showing hydrocarbon spectra very strongly, but this behaviour might not be shown by an oil-free specimen. It seemed hardly worth while to pursue experiments with a metal at once so costly and so impure, when a commercial process has been patented for producing the metal on a scale similar to that of calcium. But the experiments proved that, like barium and calcium, it can absorb coal gas and air, and give a non-conducting vacuum without difficulty.

VI.—*Production of High Vacua by Means of Calcium.*

From what has been said it will be seen that the apparatus described affords a ready means of obtaining a high vacuum by the use of calcium as an absorbent. Arndt, in the paper referred to, suggested its use in the production of high vacua, on account of the energetic action of the vapour on the residual air. A little consideration, however, shows that since argon is not absorbed by the reagent, air must be as rigorously as possible excluded. As is well known, the real difficulty in the production of high vacua depends not so much on the removal of all the original air, which is comparatively easily and quickly accomplished even with a pump, but on the effective removal of the gases which are condensed on the glass walls of the vessel being exhausted, and which tend to recondense in the pump when driven out of the vessel, and to introduce a kind of steady vapour pressure until they have all been removed. The value of calcium as a means of producing the highest vacua depends on its power to absorb almost instantly the gases condensed on the glass walls as soon as the latter are expelled by heating. It is, as stated, necessary to replace all the air in the apparatus before the absorption with calcium takes place, or the residual argon will prevent the vacuum obtained from being really good. The importance of this is increased by the fact that articles for exhaustion have usually to be provided with a very constricted orifice, so that they can be sealed safely after the vacuum has been obtained. As a consequence, any argon accumulating in the absorption chamber dams back the flow of absorbable gas from the vessel being exhausted, and enormously increases the time required, as the contents of the vessels have to diffuse and mix through the constricted orifice, and this process may require some minutes. Hence, in this method of high vacua production, the customary precautions must be taken against the leakage of air, if really high vacua, as distinguished from the apparently high vacua later to be considered, are desired.

If a Fleuss pump in good order is available, and new glass apparatus which has not before been exhausted is being dealt with, it suffices to continue the pumping while the apparatus in question is heated in the usual way to expel condensed gases, and so utilise the latter to replace the residual air remaining in the apparatus. Or, if a new charge of calcium, not previously heated in a vacuum, is employed, the same displacement of the air can be readily effected by the gases given out by the calcium before it attains its absorption temperature. In both cases the gases consist chiefly of carbon and hydrogen compounds and, being free from argon, serve well for the displacement of the remaining air. In other cases, or where more certainty is desirable, the complete replacement of the air may be effected by the use of a side tube containing a mixture of potassium chlorate and manganese dioxide, which evolves oxygen on warming. One or two small quantities of oxygen are admitted during the pumping, and the connection with the pump closed or sealed off before the calcium is brought into action.

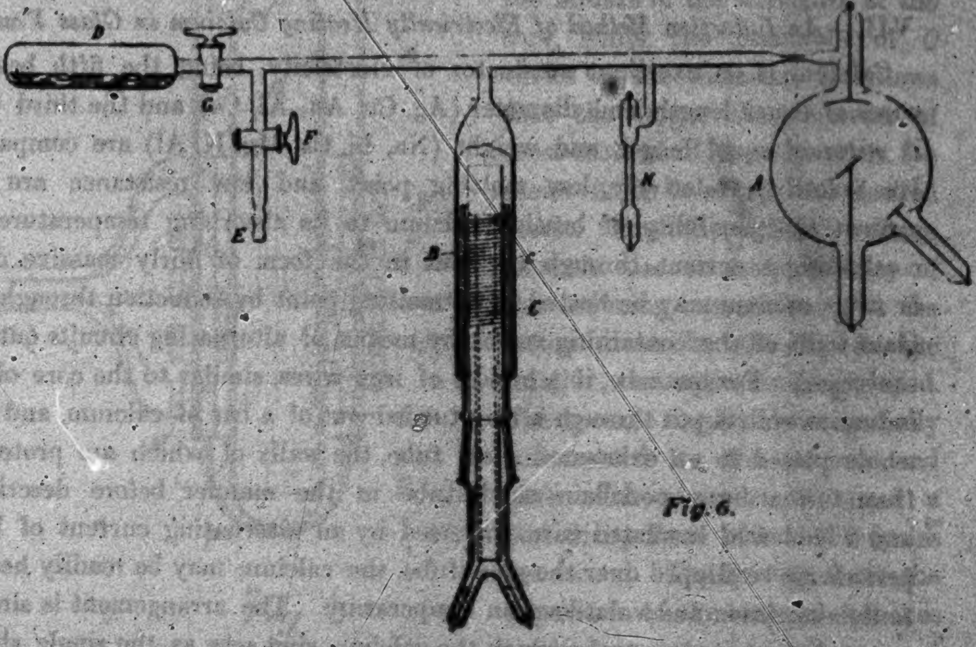


Fig. 6.

Fig. 6 shows, in diagram, an apparatus suited for the purpose of exhausting an X-ray bulb. *C* is the calcium heated by the platinum wire *c* within the glass vessel *B*. *A* is an X-ray tube, and *D* is a tube containing the oxygen mixture. The Fleuss pump is connected with *E*, and the spectrum-tube *H* is a convenience both for judging of the degree of vacuum and the character of the residual gas.

With this method, as in all methods of vacua production, the degree of rarefaction attained is the balance between the rate of absorption or removal of the gas present, and the rate of supply of fresh gas from leaks or from condensed films, or from substances such as lubricating grease or mercury which have a vapour pressure. Since the rate of absorption is extremely rapid, good results can be obtained even under poor conditions. Conditions have to be very bad indeed for any difficulty to be experienced in the production of a so-called "X-ray" or "non-conducting" vacuum. But it will be shown in the sequel that these electric discharge phenomena may be produced in vacua which could not be described as high in any other sense. With proper care the very highest vacua may be obtained by the use of calcium, as is proved by the experiment quoted in Section IV, of filling the apparatus with mercury and compressing the gaseous contents several hundred times. Personally, in crucial experiments, I should use it preferably to any other, and in the research on the positive charge carried by the α-particle* it was the final court of appeal, by which results obtained by other methods were always retried.

VII.—*An Induction Method of Electrically Heating Calcium in Glass Vessels.*

Calcium is an excellent conductor of electricity, being the fifth best if wires of equal length and diameter (Ag, Cu, Au, Al, Ca), and the third best if wires of equal length and weight (Na, Li, Ca, Mg, K, Al) are compared. Its volatility, relatively low melting point and low resistance are all against the possibility of heating calcium to its absorbing temperature by conducting a current through it. But in the form of fairly massive discs or rings calcium may be heated to its melting point by induction through the glass walls of the containing vessel by means of alternating circuits outside the vessel. For instance, if a bundle of iron wires, similar to the core of an induction coil, is put through a ring turned out of a bar of calcium, and the whole placed in an exhausted glass tube, the walls of which are protected from fusion by a porcelain shield-tube in the manner before described, and a bobbin of insulated wire traversed by an alternating current of high periodicity be slipped over the glass tube, the calcium may be readily heated to its absorption and volatilisation temperature. The arrangement is simply a step-down transformer, in which the calcium ring acts as the single short-circuited winding of the secondary, and, being of low resistance, a fraction of a volt induced in it by the magnetic flux suffices to cause the passage of a heavy current, probably of the order of a kilo-ampère, which heats it to the required high temperature. Fig. 7 shows one arrangement for this purpose.

Fig. 8 is a transverse section on the line *ww*. The iron core *M* is enclosed in a thin tube of Jena glass *P*, which is exhausted and sealed. This tube effects the double purpose of protecting the iron from excessive heat and retaining gases given off from the iron, but can be dispensed with. *C* is the calcium ring, *K* is the porcelain shield-tube, *B* is the outer glass containing tube, *N* is the external circuit through which the inducing current is passed. As the heat given out from the calcium is considerable and apt to injure insulating material, it is convenient to employ, instead of a bobbin of insulated wire of many turns, a few turns of stout, bare, copper bar or tube, and to obtain the inducing current from the secondary of a step-down transformer not shown in the drawing. Since the magnetic flux, and therefore the inducing voltage in *C*, varies as the square of the diameter of the core, while the resistance of *C* varies as the diameter, it follows that the larger the diameter of cross-section of the apparatus the easier it is to obtain the desired result. But the induced voltage depends also on the periodicity of the inducing current, so that the latter must be the higher the smaller the apparatus employed. The dynamo employed was specially constructed for the purpose and gave with variation of speed a periodicity from 200 to 400 cycles per second. The drawing shows the apparatus to the scale of 6 inches to the foot.

---

* 'Nature,' August 2, 1906, p. 316.

Fig. 7.

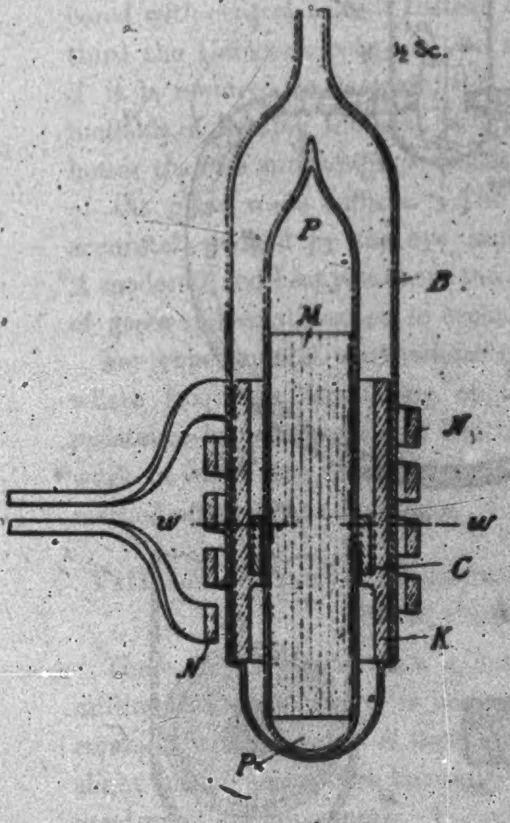
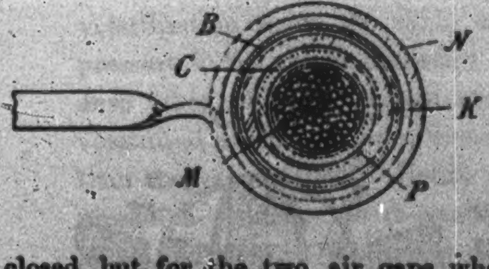


Fig. 8.



Another form of apparatus is shown in fig. 9, to the scale of 3 inches to the foot. It differs from the last mainly in that the magnetic circuit, composed of the iron strips or wires *M*, *M* *M* *M*, is closed but for the two air gaps where the glass walls of the containing vessel penetrate it. The use of the step-down transformer is unnecessary, because the inducing bobbins, represented diagrammatically by the circuit *N N N N*, are far enough removed from the source of heat not to be damaged

Fig. 9.

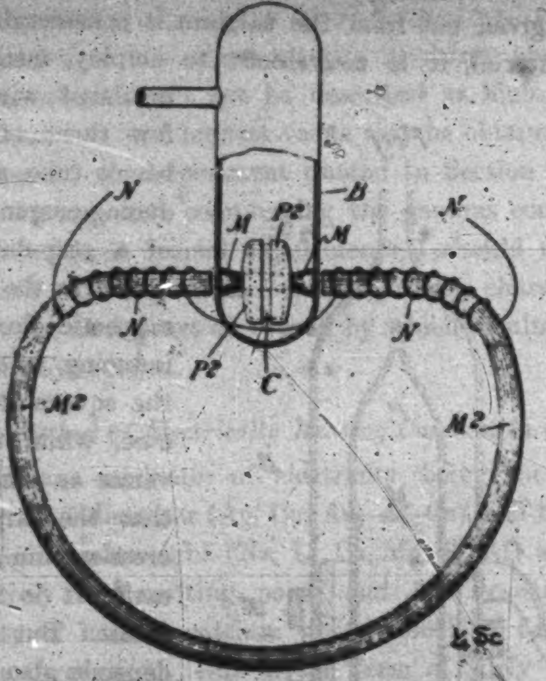

N
B
M
P²
M
N
N
N
P²
C
M²
M²
½ Sc

Fig. 10.

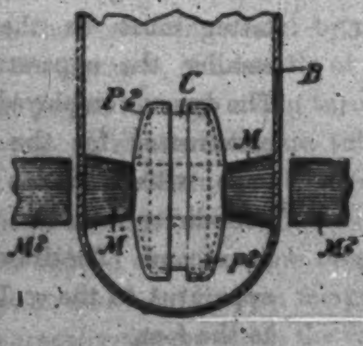

P²
C
B
M
M²
M
M²
P²

Fig. 12.

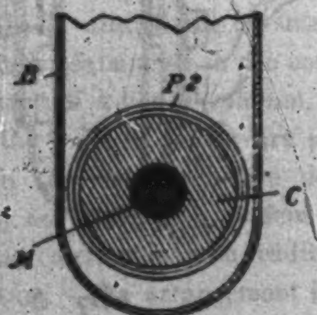


Fig. 11.

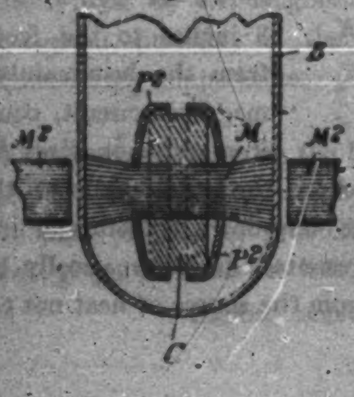
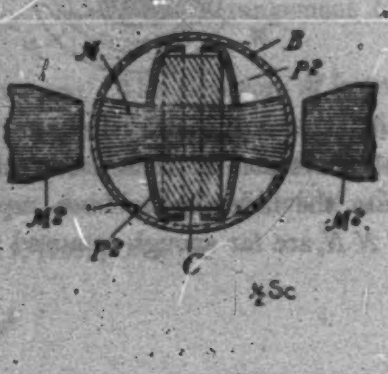

P²
B
M²
M
M²
P²
C

Fig. 13.


N
B
P²
M²
M²
P²
C
½ Sc

The part within the glass containing vessel is shown to twice the scale (6 inches to the foot) in fig. 10. Fig. 11 is a section of the same. Figs. 12 and 13 are transverse sections in vertical and horizontal planes respectively. *C* is a disc of calcium bored with a central hole, through which passes the bundle of iron wires *M M*. P_2 P_1 are two porcelain crucible lids bored with central holes. Instead of the disc of calcium shown, a disc one-third the thickness between two similar discs of copper may be employed if it is required to increase the conductivity. Since in these induction methods of heating the heat is developed in the reagent itself, the latter is hotter than its surroundings, which is a great advantage, as far less screening of the glass walls suffices. The temperature of the metal can be very accurately judged by the eye, and must be kept below the melting point. A moderate red-heat just above the cherry-red stage is necessary for absorption of gases and volatilisation to occur.

For experimental work where cost is not the primary consideration, and where frequent dismantling of the apparatus is rendered necessary, the resistance-furnace method of heating is to be preferred. But for prolonged work in which the object is simply to obtain a high vacuum, the induction method offers great advantages.

VIII.—*Some Practical Considerations in the Use of Calcium as an Absorbent for the Production of High Vacua.*

There is no doubt that a low initial pressure, not exceeding a few millimetres of mercury, is as essential a condition in causing calcium to combine with gases as a high temperature. As Arndt showed, there is a slight initial absorption below the volatilisation temperature, and this is of great practical importance. For rapid and continuous absorption volatilisation is essential. But in a case where the initial pressure is above that at which volatilisation occurs the slight initial action is often sufficient to lower the pressure to the extent necessary for the formation of vapour. When this has once taken place subsequent absorption is much facilitated, for the film of volatilised metal continues, even in the cold, to absorb, although more slowly than the vapour itself. Hence once volatilisation has taken place there is present a tendency to re-establish the condition for further vaporisation. When, however, a mixture with an unabsorbable constituent, for example, air, is being absorbed, the accumulation of this constituent hinders the volatilisation and further absorption by the calcium. Another factor operating in the same direction is the increased loss of heat by convection currents in the presence of a gas, tending to lower the temperature of the reagent and furnace, and to lower the resistance of the latter. In the usual case, where this resistance is small compared to the external resistance in the circuit, the fraction of the electrical energy dissipated within the furnace is also lowered, and so the temperature falls from a double cause. If water vapour is present the action becomes extremely marked on account of the great conductivity of this vapour to heat. The current necessary to raise the temperature in this case may be so great that, unless promptly reduced when absorption commences, the heating circuit is apt to be destroyed.

Under proper conditions of working the calcium should never be melted, although it may be volatilised completely and redeposited on the cooler part of the tube as a compact tube or ring difficult to remove by mechanical means. Used porcelain tubes should never be exposed to the air or treated with water or dilute acids, as they readily crack under this treatment. Immersion in concentrated hydrochloric acid usually serves to dissolve the volatilised metal without cracking the tube, but with the liberation of the spontaneously inflammable silicon hydride. If the calcium is melted in the tube the latter usually cracks on cooling, so that for many reasons suitable iron tubes would be better than porcelain. The narrow margin of temperature, 70° C. according to Arndt, between the volatilisation and melting point need, however, never be exceeded when experience has been gained and suitable metal is employed. The presence of hydride in the metal acts so prejudicially largely because the dissociation tension of hydrogen lessens the volatilisation and reduces still further this narrow margin, so that the melting point is the more likely to be overstepped. These conclusions as to the conditions under which calcium should be employed as an absorbent have been arrived at after over a year's continuous use of the method.

The following experiment on the effect of vapour of grease and of a very constricted orifice between the vessel being exhausted and the absorption chamber is instructive. An X-ray bulb was connected to the calcium absorption apparatus provided with a ground-joint. The latter was lubricated by the well-known mixture of rubber, paraffin-wax and vaseline, employed by Sir W. Ramsay. A spectrum-tube was provided and the apparatus exhausted by the Fleuss pump, and the connection with the latter sealed off. The calcium was brought into action and a vacuum corresponding to an alternative spark-gap of 15 cm. obtained in the X-ray tube. It was then left over night in connection with the furnace, so that the vapour from the grease of the ground-joint could exert its full effect. In the morning the vacuum was so low that there was no trace of green fluorescence in the tube. The calcium was heated and allowed to cool. In 40 minutes the 15-cm. alternative spark-gap was again attained.

Then, hour by hour, the vacuum slowly deteriorated till the alternative spark-gap was *nil* and the green fluorescence disappeared. This process of heating the calcium and leaving till the vacuum went right down was repeated day by day for a week. It was noticed that it always took 40 minutes after heating the calcium before the 15-cm. spark-gap was regained, and this period represented, as numerous experiments with the same tube show, the time taken by the gases to flow out of the X-ray bulb through the constricted orifice when a practically perfect vacuum existed on the other side. It happened that the constriction was unusually and unnecessarily narrow, such as an amateur not realising the importance of it would make, but the necessity of this constriction, where the tube is ultimately to be sealed off, imposes a natural limit on the time taken for the exhaustion, however rapid a method of absorption is employed. In this experiment the spectrum in the Plücker tube, when the vacuum was low, was due to hydrocarbons, and nitrogen was never seen. That there was no appreciable leak of air was also shown by the fact that even at the end of a week no lines of argon could be seen. This shows that the deterioration of the vacuum was simply due to vapour being slowly given off from the grease used for lubrication. A properly constructed ground-joint is wonderfully air-tight. I may mention that in 1904 I constructed one of Strutt's so-called radium clocks with a ground-joint similar to those employed in the furnaces. The period of the clock is the same now as when constructed, and it has worked continuously without re-exhaustion, proving conclusively that no trace of air has leaked through the ground-joint. Hence, in the calcium method, where the vapours of lubricants are absorbed with rapidity, as many taps, ground-joints and similar conveniences as desired may be employed without harm, provided they are well lubricated and never get heated, and that the apparatus being exhausted is sealed off as soon as the high vacuum is attained.

IX.—*Quantity of Argon Detectable by the Spectroscope.*

If air is admitted to heated calcium the oxygen and nitrogen are absorbed almost instantly, and the argon and its companions in the atmosphere remain behind in a state of great purity and freedom from ordinary polyatomic gases. In the apparatus used an arrangement of two taps for admitting known small quantities of gas was joined to the apparatus for the absorption of gases by calcium. The space between the taps was 0·13 c.c. and the total volume of the apparatus was 123 c.c. The partial pressure of argon is 0·0094 of the atmospheric, or 7·1 mm. Each quantity or "dose" therefore of 0·13 c.c. of air admitted to the apparatus corresponds to a pressure of argon of 0·0075 mm. of mercury. The vacuum-tube employed was an ordinary Plücker tube, with aluminium electrodes, of about 4·5 c.c. capacity. It was found that no trace of the argon spectrum could be seen in the tube, and no discharge would pass through until three doses of air had been admitted and absorbed. At this stage the group of greens and the orange line in the spectrum were faintly visible. With four doses the red lines were visible momentarily as the nitrogen spectrum faded, and with five doses these became permanent. After 10 doses (1·3 c.c.) of air had been introduced, the whole argon spectrum was brilliant; 4·5 c.c. were so added in small quantities and then 3 c.c. at once. In one minute the nitrogen spectrum began to clear and 1·5 minutes the argon reds were visible. In two minutes nitrogen had disappeared, and in under three minutes only argon and hydrogen were visible. The hydrogen disappeared when the heat of the furnace was reduced and the tube, giving a perfect argon spectrum, was sealed off as a memento of the experiment.

In another experiment the volume of the apparatus was 100 c.c., and 12 c.c. of air were admitted in one quantity after the calcium had been heated *in vacuo* to the absorbing temperature. This was absorbed without difficulty. The residual argon must have exerted about 1 mm. pressure. Yet the spectrum-tube showed brilliant green fluorescence. A tap was opened and the argon allowed to flow into a similar volume of 100 c.c. which had previously been perfectly exhausted. The pressure was thus reduced to about 0·5 mm., and at this stage the spectrum-tube had a resistance equivalent to an alternative spark-gap of 5 mm.

It follows from these experiments that below a pressure of 1/50 of a millimetre no discharge can be sent through a tube containing argon. At this pressure the greens and orange become faintly visible, and at 1/25 of a millimetre the reds appear. At 0·5 mm. the resistance of the tube is still so high that the discharge prefers to jump an air-gap 5 mm. long, while at a pressure of 1 mm. the tube is brightly fluorescent.

It was found that the substitution for the ordinary vacuum-tube of one of minimal volume with platinum electrodes did not much affect the pressure of gas at which the spectrum became visible. With a tube of 0·3 c.c. volume, which is as small as it is convenient to employ, a quantity of argon less than 1/100 of a cubic millimetre, measured at normal temperature and pressure, could not be detected by the spectroscope. This applies to the pure gas in the absence of almost every trace of the relatively far more conducting polyatomic gases. As in the case of helium, to be considered, smaller quantities of argon could be detected in presence of hydrogen or other polyatomic gas.

X.—*Misapprehensions Regarding High Vacua.*

The foregoing experiments with argon, and others of a similar character with other monatomic gases, serve to show that the characteristics of the electric discharge may prove a very faulty guide to the degree of a vacuum. The terms "X-ray vacuum," "fluorescent vacuum," etc., afford, apart from the knowledge of the character of the residual gas, no indication at all of the actual pressure. For if it happens that the residual gas is a pure monatomic gas, the fluorescent stage and even the non-conducting stage are reached at pressures within the range of the mercury barometer. These considerations serve to connect numerous isolated facts familiar to those who have worked with high vacua. Thus it is well known that to pump out a spectrum-tube with a mercury pump takes far less time if the gas pumped out is argon or helium than if air or hydrogen has been present.

[*Added.*—It is also well known that in vacuum-tubes filled with inert gases great heating of the electrodes occurs, even when these are made of aluminium, accompanied with the rapid disintegration of the electrode and the volatilisation of the aluminium. At the same time a rapid exhaustion of the supply of gas apparently takes place, the vacuum appears to rise, the tube rapidly becomes fluorescent with use, and the resistance increases to the non-conducting point at which no discharge can be passed through the tube. In the past this has been attributed to the absorption of the gas by the electrodes and the walls on which the volatilised aluminium is deposited. The advantages of aluminium over other metals, such as platinum, have been ascribed to a more rapid absorption in the case of the heavier metals.[†] Attempts to recover the gas supposed to be absorbed, by heating the apparatus, solution of the metal electrodes, etc., have not been successful, as only a trace of the gas is recovered in this way.

The true explanation of the phenomenon is quite different, and follows simply from the experiments given in section IX for argon, and similar ones in sections XI and XII for helium. The inert gases are not absorbed, but remain in undiminished quantity in the gaseous state in the tube, but the traces of ordinary chemically active gases always present, initially or introduced from the electrodes during the discharge, are absorbed, and the tube becomes in consequence non-conducting. The experiments of Skinner have an important bearing on this question, and in his most recent paper[‡] he summarises his conclusions. When a current is passed through a vacuum-tube, entirely independently of the nature or amount of gas filling the tube, hydrogen is evolved from the cathode and absorbed by the anode at a rate initially equal to that required by Faraday's law. Aluminium and magnesium cathodes give out hydrogen much more freely than the denser

---

[*] Compare, for example, E. C. C. Baly, 'Phil. Trans.,' A, 1903, vol. 202, p. 183.

[†] Compare Travers, 'Study of Gases,' p. 299.

[‡] 'Phil. Mag.,' November, 1906, p. 481.

metals, but the rate of *evolution* from the cathode rapidly falls off as the supply of gas in the surface layers of the metal is exhausted. If the tube is allowed a rest the initial rate is recovered. When a continuous discharge is passed through any tube, therefore, the vacuum improves, for the rate of absorption by the anode gains on the rate of evolution from the cathode, and this should suffice to explain the well-known improvement with use in the vacuum of an X-ray tube. According to Skinner, helium and argon are *not* absorbed by the electrodes, hence the rapid exhaustion or "running out" of the tube and the advantages of the aluminium electrode are to be explained only in the manner indicated. It is intended to try, by passing a unidirectional current through a tube filled with inert gas, to what gas pressure the non-conducting stage can be pushed. It is not a little remarkable from the theoretical point of view that helium, which conducts so much more readily than any other gas under usual conditions at high pressure, should exhibit the peculiar behaviour it does at low pressure in a state of purity.

Frequently in the work on the production of helium from radium, in conjunction with Sir William Ramsay, it was noticed when "running" a spectrum-tube to absorb nitrogen and reveal helium, if present, that, although a severe and prolonged running might be necessary to absorb the nitrogen, it always "ran out" first, and helium, however minute in quantity, showed itself, if present, as the nitrogen spectrum faded. When, however, the nitrogen spectrum had completely faded, which it did usually with great rapidity once it commenced to weaken visibly, the helium "ran out" almost instantly, if only in minute quantity, and the tube refused to conduct the discharge. This sharp preferential absorption, as it seemed, of the nitrogen first by the electrodes, so that, even after a quarter of an hour's hard running, the helium would survive, instantly to disappear as soon as the nitrogen faded, always seemed to me almost providential, until, recently, the true explanation became obvious.]

The explanation is also to hand why the presence of mercury vapour affects the action of the mercury pump so little. The vapour pressure of mercury at room temperature is between 1/500 and 1/1000 of a millimetre. In the case of hydrogen or carbon dioxide it is probable that this pressure would be sufficient to conduct the discharge and prevent the vacuum appearing very high to the electrical test. That "high vacua" can be obtained at all by the mercury pump is probably due to the fact that mercury vapour is monatomic.

Similar considerations apply to the vacua so readily and simply obtained by the use of charcoal cooled in liquid air according to the method now largely used in scientific investigation and first employed by Sir James Dewar.[*] It

---

[*] 'Roy. Soc. Proc.' A, 1904, vol. 74, pp. 122—131.

happens here also, as in the case of the calcium method, that the unabsorbed gases are monatomic. At liquid air temperature the helium and neon in the air remain very largely unabsorbed by charcoal. Sir W. Ramsay* has determined in this way the proportion of these gases in the atmosphere and found 17 parts per million of the two gases together. An earlier determination made by Dewar,† without the use of charcoal, was identical with this. The figures obtained by Ramsay, however, are for the total gases left uncondensed by charcoal at liquid air temperature, and have a direct bearing on the present question. Now, as Lord Blythswood and Allen‡ have shown, there is no difficulty in exhausting an X-ray bulb by the use of cooled charcoal from atmospheric pressure to the point at which it is difficult to force a discharge through the bulb. Yet the pressure of the helium and neon in the bulb must be 17 millionths of the initial pressure or about 1/75 of a millimetre. This result, although appearing strange by itself, is consistent with the experiment on the pressure of argon necessary to allow the discharge to pass. When any method of measuring the amount of gas remaining in the exhausted space other than the electrical is employed, the deficiencies of the non-conducting vacuum produced by cooled charcoal, when the vessel was originally filled with air at atmospheric pressure, become at once apparent. If, for example, the degree of vacuum obtained is measured by the rate of evaporation of liquid air in a Dewar flask, then the presence of these residual monatomic gases becomes all important. Experiments of a quantitative character on this subject are being made by Mr. Berry§ in this laboratory.

[*Added.*—Lord Blythswood and H. S. Allen‖ after showing, in the first part of their paper, that an X-ray bulb could be exhausted by cooled charcoal from atmospheric pressure in one hour to "a vacuum so good that the tube had to be heated in order to allow the discharge to pass through it," describe in the second part experiments in which the final pressures realised were measured by means of a McLeod gauge. When the apparatus was exhausted by a Fleuss pump initially to 40 mm., the final pressure attained was 0·0008 mm., whereas, starting from a pressure nearly atmospheric, the final pressure attained was ten times as great. They point out the importance of the preliminary exhaustion when an extremely high vacuum is required, owing to the presence of the less easily condensible gases, hydrogen, helium, and neon, in the air, but do not refer to the apparent inconsistency between the results with the McLeod gauge and their earlier ones with the electric discharge test.

---

* 'Roy. Soc. Proc.,' A, 1905, vol. 76, p. 111.

† 'Roy. Inst. Proc.,' 1902, vol. 17, pp. 223—230.

‡ 'Phil. Mag.,' October, 1905, p. 497.

§ See addendum to this paper.

‖ *Loc. cit.*

I was present at the meeting of the Philosophical Society of Glasgow (March 22, 1906), when Mr. Allen showed experimentally the exhaustion of an X-ray bulb from atmospheric pressure by cooled charcoal, and I was much impressed at the time with the apparent inconsistency between this result and the recent measurements of Sir W. Ramsay already cited.

The allusions in this section to the results of use of the charcoal method have reference solely to the phenomenon of the bad conducting quality of the residual inert gases that remain when air is absorbed from atmospheric pressure by use of charcoal or other methods. The question of the degree of vacuum produced under proper conditions for obtaining the best results is, of course, entirely different. Although the test of non-conductance, which has, so far, been relied upon too implicitly for gauging the goodness of the vacuum,* is useless, and may be actively misleading in the case of vacua obtained by the use of cooled charcoal without preliminary exhaustion by a pump, there is no doubt at all that, with suitable procedure, this method can give a very high degree of exhaustion.†]

XI.—*Quantity of Pure Helium Detectable by the Spectroscope.*

Mixtures of known composition were made of helium and oxygen, and known quantities introduced into the calcium absorbing apparatus of known volume. The pressure of the residual helium could thus be calculated. In one case 0·13 c.c. of helium was made up to 104 c.c. with oxygen, so that the mixture contained 1/8 per cent. of helium. Successive quantities, each of 0·13 c.c., were introduced into the apparatus, the volume of which was 89 c.c., including an ordinary Plücker tube of volume 4·5 c.c. The following observations are extracted from the note-book. The "quantities" referred to are each 0·13 c.c. of the mixture, and the test of non-conductance was an alternative spark-gap of 2·5 cm. in air.

1st quantity.—Glimpse of D_3 for a fraction of a second as the oxygen spectrum suddenly cleared and tube became non-conducting.

2nd quantity.—D_3 clear while the tube conducted, which was but momentarily.

3rd quantity.—D_3 very pure and distinct, but tube became non-conducting.

5th quantity.—D_3 at first brighter than the mercury yellows.

6th quantity.—D_3 the brightest line at first except for the oxygen orange-red line.

---

* Compare also G. Claude and René J. Lévy, 'Comptes Rendus,' 1906, vol. 142, p. 876.

† *Cf.* the experiments described by Mr. Berry in the addendum to this paper.

7th quantity.—Just before the non-conducting point the general spectrum was plainly recognisable as helium.

8th quantity.—The brighter helium red (6677) visible.

9th quantity.—The two blues and violet seen.

10th quantity.—First glimpse of the peacock-green line (5016).

Tube took four minutes before it became non-conducting.

11th quantity.—Eight minutes before non-conductance.

13th quantity.—The helium spectrum was now quite good while it lasted, but the tube became non-conducting in three minutes.

The experiment was continued without much alteration up to the point at which 35 quantities had been added. The helium spectrum was plain, and indeed brilliant, so long as the tube conducted, but always a point was reached at which the discharge refused to pass. Diffusion was hastened by alternately heating and cooling the furnace. At the 35th quantity the tube conducted one way of the commutator and not the other, and this was taken as the limiting value. Later in the day and next morning the tube showed the same result. The discharge just passed, but the spectrum was feeble. The line D_3 was clear and the peacock-green exceedingly faint. These were the only helium lines visible.

The pressure of helium corresponding to each dose is 0·0014 mm. and to 35 doses 0·049 mm. It is thus clear that pure helium at a pressure of less than 1/20 mm. is non-conducting to the discharge, while far less than this can be detected in presence of other gases. Like mercury vapour and krypton, a very small trace is visible in the spectrum of another gas. In the above experiments the D_3 line was visible plainly when only a single dose was added, so that to get the minimum quantity detectable a fresh series of experiments with more dilute mixtures was necessary.

XII.—*Most Favourable Conditions for the Detection of Infinitesimal Quantities of Helium.*

Collie* states that in presence of large quantities of mercury vapour the blue helium line, 4922, is the most delicate test for helium, and can easily be seen when none of the other helium lines are visible. It is likely, however, that the author mistook for helium a line in the spectrum of mercury which has the wave-length 4916·4 (Stark) and which is prominent in the mercury vapour-lamp spectrum. It is not often seen in the Plücker tube, except when the latter is warm and liquid mercury is present, so that the vapour pressure of the mercury is considerable. Collie has suggested for the calibration of spectroscopes a tube containing liquid mercury, helium and hydrogen, as the spectrum consists of a large number of standard lines fairly equally distributed throughout the length of the spectrum. In such a tube I kept the blue line in question under close observation in a good spectroscope. With a feeble discharge, the tube cold and the mercury spectrum faint, this line was single and due to helium only. As the strength of the discharge was increased, and the tube warmed, the mercury spectrum intensified, and a second line became visible on the more refrangible side of the helium line and distant from it roughly about as far as D_3 is distant from D_2. On still further increasing the strength of discharge the helium line disappeared entirely, and the line was again single and due to mercury only. On diminishing the discharge and allowing the mercury vapour to recondense, the less refrangible line reappeared and grew in strength as the other faded, and finally alone remained visible. Thus, it is clear that so far from enhancing the strength of the helium line, 4922, the presence of mercury serves to mask it completely even in presence of considerable quantities of helium. This line, 4916, is seen equally well in a tube containing mercury in which no helium has been introduced. Under no conditions tried has the line 4922 been seen when D_3 was invisible. The latter is by far the most delicate test for the presence of helium, and becomes visible with a quantity many times less than suffices to develop any other line in the spectrum.

---

* 'Roy. Soc. Proc.,' 1901, vol. 71, p. 25.

Some experiments with various kinds and sizes of spectrum-tube, some with aluminium and others with platinum electrodes, showed that with minimal quantities of helium at similar *pressure* it is slightly easier to detect the D_3 line in the ordinary Plücker tube of volume 4·5 c.c. than in a tube of minimum volume. But the difference is not great, and is mainly due to the sodium lines from the glass being more prominent in a tiny tube masking the D_3 line. Certainly, when the object is to detect the smallest possible *quantity* of helium, the tube should be of as small volume as possible. A series of experiments was tried in which quantities of helium, far smaller than those necessary to allow the discharge to pass when in the pure state, were examined in presence of hydrogen and oxygen. A mixture containing 0·015 per cent. of helium with oxygen was prepared by the principle of successive dilutions. Known quantities were introduced into the calcium absorption apparatus of known volume. After the oxygen had been completely absorbed, connection between the spectrum-tube and the absorption chamber was closed, and traces of oxygen and hydrogen introduced into the gas in the spectrum-tube. This was accomplished by heating a trace of solid potash, previously fused and freed from water, *in vacuo*, or by momentarily raising to redness a spiral of platinum wire by means of a current. It does not appear to make much difference which gas is added to conduct the discharge. After the first momentary heating platinum gives oxygen free from hydrogen. The potash gives hydrogen, doubtless as water vapour. The function of this gas is merely to cause the discharge to pass. Once established, a large part, perhaps the larger part, of the current is carried by the helium, the spectrum of which, under these conditions, appears with extraordinarily minute quantities.

With an ordinary Plücker tube and an apparatus of volume 111 c.c. after three doses, each of 0·13 c.c. of the 0·015-per-cent. mixture, D_3 was but momentarily visible, and could not be again brought out by introducing oxygen or hydrogen. With four doses D_3 was faint but clear and permanent, and this may be taken as the extreme limit of visibility. The partial pressure, due to the helium at this stage, is only 1/100 of that necessary to conduct the discharge when pure, being 0·0005 mm. as compared with 0·05 mm. for the case of the pure gas discussed in the last section.*

If a vacuum-tube of 0·3 c.c. volume is used, it follows that a quantity of helium, 1/4000000 part of a cubic centimetre, measured at normal temperature and pressure, would be within the range of detection by the spectroscope. For safety a margin of twice this quantity should be allowed, or 1/2000 of a cubic millimetre. This quantity weighs 10^{-10} gramme, and contains about 2×10^{13} atoms. The delicacy of the test may be indicated by the following consideration. It can be calculated on the assumption that the α-particle is an atom of helium, that a kilogramme of uranium nitrate would generate 1 c.c. of helium in a period of about 5000 years. The amount of helium produced in a single day should be within the range of spectroscopic detection. Researches on the production of helium from uranium and thorium have been in progress for some time, and it is hoped, now that the ground is cleared, that the matter will soon be put to a definite quantitative test.

In the above experiments the actual quantity of helium used was, of course, many times the amount finally examined in the spectrum-tube. It is easy, however, to fill the absorption chamber after cooling completely with mercury, and to compress the gas into the spectrum-tube. In this operation the minute quantity of hydrogen left unabsorbed by the calcium is, after the compression, just of the right amount to conduct the discharge and to reveal any trace of helium without any additional arrangement.

---

* [The point was raised in the discussion of the paper, how far it had been actually proved that the inert gases were not absorbed, at least in part, by the walls and electrodes. The last experiment answers this question, for in a tube containing only one-hundredth of the quantity of helium necessary to conduct the discharge in the pure state, the helium spectrum may be brought out afresh by introducing a minute quantity of hydrogen or oxygen, which would not have been the case if the helium had been absorbed when the tube became non-conducting.]

As an example of an actual experiment, one may be taken from the note-book from an examination of the gases present in native platinum. On the view that the scarcity of an element, after prolonged and extensive search for it, justifies the suspicion that it may be a member of a disintegration series, it was thought possible that evidence of such disintegration might appear in the presence of rare gases in platinum, as is the case with the radio-active minerals. Messrs. Johnson and Matthey very kindly lent me as much native platinum as required, and I desire to acknowledge my indebtedness to them for their kindness.

In one experiment a quantity of about 300 grammes was heated in a porcelain tube in an electric oven to 1200° C., and the gases passed into a calcium absorption chamber of the usual kind provided with a tiny spectrum-tube at the upper end. A trace of carbon dioxide, from the walls probably, first came off. Then nitrogen appeared, and, as the temperature approached 800° C., carbon dioxide in quantity. On closing the connection with the platinum and absorbing the gas with calcium, the spectrum-tube became quite non-conducting. These operations were repeated, the gas evolved being admitted and absorbed in stages. When the electric oven had reached a temperature of 1000° C., a momentary glimpse of the D_3 line was seen. At 1100° C. the peacock-green line was picked up, and the more prominent of the two reds seen extremely faintly. On forcing the discharge the argon greens could be faintly made out in a Ramsay pocket spectroscope. When the oven reached 1200° C., a large quantity of carbon dioxide had accumulated. This was admitted to the absorption chamber, and the connection sealed and the heating of the platinum stopped. On cooling the calcium after absorbing the gases, the spectrum-tube was on the verge of non-conductance, but extremely faint helium could be detected. Mercury was admitted and the contents compressed completely into the tiny spectrum-tube. The helium spectrum was now reasonably bright, all the lines being visible, together with the hydrogen red and the mercury lines. With the pocket spectroscope argon could just be detected. It was estimated from the appearance of the discharge at various stages of the compression that about 1/5 of a cubic millimetre of helium was present, a quantity 400 times as much as could have been detected, yet only representing 1/15000000 per cent. by weight of the platinum. The experiment lasted but two hours, and is given merely as an example of the ease with which an infinitesimal quantity of helium may be separated from large amounts of other gases by means of calcium, and its quantity estimated with fair probability. No weight is to be put on the result as indicating the origin of the helium. As a matter of fact, the native platinum was quite distinctly though feebly radio-active, 300 grammes of it in an electroscope producing an effect equivalent to 0·07 milligramme of uranium oxide. Clevite usually contains about 2 c.c. of helium per gramme, and is usually of about the same activity as uranium oxide. The platinum contained about 3,000,000 times less helium, and was about 4,000,000 times less radio-active than clevite, so that there is no reason to go further to explain the source of the helium than to suppose that a trace of some radio-element is present in native platinum.

Appendix.—*Results of Gauging High Vacua by the Evaporation Test.*

By Arthur John Berry.

In this note the results of some experiments, on the rate of evaporation of liquid air contained in a Dewar vessel exhausted in different ways, are described with the view to showing that this test may be used as a means of gauging the degree of vacuum produced by different processes. Owing to various causes the research has not been carried as far as it was intended, but one set of measurements, complete in themselves, have been obtained, which bear out in a clear manner one of the points discussed by Mr. Soddy in the paper preceding. Starting with a vessel filled with air at atmospheric pressure, there is no difficulty, by using the method of Sir James Dewar to produce a vacuum therein, in obtaining a vacuum apparently perfect, so far as the electric discharge test can indicate, provided that a sufficiency of charcoal is employed. It was of interest to compare the rate of evaporation of liquid air in a Dewar vessel exhausted in this manner with the rate in the same vessel exhausted also by Dewar's method, but in which the air had been first removed by an auxiliary pump. Although the electrical test reveals no difference in the degree of vacuum obtained in the two methods, it is to be expected that the thermal test will show a far higher vacuum by the second method than by the first, owing to the residuum of non-conducting inert gases left by the first method.* This expectation has been fully borne out by the experiments.

The vessel employed was of about 1 litre capacity, globular in form, and silvered on the two inner walls. During the exhaustions it was placed in an inverted position in an air oven, and the temperature maintained at

---

* Compare Lord Blythswood and H. S. Allen, 'Phil. Mag.,' October, 1905, p. 497.

350° C. A vacuum-tube served to indicate the progress of the exhaustion. At the completion of each exhaustion it was filled with liquid air, and kept in an ice chest to keep the external temperature constant. The vessel was weighed at regular intervals to determine the rate of evaporation of the air. Three different methods of exhaustion, designated throughout I, II, III, were employed.

I. In the first the exhaustion was performed by the mercury-pump. A Töpler pump of ordinary pattern, worked by hand, was used, and pumping was continued from four to five hours while the vessel was heated in the air oven. The pump had a capacity of about 450 c.c., and was provided with a phosphorus pentoxide tube and tap. The results of two similar experiments agreed well among themselves, and in the table the second of the two, which was slightly the better, is alone included.

II. In the second method the apparatus was exhausted from atmospheric pressure by cooled charcoal. As in the experiments of Lord Blythswood and H. S. Allen,* two separate charcoal bulbs were employed, the one with 97 grammes and the other with 70 grammes of charcoal freshly prepared from cocoanut shells. The first bulb alone reduced the pressure from atmospheric to the fluorescent stage in 30 minutes, and was then cut out and the second bulb brought into action. The absorption was continued one and a-half hours further, and the vessel sealed off. No discharge could be sent through the vacuum-tube at this stage.

III. The same vessel was exhausted by a duplex Fleuss pump of large size, mechanically driven, and during the action of the pump the charcoal was well heated. In this way carbon dioxide is expelled from the charcoal, and the last traces of air are swept out. It was found in a separate experiment that little or no difference was produced in the result by the displacement of the last of the air by oxygen during pumping. In this method only one charcoal bulb was used, which was connected direct by a glass tube without taps to the vessel being exhausted. The connection with the pump was sealed after the removal of the air was judged complete, and the absorption by charcoal continued for two and a-half hours.

The following table shows the results of the three methods. Weighings were taken at intervals of either 6 or 12 hours. The first column shows the time in hours from the first weighing, and the total weight of liquid air initially present in the three experiments is indicated in the first line. The succeeding lines indicate the amount that has evaporated in the 6- or 12-hour interval from the previous weighing:—

---

* *Loc. cit.*

Hours.	I.*	II.	III.
0	972 grammes	954 grammes	979 grammes
12	2 × 54·5	2 × 63	2 × 40·5
18	54	62·[illegible]	40
24	54	60	39
36	2 × 54·5	2 × 60	2 × 39
42	54	59	39
48	55	58	37
60	2 × 56	2 × 57·5	2 × 37
66	56	57	37
72	57	56	37
84	2 × 58·5	2 × 56	2 × 37
90	58	55	38
96	59 (78 remaining)	56 (18 remaining)	36
108	—	—	2 × 37
114	—	—	38
120	—	—	36
132	—	—	2 × 36
138	—	—	36
144	—	—	37 (78 remaining)

It will be seen at a glance that whereas the vacuum resulting in the second method, by cooled charcoal, but starting from atmospheric pressure, is inferior to that produced by a simple mercury pump, that obtained in the third method, by charcoal after removal of the air, is by far the best of the three. After six days 78 grammes of liquid air out of the original kilogramme remain in the vessel.

In conclusion, I desire to take this opportunity of expressing my indebtedness to Mr. Soddy, at whose suggestion the research was undertaken, for placing the apparatus required at my disposal and for many valuable suggestions.

---

* The slight increase in the rate of evaporation during this experiment is due to a shortage in the supply of ice in the ice-chest. In the other two experiments the chest was kept well filled.

DEFENDANT'S EXHIBIT No. 19.

PHYSIKALISCHE ZEITSCHRIFT

Vol. 9, 1908, p. 193

TRANSLATION

Wehnelt Cathode in High Vacuum.

A remark to the article of Fred. Soddy[1])

By J. E. Lilienfeld. 193

The observation that forms the basis of the above treatise is that with the decrease of the gas pressure from a definite limit the voltage which is necessary to start a discharge between a Wehnelt cathode and any anode markedly increases. This signifies according to the author (Soddy) that in this region of pressure "the Wehnelt cathode loses its activity."

Now I have shown in two publications [2]) one of which antedates by one year the above named article, that with the gas discharge in high vacuum obtained with special care a series of important phenomena appear. Already in the first of the above mentioned publications (pages 634-635) I have described as the outstanding characteristic the rise of the potential drop in the positive column with decreasing pressure in the range of pressure mentioned. I showed therein that this fact is diametrically opposite to that observed with otherwise customary vacua. This condition was found to be entirely independent of the nature of the electrodes (which "in a part of the investigation were large aluminum electrodes, page 631") and indicated that "it is not exclusively the electrons emitted from the oxide cathode which, as was often assumed, determined the discharge in high vacua, but that the discharge depends essentially on a second factor. I pointed out more specifically in my second paper this view, that in consequence of the absence of the last traces of gas the number (volume density) of the negative electrons supplying the current becomes great in comparison with the number of gas molecules per unit volume, so that therefore the tendency exists for the formation of the greatest possible negative space charge" - which opposes the current transport by the negative electrons.

The higher the vacuum, the greater the current density3), the more prominent this new kind of discharge becomes - while the energy consumed in the Wehnelt cathode itself for the production of the discharge with constant current density does not markedly increase. In this sense I believe that the view does not apply that "in high vacuum the Wehnelt cathode loses its activity." On the contrary, concerning the phenomenon in question, we have to do with an important factor which is very general with discharges in extreme vacua.

---

1) This paper 9-8, 1908.

2) On new phenomena in the positive column of a glow discharge. First communication - Nov. 16, 1906; second communication March 22, 1907. Verh. d. Phys. Ges. 8-9. Further measurements that will form the basis of a third publication are being made.

3) wit
dia
wit
str
att

HJvdB-G

CONTRIBUTIONS FROM THE JEFFERSON PHYSICAL
LABORATORY, HARVARD UNIVERSITY.

FRICTION IN GASES AT LOW PRESSURES.

BY J. L. HOGG.

Presented by John Trowbridge June 29, 1909; received June 29, 1909.

UNDER the title "Friction and Force due to Transpiration as dependent on Pressure in Gases," there was published[1] some time ago an account of some experiments made to determine the relation between the friction of a gas and the pressure in it, and also the relation between the force exerted by a lamp on a mica vane, blackened on the face which is turned towards the lamp, and the mean pressure in the gas in which the vane is placed. The three-fold purpose of the investigation was pointed out there, viz.:

First, to investigate the relation between friction and pressure where the pressures were so small that "slip" is appreciable; second, to determine the relation of transpiration force in the special form of apparatus described there;[2] and, third, to make use, if possible, of these two relations to test the validity of the McLeod gauge measurements of pressure, and, if these measurements should prove unreliable, to make use of one of the relations named above to measure gas pressure.

There has been much delay in carrying out the investigation with the apparatus improved in the manner indicated in the closing paragraphs of that paper, but now some results have been obtained in so far as the friction problem is concerned.

As was pointed out in the paper mentioned, the investigation was defective in two respects. It was found that, in spite of the care which was taken to exclude mercury vapor from the apparatus, some of this vapor was undoubtedly present. This no doubt was due to the fact that the whole apparatus had to be maintained at a high temperature for long periods to insure drying, and thus the presence of the least speck of liquid mercury would cause, when evaporation took place, the diffusion of comparatively large quantities of the vapor through the apparatus. Again, the logarithmic decrement due to the friction in the suspending fibre was not determined directly by experiment, and in the discussion of the results obtained its value was calculated.

---

[1] Proc. Am. Acad., 42, 6 (1906).

[2] See p. 129 of that paper.

The details of the method since used to exclude the mercury vapor and to determine the decrement due to friction in the fibre will appear later. Meanwhile a summary of what has been accomplished is given here.

First, the decrement due to the friction in the suspending fibre of the viscosity apparatus has been determined experimentally.

Second, mercury vapor has been excluded to such a degree that, even when the whole apparatus, in which the presence of the vapor would be objectionable, was kept at a temperature of 150° C., the mercury lines were absent from the spectrum of the gas enclosed.

Third, the value of the decrement has been obtained for hydrogen over a range of pressures extending from atmospheric pressure to 0.000016 mm. as indicated by the McLeod gauge.

Fourth, an equation relating pressure to decrement has been obtained which applies well at all pressures below 0.1 mm. as far as pressures have been measured. The equation, above mentioned, is of the form of Sutherland's equation given tentatively in the former paper. It is

$$\left(\frac{k}{l-\mu}-1\right)p=c.$$

In this equation k and c are constants to be determined from the observations; l is the decrement due to whatever friction there is in the gas under examination and to the friction in the fibre; p is pressure; μ is the decrement due to the friction in the fibre. Its value has been measured directly. The significance of the two slightly differing values of μ, namely, $\mu = 0.000020$ and $\mu = 0.000022$, which are found in the following table, will appear later when the measurement is discussed in detail. The first column of the table contains a series of values of the decrement for hydrogen, each of which corresponds to a definite pressure in the gas. The various values of the pressure are given in the second column. The first three of them were obtained from a manometer. Those which are marked thus,*, were obtained from measurements made with the McLeod gauge, while the others were obtained from a curve plotted from the directly observed values of the decrement and pressure. From two values of p, the corresponding values of l, and the value of μ, there are obtained two equations for the determination of the constants k and c in the above equation. These determined, it is clear that from any value of l, within the range

TABLE I.

HYDROGEN.

Log Dec.	p (observed).	p (calculated) $\mu = 0.000020$.	p (calculated) $\mu = 0.000022$.
0.07942	760.0	……	……
0.07937	435.0	……	……
0.07927	103.0	……	……
0.07768*	8.89*	……	……
0.06902*	1.24*	……	……
0.05423*	0.410*	……	……
0.02861*	0.105*	0.109	0.109
0.01140	0.0300	0.0302	0.0302
0.01056	0.0275	0.0276	0.0275
0.00936*	0.0239*	……	……
0.00887	0.0225	0.0225	0.0225
0.00710	0.0175	0.0174	0.0174
0.00620	0.0150	……	……
0.00525	0.0125	0.0125	0.0125
0.00434*	0.0102*	0.0102	0.0102
0.00426	0.0100	0.00998	0.00998
0.00306*	0.00704*	0.00702	0.00702
0.00220	0.00500	0.00497	0.00496
0.00112	0.00250	0.00247	0.00246
0.000459*	0.00098*	0.00097	0.00097
0.000215*	0.00042*	0.00043	0.00043
0.000029*	0.000016*	0.000020	0.000015

indicated above, the corresponding value of p can be obtained from the formula by a simple calculation. The numbers thus obtained for the various values of l are given in the third and fourth columns.

It would, therefore, seem highly probable that so far as hydrogen is concerned the McLeod gauge can be relied upon for pressures as low as the lowest used, and which are recorded in Table I; and that, in the case of hydrogen, the measurement of friction can be used as a convenient and accurate method of measuring pressure, provided care is taken to exclude mercury vapor. This matter will be discussed at length later.

The details of the methods used to overcome the difficulties named above follow:

Measurement of Decrement due to the Friction in the Fibre.

Referring to Figure 1 it will be seen that the tube C is inserted in such a position that nothing can pass to the viscosity apparatus from the McLeod gauge, B, or from the pump, which is connected to D, without passing through it. This tube, C, therefore, replaces the tubes of sulphur and silver whose purpose was explained in the earlier paper. C is filled with granular charcoal, and is so arranged that either a cylindrical electrical heater or a long Dewar vessel can enclose it. When C had been placed in position and sealed in place, the whole apparatus was exhausted through D by means of the mechanical pump, and then dry air was allowed to pass in through an opening placed near the pump. The exhaustion was again performed and the admission of dry air repeated. This exhaustion and admission of air were carried out alternately many times for the purpose of removing the comparatively large quantities of moisture which had been formed in the vessel during the process of making the various joints in the construction of the apparatus. When it was certain that the whole apparatus had been made fairly dry, the cylindrical electric heater was placed about the tube C, and while the exhaustion proceeded the tube was raised to a temperature of about 150° C., to hasten the removal of the gas present in large quantities in the pores of the charcoal at atmospheric pressure, and which separates from the charcoal rather slowly under reduced pressure if the temperature is kept low. When the mercury pump had been used to secure a fairly high vacuum the other parts of the apparatus, viz., the McLeod gauge, the viscosity apparatus, and the connecting tubes were heated to about 150° C., for the purpose of removing from the glass the occluded gases. After the pumping had proceeded for some time under these conditions, the heater was re-

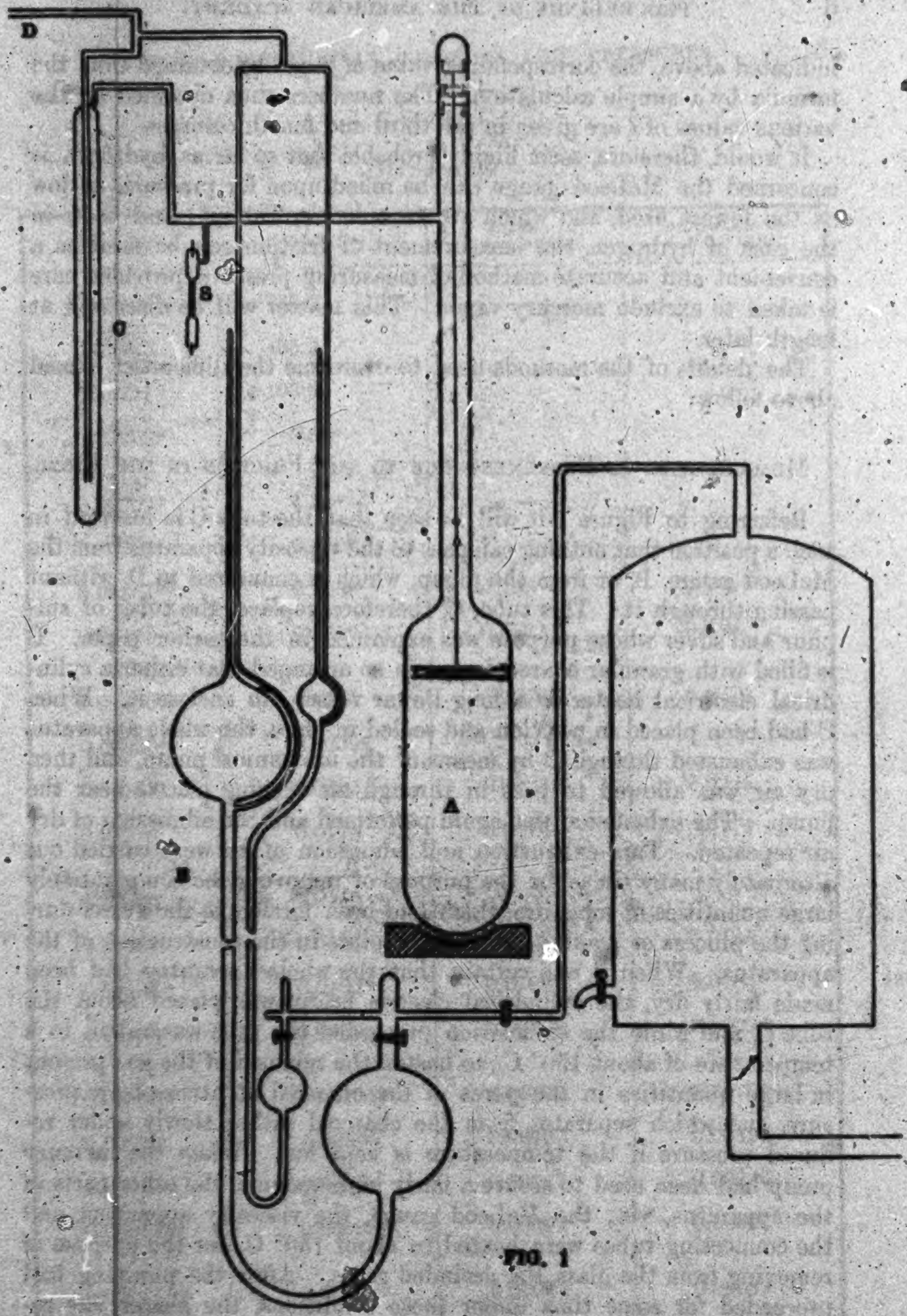


FIG. 1

moved from C and the Dewar vessel containing liquid air[3] was substituted for it, and the other part of the apparatus was allowed to cool down. The charcoal was allowed to absorb what it would at the temperature of the liquid air. Altogether the liquid air was kept surrounding the charcoal for about eighty hours, and from time to time during this interval a measurement of the decrement, l, was made. At first the diminution in the value of the decrement was fairly rapid, but after the first day the change was very slow. This, no doubt, was due in part to the slow passage of the gas towards the charcoal through the somewhat extended form of the apparatus. It was, also, probably due to the fact, which was noted later in the investigation, that at a given stage of exhaustion the raising of the free surface of the liquid air in the Dewar vessel surrounding C invariably produced a very appreciable diminution in the gas pressure in the apparatus, and the lowering of the free surface as the evaporation of the liquid air proceeded resulted in a distinct rise in the gas pressure. It is to be understood that the free surface was never allowed to fall as low as the top of the tube C, so that all of the charcoal was always below the free surface of the liquid air.

The following results show how the decrement changed with the time in the final forty-eight hours :

May 29,	12 M. to 2: 53 A. M.	Decrement 0.000051
	7: 15 P. M. to 8: 58	0.000037
	10: 53 P. M. to 1: 36 A. M. (May 30)	0.000031
May 30,	1: 36 A. M. to 4: 48	0.000028
	11: 11 A. M. to 2: 06 P. M.	0.000037*
	2: 06 P. M. to 5: 27	0.000024*
	5: 27 P. M. to 8: 21	0.000028*
	8: 21 P. M. to 11: 49	0.000022

The smallest value of the decrement obtained was 0.000022, and this could be measured moderately well. Its error cannot, I think, be as much as ten per cent. Of course, it is clear that the true value of the decrement due to the friction in the fibre is somewhat less than this, for there is still, doubtless, some gas left to offer resistance to the moving disk, so that the number to be used for μ in the above equation should be somewhat smaller than 0.000022. I have ventured to make use of the value 0.000020 as the true value to which the decrement will approach as the exhaustion is pushed higher and higher. It will be seen from Table I that the calculations are carried through not only with this value, but also with the actually measured value 0.000022. This is done simply to show what effect such a change in the value of μ has on the series of results obtained.

---

[3] The liquid air used in this investigation was obtained at the Chemical Laboratory, Harvard University.

* These were taken in the afternoon when there is considerable jarring of the apparatus and are probably not so accurate as the others.

It may be of interest to state that, at the stage of exhaustion when $\mu = 0.000022$ was obtained, the McLeod gauge indicated a pressure certainly less than 0.000001mm. It is, to be sure, of little value to give the measurement of a pressure by the gauge where a column of mercury a fraction of a millimeter high requires to be measured, and especially is this true where the tube containing the mercury has been heated and cooled repeatedly. The mercury has a habit of sticking to the glass to such an extent that pressure measurements under the conditions mentioned are surely not reliable. The value of the pressure given above, then, only indicates the order of magnitude of the pressure. Though the factor of the gauge used was 95813, yet it was quite inadequate to measure the pressure of the gas in the vessel.

REMOVAL OF WATER VAPOR AND MERCURY VAPOR FROM THE HYDROGEN IN THE VISCOSITY APPARATUS.

For this purpose it was necessary to make arrangements by which no vapor should be carried into the apparatus with the entering gas, and also all the vapor which was already in the apparatus might be taken out. The following arrangement was finally adopted, Figure 2. E is a U tube of small bore, and bent so that it may enter the long Dewar vessel already mentioned. For reasons which will appear later it was found necessary for the remainder of the investigation to replace the tube C, Figure 1, by this tube E. F is a tube leading from the gas generator. It enters G, which is similar to C of Figure 1. It can be surrounded by a heater or a Dewar vessel as circumstances may require. A connecting tube leads from G to a point on the tube H, which connects E to the viscosity apparatus A, Figure 1. I leads to the pump and McLeod gauge. Anything which proceeds from the pump or McLeod gauge towards the viscosity apparatus must pass through E. Moreover, the gas entering from the generator will, with the given arrangement, retard the diffusion of mercury vapor from the pump and gauge towards the viscosity apparatus. If there is no vapor entering with the gas, there can be none entering the viscosity apparatus without passing through E, and, since throughout the experiment this tube was kept surrounded by the liquid air, the pressure of the vapor due to diffusion from the mercury in the pump or gauge could never exceed the vapor pressure of mercury at the temperature of the liquid air. The tube G, when surrounded with the liquid air, was sufficient safeguard against the entrance of water vapor with the gas.

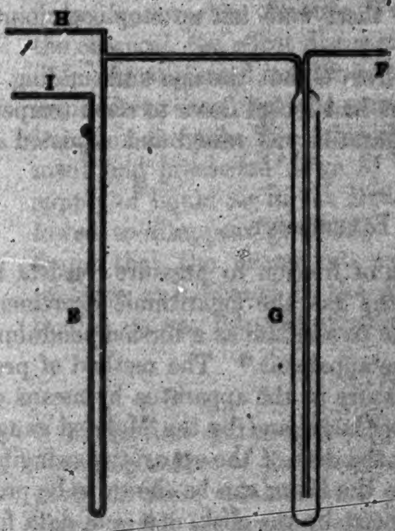


FIG. 2

The method of removing all water vapor and mercury vapor already in the apparatus beyond the tube E was that of repeated exhaustion and filling with the gas to be experimented with, the whole apparatus meanwhile being kept at a high temperature.*

At the first exhaustion, when the pressure had been reduced to a few centimeters of mercury, the tube G was surrounded by the electric heater, and the heat was applied to the oven in which the viscosity apparatus is placed. Practically the whole apparatus, except the gas generator, was kept hot while the pumping proceeded. After a fair vacuum was reached the pump was stopped and the hydrogen from the generator was allowed to enter very slowly, passing first over phosphoric pentoxide, and then over spongy platinum, heated in a combustion tube, before entering the tube G. This filling process was followed by another exhaustion under the same conditions. After the apparatus had been exhausted and filled a number of times in this way, when it seemed certain that the apparatus and the pores of the charcoal were filled with fairly pure hydrogen, the heater was removed from G, and the vessel containing the liquid air substituted for it. The same process of alternately exhausting and filling was continued, great care being taken in filling to allow the hydrogen to pass very slowly so that the drying process might be complete. Keeping the apparatus at a temperature of about 150° C. served to promote the evaporation of the mercury, which in all probability adhered to the inner glass surfaces. Comparatively large quantities of pure dry hydrogen were allowed to pass into the vessel and were then taken out. Each exhaustion would assuredly sweep out some vapor if it was present.

---

* The suspended disk was, of course, lowered before this operation began.

It would naturally collect at E. We shall have evidence as to this later. After some days of incessant work the expected result was attained, as the character of the spectrum, obtained from the spectrum tube, S, showed. Even when the temperature of the viscosity apparatus was 150° C. the mercury lines were absent. The apparatus was then very slowly filled with hydrogen. The glass tube connecting G and H was then sealed off so that there were left no stop-cock joints to give trouble by leaking.

The Dewar vessel was removed from G, but the one surrounding E still remained. After the apparatus had cooled down to room temperature the disk of the viscosity apparatus was raised and adjusted as described in the former paper.[5]

Method of Experiment.

The investigation of the relation of friction to pressure consists in measuring, for a given density of the gas, the logarithmic decrement of the suspended disk which is made to oscillate as a torsion pendulum between the two fixed plates of the apparatus.[6] The method of procedure was to measure the gas pressure in the apparatus by means of a manometer when the pressure was large, and by the McLeod gauge when it was small, and then to set the disk of the apparatus swinging and measure the decrement. Since the latter can be shown to be proportional to the resistance experienced by the disk, one gets data for the determination of the relation between friction and pressure.

It may be of interest to state here that in the first arrangement of the apparatus for the determination of the above relation instead of the simple bent tube E, a tube containing charcoal, similar to the tube C, was used. With this arrangement the mercury vapor was removed, but when observations on the decrement at different pressures were undertaken a difficulty presented itself. Although all of the tube containing the charcoal was immersed in the liquid air, the surface of which was always several inches above the top of the charcoal, yet it was found impossible to obtain a steady condition. As the evaporation of the liquid air proceeded, sufficient gas was given off from the charcoal to produce a large increase in pressure; as much as thirty per cent was observed. When a fresh supply of the liquid air was added the pressure diminished again. The difficulty became more serious as the pressure at which the observations were made became smaller.

The phenomenon was probably due to the fact that the fresh supply of liquid air was richer in nitrogen than it was after the process of boiling had proceeded for some hours. The nitrogen is the more volatile, and so the boiling will proceed more vigorously just after a fresh supply of air has been added than at any other time. Consequently, the temperature of the boiling liquid will be lower at first than it is later, and the charcoal will thus absorb better at each addition of liquid air to the Dewar vessel. The charcoal is necessary for the phenomenon, for when the tube E was substituting for the tube containing the charcoal, the effect disappeared, or became inappreciable.

---

[5] See pp. 133, 134.

[6] See pp. 124, 125 of former paper.

It was suggested earlier in the paper that there would be adduced evidence to show that the mercury driven out from the apparatus collected in the tube E. After the measurement of pressure and decrement had proceeded down to the least value given in the table, the supply of liquid air in the Dewar vessel in which E was placed was allowed to disappear gradually. As the evaporation proceeded, it was found that the decrement increased much more rapidly than the pressure as indicated by the McLeod gauge, showing that vapor was finding its way into the apparatus.

RESULTS.

In the first and second columns of Table I are contained the corresponding values of the decrement and pressure. Not all the numbers given in these columns were obtained by actual measurement. Only those which are marked with an asterisk were obtained in this way. The others were obtained as follows: A curve was plotted using the values of the pressure which were measured as abscissas and the corresponding values of the decrement as ordinates. This curve was drawn on such a scale that the value of the decrement, corresponding to any arbitrarily chosen pressure, could be obtained from the curve as accurately as it could be measured by the apparatus. The unmarked numbers in the first two columns were obtained by choosing arbitrarily a pressure and reading off from the curve the corresponding value of the decrement. In no case has this procedure involved an extrapolation.

After failing to obtain an analytical expression for the relation between the logarithmic decrement and the pressure which would be applicable over the whole range extending from very small pressures right up to atmospheric pressure, it was decided to find, if possible, an expression which would be applicable up to a certain pressure within the range for which it is known that the McLeod gauge measurements are quite reliable. Rayleigh[7] has shown that Boyle's Law holds down to 0.01mm. of mercury, and Baly and Ramsay[8] found the McLeod gauge measurements reliable for hydrogen. Recently Scheel and Heuse* have applied a membrane manometer, devised by them, to test Boyle's Law, and McLeod gauge measurements for air, and they state that they find both valid down to about 0.0001 mm., provided proper care is taken in drying the gas.

---

[7] Phil. Trans., 196 (1901).

[8] Phil. Mag., 38 (1894).

An examination of the results at pressures less than 0.1 mm. showed that the equation given above, viz.:

$$\left(\frac{k}{l-\mu}-1\right)p=c,$$

served the purpose exceedingly well, if the experimentally determined value of μ given above was used, and if the constants c and k were determined by means of values of p between 0.1 mm. and 0.01 mm. of mercury, and the corresponding values of l.

The pressures chosen for the determination of these constants were 0.0239 mm. and 0.0150 mm., the former of these being a pressure actually measured by the gauge, while the latter was chosen arbitrarily. The measurement of l corresponding to the former was 0.00936, while the value of l corresponding to the latter was 0.00620, and was obtained from the curve as described above. The values of the constants calculated from the above data are

$$c=0.1491$$
$$k=0.0676.$$

The equation now takes the form

$$\left(\frac{0.0676}{l-0.000020}-1\right)p=0.1491.$$

How well the equation gives the relation existing between p and l can be seen by a comparison of the numbers in the second and third columns of the table. A number in the third column is obtained by choosing a value of l from the first column, inserting it in the equation and deducing the value of p, which is then placed in the third column in the same horizontal row as the chosen value of l. It will be seen that the various numbers in this column agree very well with the corresponding numbers in the second column, except at the very lowest pressure, 0.000016 mm. used, when the difference is about twenty-five per cent.

---

* Verhandl. d. Deutsch. Physikal. Gesellsch., 11, 1 (1909).

If instead of using the value 0.000020 for μ, we make use of 0.000022, which was the smallest value of the decrement actually measured, the values of c and k are

$$c = 0.1494$$
$$k = 0.0677$$

and the fourth column gives the values of p calculated, in the way described, from the equation with these values for the constants instead of those used in the preceding case. This calculation is carried out to call attention to the magnitude of the change produced by a slight change in the value of the constant, μ, which is subject to some uncertainty, as has been shown. It will be seen that it is only where the decrement, l, is very small that the difference between the two results is appreciable. The smallest value of p in the fourth column is nearer to the corresponding value of p, measured by the McLeod gauge; but the measured value is subject to an inaccuracy about as great as the difference between the measured and calculated values of p.

The results given above make it highly probable that the measurements of pressure by the McLeod gauge are reliable in the case of pure, dry hydrogen for pressures as low as the smallest pressure recorded in the table.

It is to be observed that for pressures below, say, 0.01 mm. of mercury the friction with which we have to do is largely external friction, and this is proportional to the density of the gas and the mean molecular speed. The friction, and, therefore, the decrement, corresponding to a given pressure will be smaller for hydrogen than for, say, oxygen, or mercury vapor. In the case of mercury vapor the decrement at a given low pressure ought to be about ten times as great as it is for hydrogen at the same pressure, since the molecular weight of mercury is about one hundred times that of hydrogen, while the mean molecular speed is about one-tenth as great as it is for hydrogen.

To be sure it does not follow that the decrement of a mixture of hydrogen and mercury vapor, in such proportions that the partial pressures of the two are the same, is simply the sum of the two decrements obtained when the gas and vapor are separate. If one accepts the expression deduced by Meyer[10] for the external friction of a gas, and applies the same method in considering external friction of mixtures as he does in dealing with the internal friction of mixtures, he will be able better to understand how the external friction of a mixture of

---

[10] Kinetic Theory of Gases, p. 210 (Eng. Trans.).

[illegible]s depends upon the proportion in which the gases are mixed. [illegible]yer shows that the coefficient of external friction is given by

$$\tfrac{1}{4}\beta m N \Omega,$$

where m is the molecular weight of the gas; N is the number of molecules per unit volume; Ω is the mean molecular speed; and β is a constant depending upon the solid surface. He gives some experimental evidence to show that β is independent of the gas.

In the case of a mixture of gases where there are N_1 molecules of one kind and N_2 molecules of another, in each unit volume we have, if N is the total number of molecules in the unit volume,

$$N = N_1 + N_2$$

and the mean molecular weight is given by

$$m = \frac{N_1 m_1 + N_2 m_2}{N}$$

where m_1 and m_2 are the molecular weights of the two gases mixed.

Since the temperatures of the two gases are the same,

$$m_1 \Omega_1^2 = m_2 \Omega_2^2 = m \Omega^2.$$

Therefore,

$$m\Omega = m_1 \Omega_1 \sqrt{\frac{N_1}{N} + \frac{m_2}{m_1} \cdot \frac{N_2}{N}}.$$

If Boyle's Law holds, which seems a fair inference from the results given above, then we may write

$$m\Omega = m_1 \Omega_1 \sqrt{\frac{p_1}{p} + \frac{m_2}{m_1} \cdot \frac{p_2}{p}},$$

where p_1 and p_2 are the partial pressures and p is the whole pressure under the given conditions. If β is independent of the nature of the gas it follows that the ratio of the external friction of the mixture to the external friction of the gas whose partial pressure is p_1, if it were in the vessel alone, is

$$\frac{N m \Omega}{N_1 m_1 \Omega_1} = \frac{N m_1 \Omega_1 \sqrt{\frac{p_1}{p} + \frac{m_2}{m_1} \cdot \frac{p_2}{p}}}{N_1 m_1 \Omega_1} = \frac{N}{N_1} \sqrt{\frac{p_1}{p} + \frac{m_2}{m_1} \cdot \frac{p_2}{p}}.$$

If the mixture is one of hydrogen and mercury vapor such that $p_1 = p_2$, the above ratio becomes about 14. This means that if the pressure is measured by the McLeod gauge, which takes no account of the mercury vapor, the friction of the mixture would be about fourteen times as much as it would be with the same hydrogen pressure as in this case, but with the mercury vapor absent. If $p_1 = 1000p_2$, the ratio is about 1.05, and if $p_1 = 10{,}000p_2$, it becomes about 1.005.

It might be urged with regard to the method described above for freeing the hydrogen from mercury vapor that the lowest pressure of vapor obtainable by the method used is the pressure of mercury vapor at the temperature of liquid air boiling at atmospheric pressure. This pressure at 0° C. is about 0.0005 mm., but what it is at the lower temperature mentioned can hardly even be conjectured. We have simply to fall back upon the spectroscopic test. The above discussion shows, however, that if this pressure is less than 0.001 of the pressure of the hydrogen it will not very seriously affect the results. If it is as low as 0.0001 of the hydrogen pressure, then the error in the observations will easily be greater than any error introduced in this way. Considering the lowest pressure reached, namely, 0.000016 mm., the vapor pressure of mercury at the temperature of liquid air, boiling under atmospheric pressure, would require to be as low as 0.000,000,016 in order that the ratio of the partial pressures should be 1:1000.

This case serves to show how important it may be to consider mercury vapor when we are dealing with these very low pressures. It indicates that, in all high vacua work where we are considering the properties of a particular gas, it is important that great care should be taken to exclude this vapor. The McLeod gauge, of course, takes no cognizance of it, and in fact serves to introduce the vapor where it is not wanted. In all cases where the vacuum is high, and it is desirable to know the pressure in the vessel, and yet keep the gas pure, it would be desirable to have a gauge which would not introduce any impurity.

If the inference made above as to the validity of the McLeod gauge measurements on gas pressure is allowed, then we can say that reliance may be placed upon the measurements of pressure from decrement measurements in the apparatus used in this investigation. This method need introduce no mercury vapor, but it takes account of all that is in the vessel. Moreover, a discussion similar to that used for mercury vapor will show that in the case of oxygen the decrement, corresponding to a certain gas pressure, will be about four times as great as it is in the case of hydrogen. In the case of oxygen, therefore, a pressure of 0.00001 mm. should be measured with an accuracy of from five to ten per cent. This would indicate an absolute error of less than 0.000,001 mm.

The investigation is now being extended to the case of oxygen and nitrogen. The data obtained by using these gases, besides showing whether their behavior is like that of hydrogen, should give some more information regarding the quantity, β, which enters the foregoing discussion.

JEFFERSON PHYSICAL LABORATORY,
CAMBRIDGE, MASS.

DEFENDANT'S EXHIBIT No. 21.

[TRANSLATION]

A Contribution to the Knowledge of the Inertia of Moving Electrons.

[Beitrag zur Kenntnis der tragen Masse Bewegter Elektronen.]

By E. HUPKA

Annalen der Physik. Ser. 4 Vol. 31 (1910) p. 169.

[169]

The development which the Theory of Electricity and Magnetism has undergone since it was placed on an atomistic basis has led to a modification and a clearer understanding of various fundamental concepts from other fields of physics. In particular the concept of the inertia of matter has been broadened; the earlier electrodynamics admitted no functional dependence of inertia upon motion, whereas the newer electron-theories require the inertia of an electron to vary with its speed. Two of these theories are of especial interest because of their systematic structure; Abraham's theory of the rigid electron,[1] and the Lorentz-Einstein theory.[2] The difference between the two is best characterized by their relations to the Principle of Relativity. This principle states that the equations of motion have the same form in a coordinate-system at absolute rest as in a coordinate-system moving with uniform velocity relatively to the former one. The Abraham theory—we shall, like Planck, call it the "sphere-theory" for shortness—is incompatible with the principle of relativity; the Lorentz-Einstein theory—hereafter to be called the "relativity-theory"—makes this principle, together with a suitable [170] definition of time, the foundation of all its developments.

It is obvious that theories starting from such different viewpoints must lead to different conclusions about

phenomena involving motion, and these conclusions can be put to an experimental test and thus a decision between the two theories obtained. The best promise of success is offered by an investigation of the dependence of the mass of a moving electron on its speed; each theory predicting dependence but not the same law of dependence. W. Kaufmann, in his beautiful work on "The Constitution of the Electron",[3] demonstrated the existence of such a dependence by experiment. The data he gives cannot be brought into complete accord with either theory; the deviations from either exceed the magnitude of the experimental uncertainty as assigned by Kaufmann. From his measurements and those of H. Starke,[4] A. Bestelmeyer,[5] J. Classen[6] and others we may consider the fact of dependence of the inertia of an electron upon its speed as experimentally established. These experiments however did not form an adequate basis for criticizing the theories. Bucherer has recently[7] described experiments which support the relativity theory. Considering the importance of the question to the further development of the theories, a new test with different means should not be superfluous. Kaufmann and Bucherer worked with the β-rays of radium salts. The experiments here to be described (they were going on before Bucherer's article appeared)
[171] were performed with cathode rays of high speed. It is true that Starke's experiment, in which the discharge was produced by the applied potential alone, indicated that the range of velocities which could be thus attained would not be sufficiently wide to give a satisfactory accuracy; but the perfection to which modern methods of evacuation have been brought makes it possible to generate the cathode rays in some other way and then accelerate them by means of high static potentials, without involving a visible discharge and the associated complications. This was attained by producing a stream of electrons photo-electrically and bringing it

up to a great speed by means of high potential differences.

B. THE EXPERIMENTS

1. *Theory of the Experiments*

As the velocity of emission of the rays produced in this way amounts to only a few volts, according to the measurements of E. Ladenburg[8] and K. Markau,[9] and therefore can be regarded as infinitely small relatively to the final velocities attained, the equations given by Planck[10] may be used as the basis for these calculations. They are the same for both theories.

$$(1) \qquad E = \varepsilon P . 10^8 = q p - H;$$

$$(2) \qquad p = \varepsilon H \rho$$

E is the energy, H the kinetic potential of an electron moving with velocity q, ε is the elementary electrical charge in electro-magnetic units, P is the accelerating potential in volts, *H* the intensity of the field used for magnetic deflection, ρ the radius of curvature of the trajectory and $p = \delta H / \delta q$ the impulse-vector. The difference between the two theories is characterized by the

[172] following equations:

$$(3) \qquad H = -\frac{3}{4} \mu_0 c^2 \left[\frac{c^2 - q^2}{2 q c} \ln \left(\frac{c + q}{c - q} \right) - 1 \right]$$

for the sphere-theory

$$(4) \qquad H = - \mu_0 c^2 \left(\sqrt{1 - \frac{q^2}{c^2}} - 1 \right)$$

for the relativity- theory.

c is the velocity of light, μ_0 is the mass of the electron for $q = 0$. If we also take $\beta = q/c$ and $\eta_0 = \varepsilon / \mu_0$, we obtain from (1) and (3) or from (1) and (4):

(I) (5)

$$p = \frac{9.10^2.c}{4\,\eta_0}\left(\frac{1}{\beta}\ln\frac{1+\beta}{1-\beta} - 2\right)$$

for the sphere-theory.

(6)

$$p' = \frac{3.10^2.c}{\eta_0}\left(\frac{1}{\sqrt{1-\beta'^2}} - 1\right)$$

for the relativity-theory.

From $P = \mu q$ (μ is the inertia of the electron for velocity q) and the combination of equation (2) with (3) or (4), we obtain

(II) (7)

$$\frac{1}{c}\,\eta_0\, H\rho = \frac{3}{4}\,\frac{1}{\beta}\left(\frac{1+\beta^2}{2\beta}\ln\frac{1+\beta}{1-\beta} - 1\right)$$

for the sphere-theory.

(8)

$$\frac{1}{c}\,\eta_0\, H\rho = \frac{\beta'}{\sqrt{1-\beta'^2}}$$

for the relativity-theory.

The equations (I) contain only β, η_0, and some known constants; the equation (II) contain these and the quantities H and ρ, to be obtained by experiment, as well. We can assume a definite value for η_0, then determine the function β from η_0 and P, by means of (I). Insert this expression for β in (II) and see whether η_0 comes out constant in (II). If it comes out constant on either theory, that theory is the right one.

Another consideration will lead to the same equations. If as before, we designate by E the energy of the electron, using E for its value of velocity q, and E_0 for its value at the initial velocity q_0; by P and P_0 the corresponding potentials in volts; by e, the elementary electrical change in electrostatic units, by a the radius of the electron at rest, we obtain from the principle of conservation energy the following relation.

[173]

$$E - E_0 = \frac{e(P - P_0)}{300}. \tag{9}$$

In the sphere-theory the entire energy is electro-magnetic, therefore, if W is this energy,

$$E - E_0 = W - W_0.$$

But in case of a surface distribution of charge, we have:

$$W = \frac{e^2}{2a}\frac{1}{\beta}\ln\frac{1+\beta}{1-\beta}; \tag{10}$$

In the case of a volume distribution of charge, on the other hand

$$W = \frac{3\,e^2}{5a}\frac{1}{\beta}\ln\frac{1+\beta}{1-\beta}; \tag{11}$$

or, since:—

$$\frac{e^2}{a} = \frac{3}{2}\mu_0 c^2 \text{ for surface charge} \tag{12}$$

$$\frac{e^2}{a} = \frac{5}{4}\mu_0\, c^2 \text{ for volume charge.} \tag{13}$$

we get, irrespective the distribution of the charge,

$$\frac{P - P_0}{300} = \frac{3\mu_0\, c^2}{4e}\left(\frac{1}{\beta}\ln\frac{1+\beta}{1-\beta} - \frac{1}{\beta_0}\ln\frac{1+\beta_0}{1-\beta_0}\right). \tag{14}$$

In the relativity-theory we have in addition to the purely electro-magnetic energy W an inner potential energy L of the electron. The energy equation is as follows:—

$$W - W_0 + L - L_0 = e\left(\frac{P - P_0}{300}\right). \tag{15}$$

In the case of surface charge, we have:—

$$W = \frac{e^2}{2a\sqrt{1-\beta^2}}\left(1 + \frac{\beta^2}{3}\right). \tag{16}$$

$$L - L_0 = \frac{e^2}{6a}\left(\sqrt{1-\beta^2} - \sqrt{1-\beta_0{}^2}\right). \tag{17}$$

If these values are substituted in (15) we get:

(18)

$$\frac{P - P_0}{300} = \frac{e}{6a}\left(\frac{3 + \beta^2}{\sqrt{1 - \beta^2}} - \frac{3 + \beta_0{}^2}{\sqrt{1 - \beta_0{}^2}} + \sqrt{1 - \beta^2} - \sqrt{1 -}\right.$$

In the case of volume charge, the right hand side must be multiplied by $\frac{6}{5}$. By carrying out the substitutions (12) and (13), we obtain the following relation which [174] is independent of the mode of distribution of the charge:

(19)

$$\frac{P - P_0}{300} = \frac{\mu_0 c^2}{4e}\left(\frac{3 + \beta^2}{\sqrt{1 - \beta^2}} - \frac{3 + \beta_0{}^2}{\sqrt{1 - \beta_0{}^2}} + \sqrt{1 - \beta^2} - \sqrt{1}\right.$$

If we write

$$\frac{e}{\mu_0 c} = \frac{\varepsilon}{\mu_0} = \eta_0.$$

we obtain

$$(20) \quad P - P_0 = \frac{9.10^2 c}{4\,\eta_0}\left(\frac{1}{\beta}\ln\frac{1 + \beta}{1 - \beta} - \frac{1}{\beta_0}\ln\frac{1 + \beta_0}{1 - \beta_0}\right)$$

For the sphere-theory.

$$(21) \quad P - P_0 = \frac{3.10^2 c}{4\,\eta_0}\left(\frac{1}{\sqrt{1 - \beta^2}} - \frac{1}{\sqrt{1 - \beta_0{}^2}}\right)$$

for the relativity-theory.

and for small values of the initial velocity, exactly as in equations (5) and (6).

$$(22) \quad P = \frac{9.10^2 c}{4\,\eta_0}\left(\frac{1}{\beta}\ln\frac{1 + \beta}{1 - \beta} - 2\right)$$

the sphere-theory.

$$(23) \quad P' = \frac{3.10^2 c}{\eta_0}\left(\frac{1}{\sqrt{1 - \beta'^2}} - 1\right)$$

For the relativity theory.

Developed into series, these equations are:

$$(22\text{-a})\quad P = \frac{3.10^2 c}{2\,\eta_0}\left(\beta^2 + \frac{3}{5}\beta^4 + \ldots + \frac{3}{2n+1}\beta^{2n} + \ldots\right)$$

Sphere-theory,

(23-a)

$$P' = \frac{3.10^2 c}{\eta_0}\left(\frac{1}{2}\beta'^2 + \frac{3}{8}\beta'^4 + \ldots + (-1)^n\left(n - \frac{1}{2}\right)\beta'^{2n} + \ldots\right)$$

(for the relativity theory)

For small velocities we can be satisfied with the first term of the series. We then obtain, on both theories:

$$(24)\qquad P = P' = \frac{3.10^2.c}{2\,\eta_0}\beta^2.$$

In the former theory of electricity, and magnetism which did not recognize the dependence of. mass upon the velocity, this equation was regarded as valid for higher velocities as well.

It would be worth while to discuss these equations as Planck has already done in regard to what conclusions may be drawn, as to the quantitative difference [175] between the theories. A ray which has fallen through a given potential P has a certain energy E which is independent of the theory selected. Hence, we have the following equation:

$$(25)\qquad \frac{3}{2}\left(\frac{1}{2\beta}\ln\frac{1+\beta}{1-\beta} - 1\right) = \frac{1}{\sqrt{1-\beta'^2}} - 1.$$

The magnetic deviability is characterized by the reciprocal value $(1/c)\ \eta_0\ H_\rho$. From this it follows that:—

$$\beta' < \beta$$

$$\frac{\beta'}{\sqrt{1-\beta'^2}} > \frac{3}{4}\,\frac{1}{\beta}\left(\frac{1+\beta^2}{2\beta}\ln\frac{1+\beta}{1-\beta} - 1\right)$$

that is, a ray which has fallen through a given potential possesses according to the sphere theory a greater velocity and a greater magnetic deviability than according to the relativity-theory. The difference disappears in the cases of very small and very high potentials; a maximum is obtained, as Planck has shown for $P = 3.2\ 10^5$ Volt ($\beta = 0{,}834$). One-half the velocity of light is equivalent to a discharge potential of about 75,000 volts, on the sphere-theory and about 78,000 volts on the relativity-theory.[11)]

2. *The Experimental Details.*

A. Apparatus and Technique.

The idea suggested by these theories was realized by the arrangement shown in Figure No. 1. By light from a quartz mercury lamp L a stream of electrons was

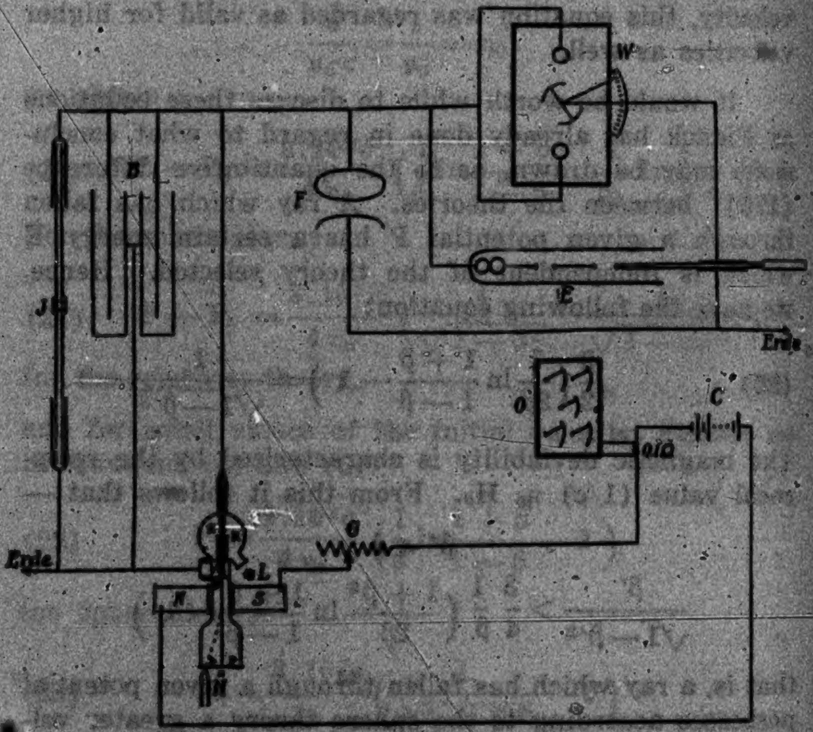


Fig. 1.

liberated from a copper cathode K in a discharge tube R which was evacuated to a high degree by means of coconut charcoal and liquid air. The beam, highly accelerated by a field applied between the cathode and the anode A, traversed the anode which had the shape of a diaphragm [i.e., a hole in a screen]—with constant speed, and then a second diaphragm D over which were stretched two crossed Wollaston wires; the beam cast the shadow of this cross upon a phosphorescent screen P at the end of the tube. A pair of coils NS was placed with its axis perpendicular to the axis of the tube behind the second diaphragm; when a current (to be called the magnetic current) was sent through these coils the beam was deflected and the shadow of the cross displaced from a to b. To escape disturbances from the earth's magnetic field the discharge tube was screwed into a perfectly iron-free support parallel to the magnetic meridian; the deflections were in the vertical plane.

A scheme for producing high static potential differences and measuring them very accurately has been [177] worked out by Müller[12] in this Institute and has been briefly described. This method was used in the present case. The cathode was connected with the negative pole of a battery of Leyden jars, which was charged

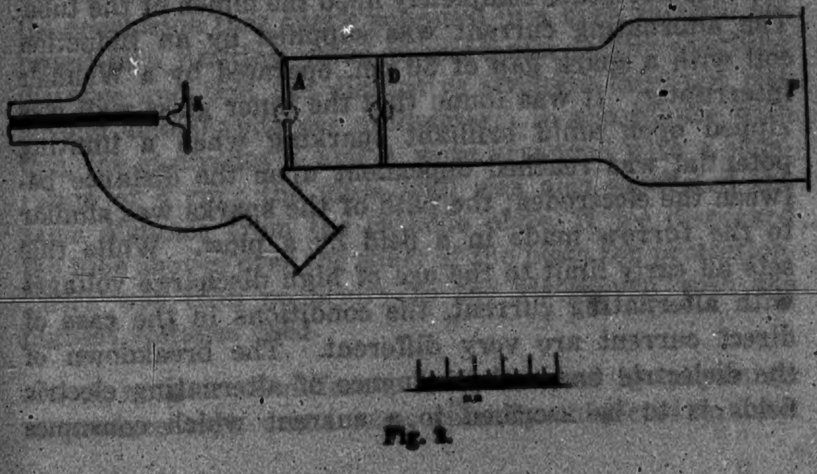


Fig. 1.

by an electrostatic machine J constructed for high potential differences and having plates of a diameter of 90 cm.; the positive pole and the anode were earthed through a lightning-conductor. The P.D. could be regulated by means of a subdivided spark-gap (cf. 12); the readings were taken with a bifilar torsion-balance with pointer and scale, calibrated from observed sparking-distance by Müller's method.

The magnetic current was taken from a 20-volt storage-battery C, regulated by a sliding rheostat and measured by a compensator across a standard resistance of 0.1 ohm (calibrated by the Physikalisch Technische Reichsanstalt) immersed in paraffin-oil. The displacement of the shadow was observed with a microscope magnifying about 16 fold.

The opinion is often expressed, based on experience with high frequency alternating currents, that even in the best vacuum the use of high voltages is out of the question owing to the danger of breaking the glass walls. I thoroughly confirm this information from my [178] own experience as far as alternating current is concerned. At first I expect to obtain higher discharge potentials by increasing the cathode drop and for this purpose I put insulated electrodes between the cathodes and anode. This was not successful unless these intermediate electrodes completely filled the lumen of the tube. The alternating current was supplied by an induction coil with a spark gap of 30 cm. operated by a Wehnelt interrupter. It was found that the inner glass wall was ripped open amid brilliant sparking when a limiting potential was reached dependent upon the distance between the electrodes; the path of the sparks was similar to the furrow made in a field by a plow. While this sets an early limit to the use of high discharge voltages with alternating current, the conditions in the case of direct current are very different. The breakdown of the dielectric under the influence of alternating electric fields is to be ascribed to a current which consumes energy. But the value of the resistance deduced from alternating current losses, corresponding to this current, is, as experiments show, very small in comparison with the direct current resistance. For a telephone cable[13] direct current measurement gives an insulation resistance of 1,000 megohms and an a.c. resistance of about 100,000 ohms; a paper condenser[14] with a capacity of 2 microfarads has an insulation resistance of seventy million ohms and an a.c. resistance of about 2,500 ohms on alternating current of 800 to 900 cycles (talking currents). We have at present no satisfactory explanation for these facts. A part of the loss is perhaps due to molecular friction caused by the alternating polarization of the dielectric; the result would be for the electric in- [179] duction to lag behind electric field. The dielectric loss would then be analogous to the loss by hysteresis in magnetic substances.[15] According to the recent investigations of E. V. Schweidler,[16] this assumption does not afford a quantitative explanation. Perhaps a current due to conduction is involved, possibly electrolytic in nature. In any case, it is certain that with direct current, there will be less strain to the dielectric, in this instance to the glass wall of the discharge tube, than in the case of alternating current.

Experiments were performed by Madelung[17] on the disruptive strength of high vacua which led him to the conclusion that spark potential in a high vacuum approaches a limiting value proportional to the sparking distance and that the disruptive strength does not rise beyond 40,000 volts per millimeter. In accordance with this, the electrodes K and A were arranged with a separation of 4 cm.; the glass wall was also separated the same distance from the cathode plate, if we disregard the tube shoved over the shaft of the plate for protection. There was then no injury to the glass even with the highest voltages used.

A number of different methods used by physicists to produce high vacua were recently subjected to trial by Heuse and Scheel[18] in the Physikalisch-Technischen Reichsanstalt. As a result of these experiments, it may be stated that the maximum degree of evacuation can be reached only when coconut charcoal and liquid air are used. The lowest pressures (0.000007 millimeters) were obtained in about two hours after a preliminary evacuation with a Gaede pump. I have also made ex- [180] periments with the process of calcium vaporization suggested by Soddy.[19] In one case a calcium pencil connected in the circuit by a loose contact was vaporized by direct short-circuiting and formation of an arc. Another time pieces of calcium, the size of peas, were put into a porcelain tube cemented to the vessel to be evacuated and closed at the end; this was carefully heated to a red heat by the flame of a blower. The degrees of evacuation obtained in this manner were not inconsiderable; for instance, a vessel of about ½ liter capacity was reduced from a water jet vacuum to a hard X-ray vacuum at the moment of vaporization. For the present purpose, however, this method was not adequate. The charcoal and liquid air method, therefore, alone was used. To the side of the enlarged part (containing the phosphorescent screen) of the discharge tube, carrying the phosphorescent screen, was soldered a container about 15 cm. long and 2 cm. wide which was filled half full with coconut charcoal. A wad of glass wool was used to prevent the carbon particles from falling into the discharge tube. The apparatus was so connected with the mercury pump, that the carbon tube was horizontal in position. A sheet of metal about 8 cm. wide was slipped over it and was heated by a multiple-burner from below to a temperature near the melting point of glass.

Special care was taken in preparing the carbon. The shells of a coconut were cut up to the size of peas and carbonized by dry distillation in a metal box with a perforated cover and with a reduced amount of air. The process could be regarded as finished when the clouds of yellowish white smoke disappeared. The product formed in this way had a greyish black appearance and matt fracture; on account of the amount of tar it contained it could not be used for evacuation; it had to be glowed in a glass tube under a vacuum. This was done by a water jet pump, the tube being heated about 6 to 7 hours to a temperature of about 400 degrees. This gave the carbon a deep black color and the fracture was mirror-like and conchoidal. This preparation also could [181] not be used until after the remaining nyrocarbons had been removed by continuous evacuation and heating for several days in a high vacuum (mercury pump); the two phosphorus pentoxide tubes attached for drying took on a brown color and had to be changed many times. The definitive experiments could not be started until the drying-material remained white. It was found desirable not to keep the mercury pump continuously in operation but to work intermittently; at first it was evacuated until the glass wall of a Geissler tube, serving as a vacuum-indicator and opening into the container, displayed green fluorescence; the pump was then stopped and I waited until the cathode dark space was only one millimeter wide owing to the giving off of gas from the carbon; then the pump was set in operation again and was evacuated until the fluorescence began; the pump was again stopped until the cathode dark space had been reduced to one millimeter, and so on. Possibly, there is a certain value of the pressure-gradient favorable to the rapid emptying of the container while at lower pressures the friction of the gas on the walls acts as a hindrance to evacuation. In any case, the process still occupied from six to eight hours. Finally, when a spark gap of 3 cm. in parallel with the indicator operated with the carbon heated to the highest possible degree, the container was separated from the pump. A method of evacuation with coconut charcoal and liquid air, which is possibly promising, was used at about the same time independently by Heuse and Scheel, by Regener in the Physics Institute, and by myself; a number of charcoal tubes are fused in series to the container to be evacuated, all the tubes are heated at the same time, while they are constantly being evacuated by the pump (a water jet pump will do); then one of the tubes is cooled to room temperature; this absorbs the gas given off by the other tubes; the cooled tube is sealed off from the container, and then the next carbon tube is cooled, melted off from the container, etc., until only one tube [182] is left. If this is now placed in liquid air, the highest attainable vacuum is obtained.

According to experiments of E. Tieffenbach in this Institute, when charcoal is dipped into liquid air there is a fairly rapid fall of temperature down to about 100° c, after which the further decline is extremely slow. Hence after applying the liquid air to the charcoal we waited 3 or 4 hours before beginning with the measurements, mean-while constantly refilling to replace the evaporated air.

Vacua made in this way stood up under about 90,000 volts without a discharge taking place of itself. Under these conditions effects are observed which are very remarkable. In spite of a discharge potential which in air at atmospheric pressure corresponds to a gap of 8 cm. between 5 cm. balls, the eye does not perceive the slightest light inside the tube. If ultra-violet light is allowed to fall on the cathode a bright spot appears on the phosphorescent screen. If the source of radiation is screened off by glass plates, this phenomenon disappears. If the vacuum is not high enough (this was especially the case after the discharge tube had been stored for some time at atmospheric pressure) sparks occurred in the vacuum at the higher voltages. These were brilliant and made almost no noise; they were able to cause short-circuits, by the excitation of oscillations, in the wiring in rooms twenty meters and more away. Studied with the hand spectroscope they displaced in particular the spectrum of aluminium, with the exception of one yellow line. If the vacuum is harder and the sparking, therefore, less frequent, the glass becomes fluorescent before discharge. Reichenheim[20] recently made a study of the fluorescence-colors which the glass displays under the action of cathode rays, but found that [183] instead of the ordinary yellowish green color the fluorescence displayed at times a marked blue. Reichenheim ascribed this to the occurrence of secondary rays. We observed both colors in our experiments, green fluorescence in a relatively poor vacuum and blue in a good vacuum.[21)] Perhaps this is due to the fact that the blue color is the actual fluorescence due to the glass, whereas the green is due to adhering films of gas.

A circular sky-blue spot of phosphorescence appeared on the screen with an outline, which was very sharp even when enlarged with the microscope. Its intrinsic brightness was very notable, considering the small number of electrodes released by the photo-electric effect; in a darkened room it could be clearly observed at a distance of several meters. To prevent disturbing charges on the screen (the conductivity of the substance was usually sufficient for this) a fine-meshed wire net was stretched over the screen and grounded.

The source of ultra-violet light was a quartz mercury vapor high-pressure 220-volt lamp from the Heraceus Company, and this was operated on 130 to 140 volts terminal voltages and about 3.5 ampere from the city supply, with a suitable ballast resistance.

This was enclosed in a zinc box to keep the light out of the room; a beam of the light passed through a tube applied at an angle of 45°, and through a quartz window into the discharge-tube. [It is not clear whether the tube was attached to the box or to the discharge-tube, but probably the latter—K. K. D.] The wires leading to the lamp were so arranged as not to affect the magnetic field in the discharge-tube, and when a similarly [184] placed current was suddenly raised from 2 to 5 amperes no displacement of the phosphorescent spot could be detected.

The quartz window was a plate 4 cm. in diameter from the Busch Company in Rathenow and it was out perpendicularly to the optical axis. White cement No. 849-A from the Liliendahl Company in Neudietendorf was used for cementing it to the ground edge of the glass tube. This material has proved extraordinarily good as a vacuum cement; it is to be preferred to ordinary red sealing wax because of its low melting point, its fine-grainedness and especially its toughness. When sealing-wax is used it eventually begins to leak through microscopic cracks and breaks, produced by mechanical jarrings or by non-uniform temperatures and due to the brittleness of the substance. If we wash the shellac out with alcohol, we obtain a material which because of its calcium content gives a beautiful sky-blue phosphorescence under the influence of cathode rays.

The cathode is made of copper since copper is the most active substance photo-electrically next to carbon; a sufficiently high vacuum could not be expected with carbon (lampblack). Aluminium was chosen for the diaphragms because it gives off the least gas in a vacuum. Unfortunately, I could not obtain English aluminium which contains occluded gases to only a small degree,[22] but a few sparks produced in a high vacuum by very high voltages removed sufficient of the gas from the electrodes.

To obtain a suitable phosphorescent material, I made unsuccessful experiments for a long time on the products of the various firms; finally, I found that Kahlbaum's "Sidotblende" can be used. The white powder was stirred up into a milky paste with a 30 per cent sodium water glass solution in a porcelain crucible, was [185] applied evenly to a heated mirror-glass plate with a marten hair brush and finally the coating was dried as rapidly as possible over a flame at a given distance away from it. The screen was then cemented to the end of the tube in the same way as the quartz plate. The two cemented joints were carefully screened for protection against injury from ultra-violet light or cathode rays.

The magnet coils HS each had 400 windings of 1-millimeter enameled wire which was wound in three layers on two boxwood cylinders with a diameter of 6 centimeters and a length of fifteen centimeters. The whole apparatus, discharge tube and coils, was supported by wooden frames strengthened with rods at the side; a number of brass screws and clamps held it in place. Two wooden clamps held the frame to an oak table. Blows with a heavy hammer 5 centimeters away from one leg of the experiment table on the stone floor did not cause the phosphorescent spot to be displaced at all.

To obtain and measure the accelerating potentials we made use of a part of Müller's apparatus. In working with this apparatus we used the same care as did Müller; especially in regard to insulation were the previously approved precautions taken. I was very grateful for the advise of Müller in this matter.

Dish shaped electrodes, for which Müller's measurements are most accurate, were used for calibration. The delay in sparking was eliminated by using Röntgen rays. The X-ray tube with watercooled anticathode from the Gundelach Co. was operated by an induction coil with a spark gap of thirty centimeters and a Wehnelt interrupter. A Bamburg type of cathetometer was used to measure the separation between the electrodes. The positive pole of all parts of the high tension apparatus was connected, through three copper tapes two [186] centimeters wide, with a lightning conductor. The metal tapes were soldered to the lightning conductors at a point about three meters away from the ground. In this way alone was it possible to avoid the disturbances throughout the building (sparking from the gas or water faucets), resulting from earthing the system to the gas or water mains.

To regulate the magnetic current a ten ohm resistance was used and also a sliding rheostat of 2.5 ohms in series with it. A Raps compensator was used to measure the current. The standard cell of this apparatus was compared with a standard cell calibrated by the Physikalisch-Technische Reichsanstalt. The galvanometer, which served as a zero-instrument, had a resistance of 1,000 ohms and a sensitivity of $2.7 . 10^{-9}$ ampere per millimeter of deflection.

The reading microscope was provided with a micrometer thread; it was supported by a telescope base which was 1¼ meters in height.

The details in regard to the discharge tubes, especially the dimensions of the different parts may be obtained from figure No. 2.

B. The Measurements and Results.

The method of measurement used was a relative one. The absolute value of the deflections was not determined, but it was kept constant, when the potential difference between the electrodes was varied, by suitable regulation of the magnetic current, and this constancy was tested by the microscope. The experimental procedure was as follows: A given P.D. was established between cathode and diaphragm and at the same time the magnetic current J was adjusted to a given intensity; then the shadow of the crossed threads was brought in alignment with the micrometer-thread and the current and voltage were read. Then with the position of the microscope and the discharge tube unchanged, a new value was given the voltage, the magnetic current was changed correspondingly, and the voltage and current were again read at the moment when the micrometer-thread and the shadow coincided. In this way, are obtained directly the data necessary for the further
[187] calculations, viz., a series of corresponding values of P and J or of P and H, and these correspond to the same deflection a b of the bundle of cathode rays, and therefore, also to the same value of ρ.

The accuracy of the microscope readings was about 0.015 millimeter and the total deflection on a b was 15 to 30 millimeters. The greatest possible error in the determination of the potential was estimated at ± 80 volts. The greatest possible error in the measurement of the current was ± 0.5 Promille. Static charges inside the tube were not detected in any of the experiments employed in the computations. Charges of this kind make their presence known by irregular flickering displacements of the spot of phosphorescence in the microscope, before they are visible to the naked eye through the fluorescence of the glass.

In explanation of the table following, note that the quantity C in the last column was obtained by dividing equations (II) by the magnetic current J. For, if we set the magnetic field H equal to KJ,—K being a quantity which is constant throughout any one run—the left-hand members of equations (II) assume the form $\frac{1}{c} \eta_0 K J_\rho$; and dividing this by J_1 the quotient $\frac{1}{c} \eta_0 K_\rho$ will be found to be constant for whichever theory conforms to the facts. The values corresponding to the case of constant mass were obtained from equation (24). The value $\eta_0 = 1.77 \cdot 10^7$ found by Classen is the basis of the calculation of β from (I) or (24). The same value was obtained in Bucherer's[23)] measurements and recently by Wolz.[24)] The choice of a different value affects only the absolute value of C (β), without interfering with its general trend. Table X given at the end shows this very clearly; in this table of the value $\eta_0 = 1.77 \cdot 10^7$, we took $\eta_0 = 1.80 \cdot 10^7$.

[188]

TABLE I.

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativ-theorie β	Konst. Masse Cβ	Kugeltheorie Cβ	Relativ-theorie Cβ
					3,73+	3,83+	3,85+
17430	0,06845	0,261835	0,256496	0,255000	0,0953	0,0202	0,0079
19310	07211	275594	269474	268013	918	209	80
20960	07518	287127	280170	278569	892	205	83
23340	07943	302993	294901	292979	846	197	81
24710	08178	311750	302985	300872	821	193	79
26520	08480	322969	313214	310936	785	178	79
29560	08966	340983	329492	326874	730	170	78
30450	09104	346075	334058	331384	714	159	81
32540	09420	357758	344549	341547	679	154	81
36130	09943	376973	361601	358128	613	147	78
38160	10229	387427	370799	367029	575	139	75
40000	10482	396655	378830	374841	542	130	75
42130	10768	407073	387910	383594	508	125	76
44170	11035	416810	396247	391701	472	124	80
46010	11274	425400	403569	398797	433	111	75
47930	11517	434200	411062	405978	401	108	75
49920	11768	443120	418612	413246	355	090	65
51980	12018	452170	425135	420586	325	084	75
53500	12198	458722	431610	425797	306	083	81
55460	12433	467056	438575	432425	265	081	75
57760	12702	476650	446411	440022	226	076	78
59800	12935	484989	453211	446492	194	073	79
62320	13222	495111	461439	454319	145	048	74
66410	13676	511078	474228	466536	071	042	70

TABLE II.

					2,09+	2,14+	2,15+
19440	0,12983	0,276520	0,270343	0,268883	0,0398	0,0062	0,0002
20320	13278	282707	276085	274516	391	57	01
22250	13908	295836	288267	286492	371	63	01

TABLE II (Continued).

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativ-theorie β	Konst. Masse Cβ	Kugeltheorie Cβ	Relativ-theorie Cβ
					2,09+	2,14+	2,15+
23830	0,14402	0,306153	0,297851	0,295813	0,0358	0,0059	0,0003
25510	14914	316764	307551	305341	340	51	01
26340	15160	321877	312218	309978	332	49	06
27300	15436	327686	317528	315082	329	55	09
28690	15836	335931	324937	322394	313	48	07
30700	16402	347500	335338	332606	286	35	03
31600	16643	352550	339944	337008	283	40	08
32100	16782	355325	342395	339452	277	34	04
34370	17383	367682	353374	350172	254	34	06
35490	17673	373618	358645	355235	241	33	04
37400	18158	383545	367376	363723	223	29	04
38600	18461	389645	372719	368943	206	23	02
40740	18980	400300	382005	377937	190	24	07
42220	19337	407510	388292	383954	174	22	04
44470	19865	418227	397458	392858	153	19	06
45590	20128	423470	401922	397177	139	13	02
48500	20787	436770	413225	408097	111	09	05
51600	21473	450520	424759	419253	080	02	06
53240	21825	457611	430686	424906	068	02	08

TABLE III.

					2,28+	2,35+	2,36+
31690	0,15143	0,353054	0,340387	0,337448	0,0515	0,0098	0,0074
34270	15770	367150	352904	349708	482	92	76
39830	17042	395809	378088	374130	426	85	73
43400	17822	413170	393149	388682	383	76	70
47100	18599	430420	407844	402892	342	68	69
47100	18599	430420	407844	402892	299	68	69
53900	19960	460433	433081	427168	268	62	70
57330	20619	474867	444952	438608	231	48	70

TABLE III (Continued).

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativ-theorie β	Konst. Masse $C\beta$	Kugeltheorie $C\beta$	Relativ-theorie $C\beta$
					2,53+	2,61+	2,63+
60220	0,21161	0,486659	0,454591	0,447824	0,0199	0,0041	0.0069
62930	21659	497522	463371	456182	171	34	70
66300	22267	510667	473893	466213	134	28	69
68880	22723	520512	481693	473628	106	27	68
72000	23264	532175	490850	482328	075	18	69
74080	23623	539800	496779	487973	051	11	67

TABLE IV.

					2,53+	2,61+	2,63+
32310	0,13747	0,356492	0,343423	0,340462	0,0632	0,0153	0,0040
33180	13936	361258	347683	344566	623	156	42
35870	14506	375612	360418	356953	594	157	43
37630	14873	384725	368422	364724	567	146	37
39020	15152	391764	374552	370741	555	147	46
42240	15791	407609	388377	384035	512	138	47
44860	16289	420060	399032	394362	488	140	47
47530	16790	432370	409530	404491	452	132	44
50670	17364	446440	421391	415928	411	120	41
54110	17972	461340	433778	427888	370	110	42
57450	18546	475367	445365	438999	332	109	45
60520	19066	487900	455577	448776	290	096	39
64720	19752	504544	469043	461584	244	088	44
67240	20154	514267	476756	468968	217	090	46
69830	20565	524087	484489	476304	184	082	42
72150	20925	545125	491277	482735	158	075	42
75860	21491	546250	501782	492694	117	070	47
78320	21866	555037	508527	499106	084	060	41

TABLE V.

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativ-theorie β	Konst. Masse Cβ	Kugeltheorie Cβ	Relativ-theorie Cβ
					2,36+	2,43+	2,45+
33430	0,15020	0,362617	0,348908	0,345745	0,0542	0,0157	0,0037
35940	15592	375983	360737	357270	514	152	33
38510	16160	389200	372326	368551	484	148	34
40550	16598	399873	381198	377142	461	141	34
42980	17110	411160	391445	386999	431	134	30
45950	17715	425130	403333	398565	398	129	32
49510	18419	441300	417056	411780	358	122	33
51680	18841	450860	425049	419539	330	110	31
55650	19585	467856	439250	433052	288	110	32
57600	19946	475978	445871	439495	263	102	30
60200	20414	486611	454525	447761	237	098	30
63420	20980	499444	464924	457679	206	094	36
66300	21481	510667	473393	466213	173	090	37
68780	21905	520125	481398	473346	145	087	33
69840	22083	524122	484519	476332	134	084	33
73400	22677	537312	494840	486127	094	072	32
75440	23009	544725	500631	491598	074	072	36
77620	23365	552550	506608	497283	048	065	33
79190	23617	558100	510882	501323	031	064	34

TABLE VI.

					2,49+	2,57+	2,59+
34270	0,14404	0,367150	0,352904	0,349708	0,0590	0,0130	0,0022
36930	14966	381127	365239	361679	562	131	22
39900	15576	396164	378394	374423	534	127	25
43710	16335	414640	394391	389924	484	116	22
44780	16540	419680	398709	394053	474	118	23
50800	17579	444800	420051	414605	403	102	20

TABLE VI (Continued).

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativtheorie β	Konst. Masse Cβ	Kugeltheorie Cβ	Relativtheorie Cβ
					2,51+	2,60+	2,62+
54480	18332	462911	435093	429157	352	088	20
57920	18932	477300	446951	440530	311	085	20
61270	19502	490911	458041	451112	272	075	20
64130	19975	502237	467174	459847	243	072	25
67530	20534	515387	477639	469818	199	066	20
69610	20862	523262	483842	475685	182	067	24
71600	21176	530687	489700	481243	161	062	26
74160	21581	540100	497007	488190	126	050	21
76620	21957	548975	503866	494675	102	050	25
77280	2206(0)	551325	505676	496396	092	046	23

TABLE VII.

					2,51+	2,60+	2,62+
34690	0,14334	0,369383	0,354880	0,351618	0,0670	0,0116	0,0004
37480	14919	383956	367740	364071	636	111	02
40960	15624	401382	382940	378858	591	099	02
45200	16442	421650	400392	395673	545	099	05
48850	17120	438340	414552	409398	504	092	11
53490	17957	458690	431574	425768	444	075	05
58160	18765	478289	447762	441291	388	071	06
60920	19231	489511	456891	450043	354	060	05
64120	19750	502200	457208	459817	317	063	06
65770	20024	508612	472278	464660	301	053	06
68700	20498	519825	481163	473121	260	045	[illegible]
71010	20859	528437	487963	479628	234	040	04
73500	21248	537675	495125	486399	205	030	01
75080	21488	543425	499629	490660	189	030	06
77500	21857	552112	506278	496970	160	025	04
78840	22053	556862	509953	500446	151	031	11
79920	22219	560675	512816	508152	134	022	08

TABLE VII (Continued).

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativ.-theorie β	Konst. Masse Cβ	Kugeltheorie Cβ	Relativ.-theorie Cβ
31550	0,22460	0,566357	0,517134	0,507236	0,0116	0,0020	0,0006
32780	22642	570612	520378	510305	101	018	07
34800	22934	577537	525536	515162	082	017	10
37170	23286	585543	531531	520826	046	004	02
38400	23457	589671	534559	523662	038	005	06

TABEL VIII.

					1,89+	1,94+	1,95+
35540	0,19415	0,373883	0,358880	0,355461	0,0357	0,0125	0,0078
37880	20070	386000	369559	365811	333	117	83
40200	20687	397636	379703	375678	322	122	96
42230	21244	407560	388335	383994	285	101	77
44500	21831	418370	397579	392980	264	097	77
47860	22665	433880	410797	405718	243	102	86
50370	23271	445110	420304	414855	227	105	93
52550	23794	454644	428200	422540	207	097	93
54430	24257	462700	434915	428985	175	079	78
56450	24720	471200	441988	435696	162	084	83
58700	25231	480511	449585	443004	144	084	85
60160	25563	486444	454394	447634	129	077	83
61650	25897	492433	459290	452272	115	073	82
65000	26630	505637	469931	462403	088	069	85
66880	2703(0)	512900	475660	467913	075	072	88
67850	27252	516611	478614	470727	057	062	79
70020	27703	524800	485048	476829	043	063	83

TABLE IX.

					2,54+	2,93+	2,96+
45330	0,14608	0,422250	0,400902	0,396174	0,0505	0,0119	0,0045
48300	15096	435866	412466	407353	473	118	51
51320	15578	449280	423745	418252	441	118	51

TABLE IX (Continued).

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativ.-theorie β	Konst. Masse Cβ	Kugeltheorie Cβ	Relativ.-theorie Cβ
					2,84+	2,93+	2,95+
53670	0,15949	0,459460	0,432214	0,426380	0,0409	0,0109	0,0059
55900	16279	468489	439783	433548	379	109	65
58200	16647	478456	447897	441418	341	099	53
60630	17015	488333	455938	449128	301	081	45
62740	17321	496767	462769	455602	280	082	51
65250	17680	506600	470694	463136	253	085	59
67100	17955	513738	476477	468558	212	076	41
69430	18278	522578	483312	475178	190	069	51
71650	18590	530878	489847	481379	157	056	46
72940	18765	535625	493529	484879	144	055	50
75700	19135	545678	501344	492276	117	057	59
77430	19372	551863	506087	496787	088	049	53

TABLE X.

					3,76+	3,86+	3,89+
17430	0,06845	0,264047	0,258598	0,257166	0,0975	0,0233	0,0010
19310	07211	277920	271618	270193	941	235	16
20960	07518	289547	282401	280788	914	235	15
23340	07945	305550	297283	295268	868	231	10
24710	08178	314386	305378	303214	843	220	10
26520	08480	325693	315703	313326	807	212	09
29560	08966	343858	332067	329451	751	197	17
30450	09164	348992	336700	333905	735	189	12
32540	09420	360775	347251	344149	699	190	17
36130	09943	380155	364385	360863	633	179	15
38160	10229	390700	373623	369845	595	169	16
40000	10482	400000	381745	377681	561	165	15
42180	10768	410509	390898	386456	522	163	14
44170	11035	420830	399266	394588	491	161	18
46910	11274	428990	406626	401740	452	146	15

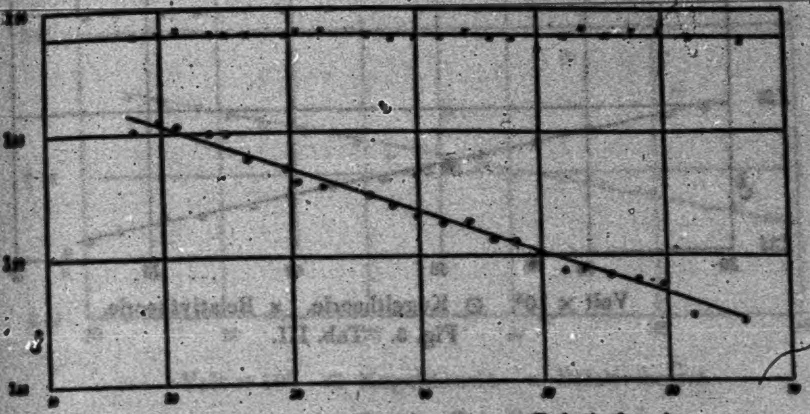
TABLE X (Continued).

Spannung P in Volt	Magnetstrom J in C.G.S.	Konst. Masse β	Kugeltheorie β	Relativ-theorie β	Konst. Masse Cβ	Kugeltheorie Cβ	Relativ-theorie Cβ
					3,76+	3,86+	3,89+
47930	0,11517	0,437867	0,414144	0,409002	0,0419	0,0142	0,0017
49920	11768	446860	421738	416274	373	125	07
51980	12018	455989	429826	423606	342	121	14
53500	12198	462590	434832	428902	324	127	25
55400	12433	471000	441819	435529	282	120	17
57760	12702	480678	449715	443128	242	118	18
59800	12935	489078	456543	449707	210	110	25
62320	13222	499289	464786	457546	162	094	18
66410	13676	515400	477657	469836	086	086	18

[194]

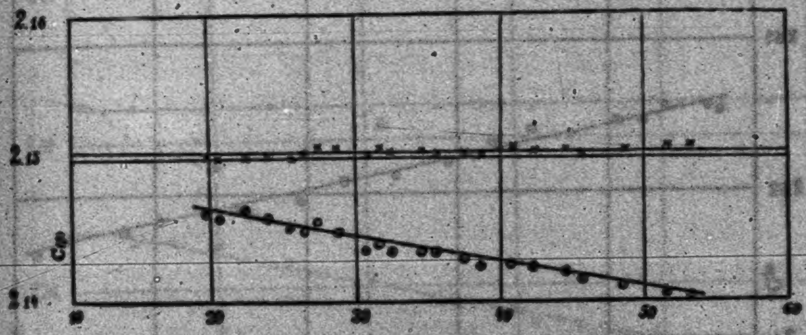
The experiments are favorable to the relativity-theory. While the value of C (β) calculated from the relativity-theory varies very slightly about a constant average value, the corresponding C (β) calculated by the sphere-theory decreases at a nearly uniform rate with increasing voltage P. The amount of the decrease about six to twenty times as great as the average deviation of C (β), computed by the relativity-theory, from its mean. In accordance with a result obtained above theoretically, the values of β calculated by the sphere-theory are greater than the equivalent values by the relativity-theory. Very great deviations are obtained if a constant mass is assumed. In this case, the rays under a discharge potential of 250,000 volts would reach the velocity of light. The value C (β) which is inversely proportional to the magnetic deviability, comes out smaller by the sphere-theory than by the relativity-theory, as theory requires.

A graphical representation of the experiments (Tables I to X) is furnished by the curves in Figures No. 3 to No. 11. The curves for the hypothesis of constant mass are left out of the figures on account of lack of space. They also would show a practically straight line and would form an angle of about 70° with the horizontal. If the curves are extrapolated graphically by prolonging the curves in the direction of decreasing voltages, common points of intersection are reached in the neighborhood of zero potential.



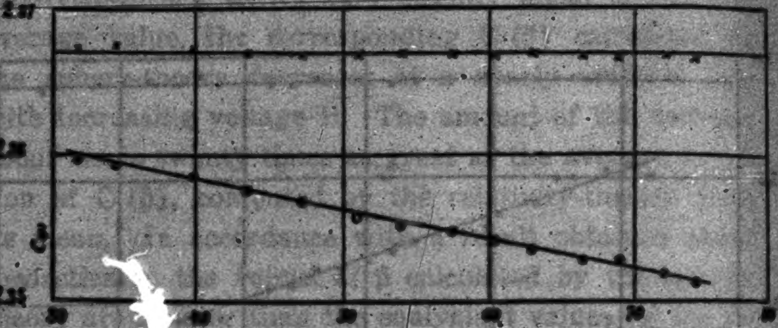
Volt × 10^3. ⊙ Kugeltheorie. × Relativtheorie.

Fig. 3. Tab. I.

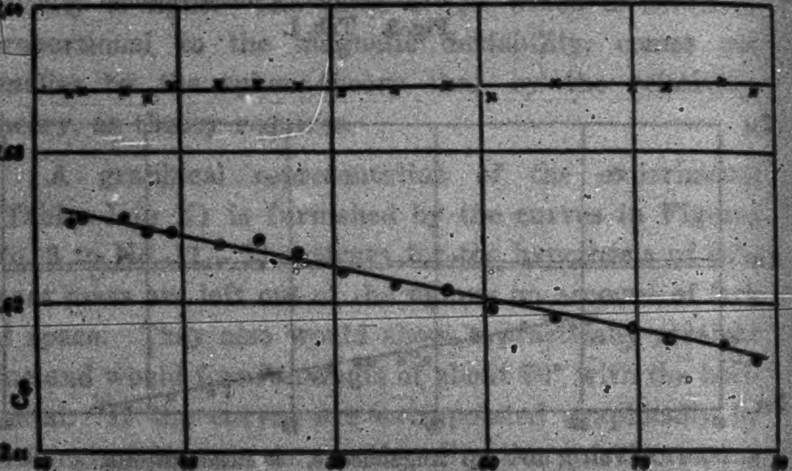


Volt × 10^3. ⊙ Kugeltheorie. × Relativtheorie.

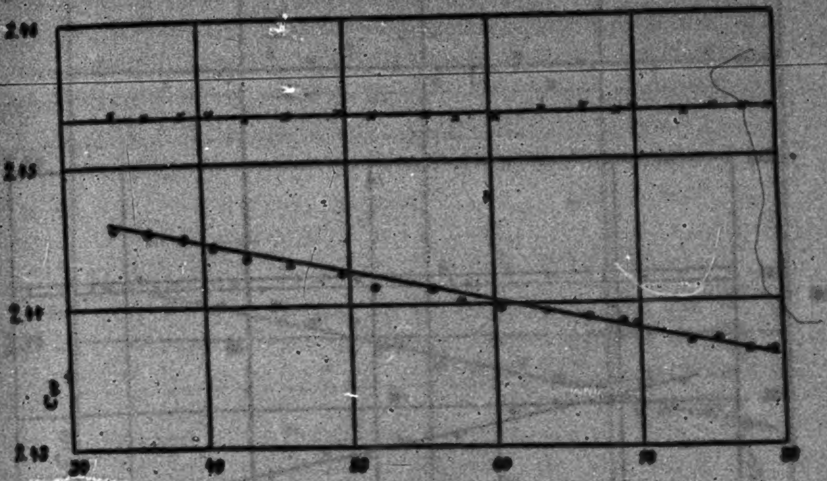
Fig. 4. Tab. II.



[illegible]t × 10^8. ⊙ Kugeltheorie. × Relativtheorie.
Fig. 5. Tab. III.

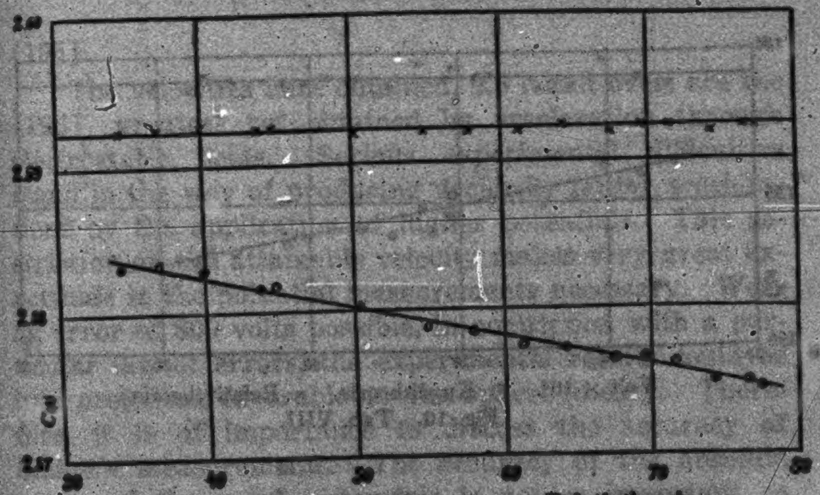


Volt × 10^8. ⊙ Kugeltheorie. × Relativtheorie.
Fig. 6. Tab. IV.

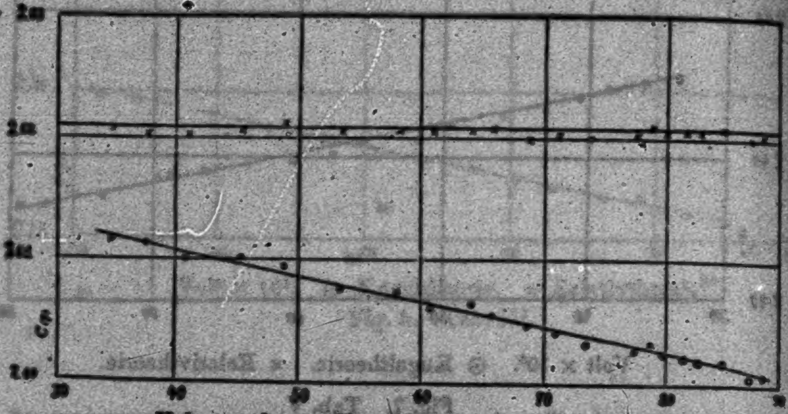


Volt × 10³. ⊙ Kugeltheorie. × Relativtheorie.

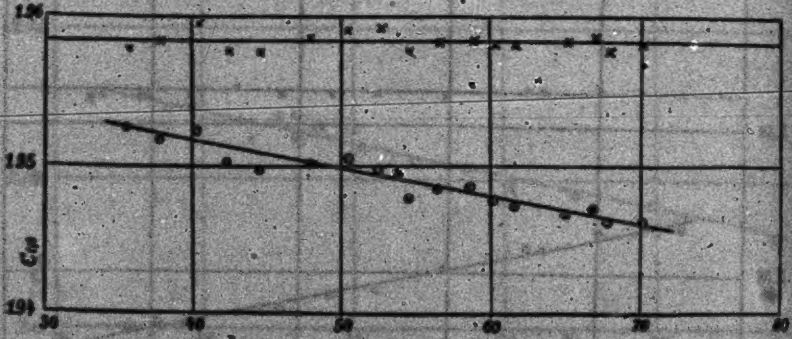
Fig. 7. Tab. V.



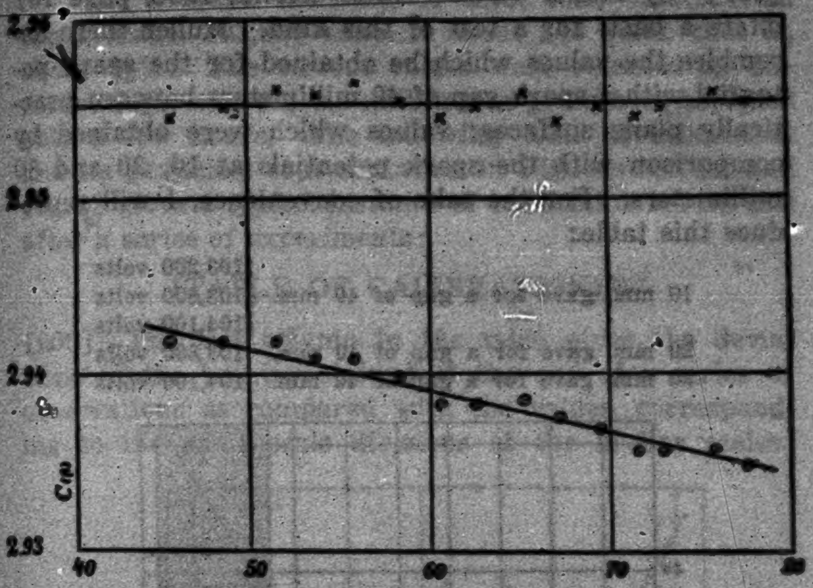
Volt × 10³. ⊙ Kugeltheorie. × Relativtheorie.
Fig. 8. Tab. VI.



Volt × 10^6. ⊙ Kugeltheorie. × Relativtheorie.
Fig. 9. Tab. VII.



Volt × 10^5. ⊙ Kugeltheorie. × Relativtheorie.
Fig. 10. Tab. VIII.



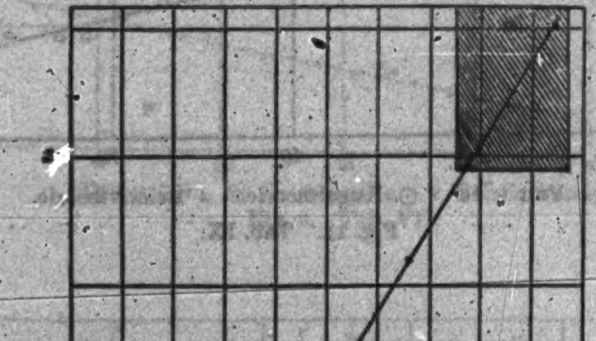
Volt × 10³. ⊙ Kugeltheorie. × Relativtheorie.
Fig. 11. Tab. IX.

[195]

The velocities here obtained, 0.5 c and over, are the [198] greatest yet obtained by acceleration through electrostatic fields. Serious experimental difficulties stand in the way of producing decidedly larger accelerations by the application of higher potentials. This restriction on the attainable velocity makes very great exactitude in the potential measurements necessary. Were an error of 800 volts possible, in connection with a particular law of errors, the experimental results could be interpreted as favorable to the sphere theory. Therefore, it is of importance to discuss the accuracy of Müller's measurements. The accuracy of the absolute values of the spark potentials is not so important as the ratio of the individual values to one another since the multiplication of the absolute values by a factor nearly equal to unity has only a slight effect upon the results of the measurements given above. A table given

[199] by Müller (Dissertation, Berlin, 1908, page 70) offers a basis for a test of this kind. Müller there assembles the values which he obtained for the spark potential with a spark gap of 40 millimeters between practically plane surfaces; values which were obtained by comparison with the spark potentials at 10, 20 and 30 millimeters. For the sake of convenience, I will reproduce this table:

10 mm. gave for a gap of 40 mm.	103,200 volts 103,800 volts 104,100 volts
20 mm. gave for a gap of 40 mm.	103,800 volts
30 mm. gave for a gap of 40 mm.	104,100 volts



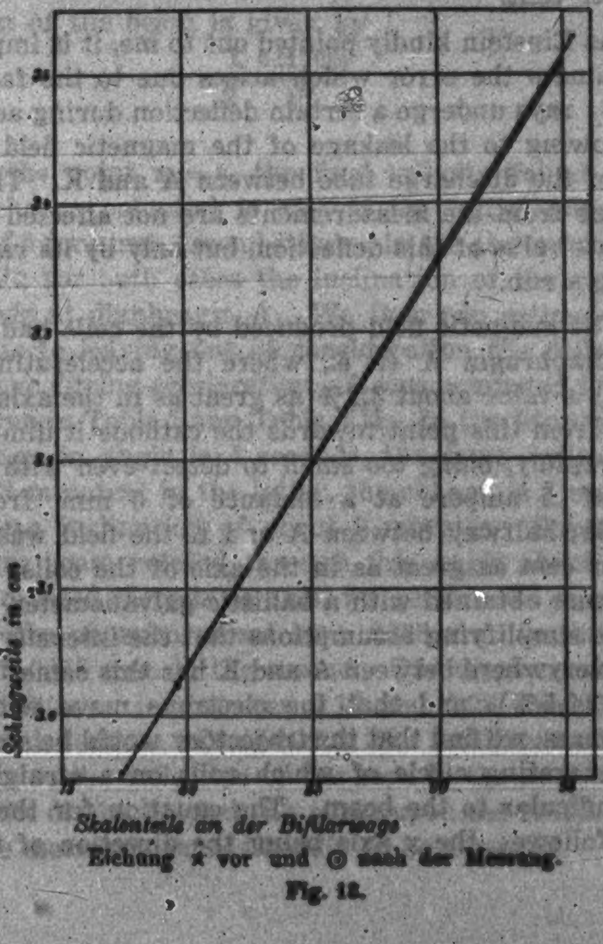
Eichung × vor und ⊙ nach den Messungen.

Fig. 12.

The average deviation of these final values from the average, 103,800 volts, is about 240 volts, that is, about ¼%. The various values were obtained on different days, whereas the calibrations given here occupied only a few hours. The following table of calibration and its graphical representation in Figures No. 12 and No. 13 gives a typical instance of calibration before and after a series of experiments:

(TABLE OF CALIBRATION)[25]

[200] The last column in the table gives the deviations of the points obtained at the end of a series of observations as compared with the values, corresponding to the same scale divisions of the bi-filar scales;



Eichung ✱ vor und ◎ nach der Messung.

Fig. 12.

found by interpolation based on the calibrated curve plotted at the beginning of the series. Figure No. 13 represents the region of maximum deviation on a scale enlarged five times. In the other series of experiments here presented the calibrations taken before and after the observations displayed an equally good agreement. [201] When the smallness of these deviations is considered, it must be assumed that the errors in the determination of the discharge potential reduce essentially to the errors in Müller's measurements of potential. But according to the above table, and also the remaining data of Müller, it cannot be assumed that these errors exceed ¼%. But the interpretation of the data in favor of the sphere-theory would require an error of about one per cent.

As Einstein kindly pointed out to me, it is important to estimate the error which arises due to the fact that [202] rays undergo a certain deflection during acceleration, owing to the leakage of the magnetic field in the part of the discharge tube between A and K. The conclusions from the measurements are not affected by the absolute value of this deflection, but only by its variation during a run.

The magnetic field produced by the coils had as the first diaphragm A (i. e., where the accelerating field ended) a value about 3.2% as great as in the axis of the coils; from this point towards the cathode it diminished very rapidly, being too small to detect even with a current of .5 ampere at a distance of 5 mm. from the cathode; halfway between A and K the field was about 0.5 per cent as great as in the axis of the coils. These data were obtained with a ballistic galvanometer. Making the simplifying assumptions that the intensity of the field everywhere between A and K has this same "mean" value (0.5%), and that the electrons move with constant mass, we find that the trajectory would be a cycloid, the generating circle of which rolls on a straight line perpendicular to the beam. The equation for the curve is as follows: the x axis being the direction of the accelerating electric field and the y axis being perpendicular to the electric and magnetic fields.

$$x = \frac{P'}{\eta_0 s H'^2}\left(1 - \cos\frac{sH'c\beta_s}{P'}\right)$$

$$y = \frac{P'}{\eta_0 s H'^2}\left(\frac{sH'c\beta_s}{P'} - \sin\frac{sH'c\beta_s}{P'}\right)$$

P' is the potential in C.G.S. units producing the total acceleration, η_0 is the specific charge of the electron, s is the distance between the plates K and A, H' is the average magnetic field between K and A, and β_s is the ratio of the velocity at the point (x, y) to the velocity of light; all the quantities being measured in electromagnetic units. The angle between the x axis and the direction of the beam is given by

$$\frac{1}{2}\,\frac{sH'c\beta_s}{P'}$$

[203]

At the point $x = s$, the final velocity found from the discharge potential is $c\beta$. If the initial and final values of β for a run are substituted in the above formula, we obtain for both cases the inclination of the rays to the x axis at diaphragm A. We then can estimate the error due to leaving out of consideration the deflection of the rays during acceleration. It was computed for the runs given in Table I and Table VII. In the former case the change in angle is 4 seconds, the mean inclination being 3.3 minutes; in the latter, the change is 7 seconds on a mean inclination of about 5 minutes. Supposing the entire beam rotated through this angle about [one of the] crossed threads as axis, we get for the displacement of the phosphorescent spot .0033 mm. in the first case and .0056 mm. in the second. The displacement of the spot thus varies between 0.17 and 0.28 Promille of the total deflection. Considering the smallness of this error due to the deflection of the rays in the accelerated part of the discharge path, an effect upon the conclusions from the measurements is hardly to be expected.

C. Summary and Conclusion.

The experiments herein described have shown that the maintenance of high voltages up to 90,000 volts is possible in a high vacuum without the occurrence of spontaneous discharge, and that very rapid cathode rays are obtained in this way ($q > 0.5\,c$). The velocities obtained in this way are decidedly less than those of the most rapid β-rays, but the electron rays accelerated by electric fields have the advantage over the β-rays of homogeneity, and therefore, are sepecially suited to accurate measurements.

The most important result of these experiments, [204] however, is their contribution to a decision between the antagonistic theories of Abraham and Lorentz-Einstein. The measurements which we have given support the latter theory. As is well known, Bucherer arrived at the same results. However, the hitherto available results of observation are not sufficient to afford a criterion of this question of the validity of the principle of relativity which is so important to the entire subject of physics; and perhaps not to physics alone. For this reason, it is much to be desired that further experiments be performed with the greatest possible variation of method, and involving the more widely different type of physical phenomena.

This investigation was made in the Physics Institute at the University of Berlin under the direction of Professor Doctor Rubens.

Berlin—Physics Institute.
(Nov. 3, 1909.)

KKD-QT

NOTES.

1. M. Abraham, Ann. d. Phys. 10, p. 105, 1903.
2. H. A. Lorentz, Versl. Kon. Akad. v. Wet., Amsterdam, 1904, p. 809; A. Einstein, Ann. d. Phys. 17, p. 891, 1905.
3. W. Kaufmann, Berl. Ber. 1905, p. 949; Ann. d. Phys. 19, p. 497, 1906.
4. H. Starke, Verh. d. Deutsch. Phys. Ges. 5, p. 241, 1903.
5. A. Bestelmayer, Ann. d. Phys. 22, p. 429, 1907.
6. J. Classen, Physik. Zeitschr. 9, p. 762, 1908; Verh. d. Deutsch. Phys. Ges. 10, p. 700, 1908; Jahrb. d. Hamb. Wiss. Anst. 25, 1907.
7. A. H. Bucherer, Physik. Zeitschr. 9, p. 755, 1908; Verh. d. Deutsch. Phys. Ges. 10, p. 688, 1908; Ann. d. Phys. 28, p. 585, 1909.
8. E. Ladenburg, Physik. Zeitschr. 8, p. 590, 1907.
9. E. Ladenburg and K. Markau, Physik. Zeitschr. 9, p. 821, 1908. 1908.
10. M. Planck, Physik Zeitschr. 7, p. 753, 1906; Verh. d. Deutsch. Phys. Ges. 8, p. 418, 1906.
11. Kaufmann in "Ueber die Konstitution des Elektrons" gives 140,000 volts as the voltage required to reach one-half the velocity of light; the discrepancy is apparently due to an oversight.
12. C. Müller, Diss. Berlin 1908; Ann. d. Phys. 28, p. 585, 1909.
13. Béla Gati, Elektrotechnik and Maschinenbau (Wien) 26, p. 263, 1908.
14. According to measurements made in the Kaiserl. Telegr.-Vers.-Amt.
15. B. Monasch, Ann. d. Phys. 22, p. 905, 1907.
16. E. v. Schweidler, Ann. d. Phys. 24, p. 711, 1907.
17. E. Madelung, Physik. Zeitschr. 8, p. 68, 1907.
18. K. Scheel and W. Heuse, Zeitschr. f. Instrumentenk. 29, p. 46, 1909.

19. F. Soddy, Proc. Roy. Soc. 78, (A) p. 429, 1907.

20. O. Reichenheim, Verhandl. d. Deutsch. Physik, Gesellsch. 11, p. 45, 1909.

21, It should be noted that insufficient vacua of this kind are never used in measurements.

22. R. v. Hirsch and F. Soddy, Phil. Mag. (6) 14, p. 779, 1907.

23. A. H. Bucherer, Ann. d. Phys. 28, p. 585; 29, p. 1063, 1909.

24. K. Wolz, Ann. d. Phys. 30, p. 273, 1909.

25. Each of the values in the table is the average of ten observations.

DEFENDANT'S EXHIBIT No. 22.

Physikalische Zeitschrift
Vol. 10 (1909)
pp. 168-176
[TRANSLATION]

CONCERNING SLOW CATHODE RAYS[1]

By O. v. Baeyer

[168]

For the specific charge of the electron, the measurements with slow cathode rays as distinguished from determinations with rays of greater velocity have given results of very poor agreement. In particular this holds for the method given by J. J. Thomson[2] for the determination of the path of the electrons which move in a homogeneous electric field and a magnetic field at right angles to the electric field. In the following I have investigated the peculiarities of slow cathode rays to explain a ground for these departures, and indeed the following points were especially considered in a more exact investigation:

1. The production of the most homogeneous slow cathode rays of great intensity by means of glowing oxide cathodes.
2. The ionizing power.
3. The determination of their velocities (in volts),
4. Secondary radiation or reflection.

Lenard[3] has investigated slow cathode rays produced by the photo-electric effect. The electrons leaving the cathode through the agency of ultra-violet light have, according to his investigations, considerable initial velocities, and indeed about 70 per cent of the aggregate have initial velocities above zero.

One cannot therefore in this way obtain a true homogeneous radiation with small velocity.

I.

On the other hand for this purpose the method of Wehnelt[4] for the production of electrons from glowing oxide cathodes is clearly superior. In general the electrons escaping from the glowing oxide possess initial velocities, as already shown by Elster and Geitel.[5] The consideration of the saturation curves on such electrodes shows, however, that the number of electrons escaping with noticeable initial velocity is vanishingly small in comparison with the total.

In analogy with the views of Lenard one obtains the number of the particles escaping with initial velocity by measuring the current which flows from the uncharged glowing oxide to its surroundings. All saturation curves of this kind show a very steep drop at zero. A more exact investigation of this point is, however, impossible without further means. If one uses, for example, an electrically incandescent wire inside a coaxial cylinder and measures the current flowing from the wire to the cylinder by a galvanometer, then since one connects either the positive or negative conductor of the heating current with the galvanometer and thereby with the cylinder, one obtains a positive or negative potential which corresponds to the potential difference on the wire.[6] Further, the magnetic field set up on the surface of the glowing wire by the considerable heating current eventually influences the whole slow cathode rays. To eliminate this difficulty, I have used for all measurements[7] a motor-driven mercury commutator which in its revolutions (five to ten times per second) closes the circuit first to the heating current, and while this is opened the circuit to the galvanometer. In this way only the electron current is measured which exists when the wire is still glowing, but not traversed by the heating current. The arrangement for the taking of the saturation curve is shown in the following Figure 1.

C is a cylinder brought into the evacuated tube, D the heating wire coated with calcium oxide. The conduction of the heating current goes from battery B over the two contacts of the commutator. The other side of the commutator connects one of the conductors of the heating current with the galvanometer, whence the current flows from the source of potential to C, the source of potential being a variable shunt resistance W, whose terminals are connected to battery B_1. The correct [169] operation of the commutator can then be adjusted so that the commutation of the heating current has no influence on the deflection of the galvanometer. For the taking of measurements there was used a Siemens and Halske galvanometer (sensitivity 5.10^{-10} amperes per scale devision) which could be shunted with a known resistance for the measurement of large currents. The shape of the saturation curve is shown by curve 1, Figure 2. The current at $V = 0$ was especially tested. There was found throughout a value under ½ per cent of the value at 22 volts where the saturation current was closely approached. The arrangement afforded a means also of determining the number of electrons which escaped with a positive charge on D.

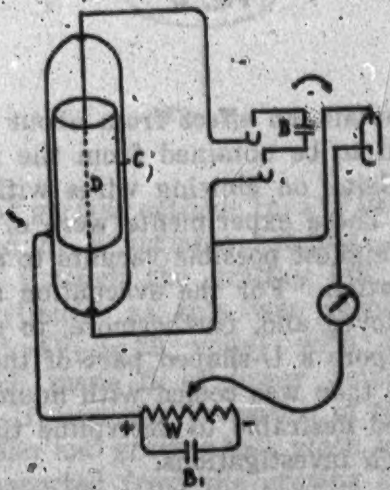


Fig. 1.

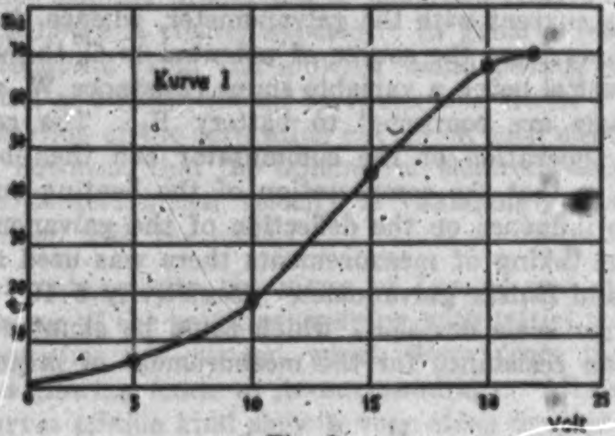


Fig. 2.

One can here obtain an effect from about 0 to 2 volts as was expected to be obtained from the investigation of Elster and Geitel on glowing wires without calcium oxide coating. These experiments were of course carried out in the highest possible vacuum to avoid the influence of ionization. For the evacuation a Kaufmann pump was employed and, furthermore, to remove mercury and fat vapors a U-shaped part of the connection to the discharge tube was cooled with liquid air. However, it appeared desirable to determine the ionization occurring in such investigations.

II. *Ionization of Slow Cathode Rays.*

Lenard[8] has shown that the limiting velocity of ionization for photo-electrically produced electrons lies at about ten volts. It does not appear certain without any further investigation that the same relations would hold with the very intense rays which we here use. The investigation was carried through in a manner analogous to that of Lenard. The glowing wire was surrounded by a cylindrical wire grating of 1 cm. diameter (wire diameter .1 mm., mesh .3 mm.); this was surrounded by a second cylinder of 2 cm. diameter. Between wire and grating cathode rays of various velocities were produced by a variable potential difference, V_1. These passed through the grating but did not reach the second cylinder, as this was placed at a negative potential ($V_2 = 20$ volts) with respect to the grating, which made it of lower potential than the heated wire. If, however, ionization of the gas contents between cylinder and grating took place, positive charges must be transported from the grating to the cylinder. If this ionization is considerable in comparison with the transported electrons, this current must be capable of detection by a galvanometer in circuit between the second cylinder and the grating. From $V_1 = 0$ to $V_1 = 10$ volts, no current was to be detected between the outer cylinder [170] and the grating. If, however, V_1 exceeded 10 volts a positive current from cylinder to grating appeared which rapidly increased with increasing V_1. This positive current did not become greater by an increase in

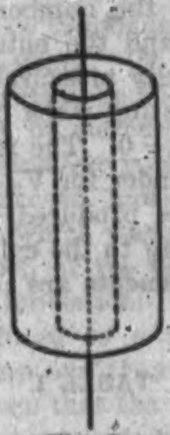


Fig. 3.

the negative potential of V_2 whence it follows that saturation was already reached. There was shown therefore a completely analogous relation to the case when the cathode rays of extremely small value were produced by the photo-electric effect. In order to determine the number of positive ions produced per electron, it is necessary to measure the number of electrons passing between the grating and the outer cylinder. For this purpose I simultaneously measured the current between outer cylinder and grating when both were at the same potential—that is, $V_2 = 0$. The ratio of the current between grating and cylinder for $V_2 = 20$ volts and $V_2 = 0$ gives the positive ions produced by an electron in its course from the grating to the cylinder and back to the grating. The measurements are collected in the following Table I.

TABLE I.

Voltage between cathode wire & wire net. V_1	Aggregate of the electrons passing from wire net to the outer cylinder (measured by the magnitude of the current at $V_2 = 0$)	Aggregate of the positive ions produced between wire netting and cylinder (measured by the current at $V_2 = 20$ volts)	No. of positive ions formed per electron
Volts	i —	i +	$\frac{i+}{i-}$
14	20,000 9)	16	0.0008
13	16,000	7	0.0004
12	13,000	4	0.0003
11	9,000	3	0.0003

The pressure in this investigation was about .01 mm. However, an exact determination of the pressure when glowing wires were used was excluded, for the same reasons I had to abandon the investigation of different gases, as determinations of the increase of the gas content due to the continuous evolution of gas from the wire and the continuously occurring occlusion of gases was impossible. Since the measurements showed that with the methods of measurement here used an ionization under 10 volts could not be detected, it is not necessary of course within these limits to take into account the errors of a still smaller ionization.

According to the views of Start[10)] this limiting velocity of ten volts, corresponds to the beginning of ionization in mercury vapor. To decide this point was of importance, as one should be able to use higher velocities by the elimination of mercury vapor in all investigations in which the smallest possible ionization is conditioned. I did not succeed, however, by the condensation of mercury vapor which was attained by the cooling of the U-formed branch of the tube with liquid air, in appreciably reducing ionization. For instance, the discharge tube was reduced to a pressure of .005 mm. with the mercury pump and then sealed off with a stop cock. It was found then that the velocity with a voltage of 14 volts on the wire grating was, for the current conditioned by positive ions, $V_2 = 20$.

$$i + = 50 \text{ scale deflections}$$

while the negative current carried by the electrons at $V_2 = 0$.

$$i - = 86000 \text{ scale deflections}$$

With the U tube cooled with liquid air, corresponding values were:

$$i + = 85 \text{ scale deflections}$$
$$i - = 106000 \text{ scale deflections.}$$

As one sees in both cases the number of positive ions formed per electron are very approximately equal. If the vacuum was raised as high as possible by the application of charcoal cooled with liquid air it was easily attained that the ionization with not too high velocities became no longer measurable by the methods here given.

III. *Velocity of the Rays Produced.*

With the same experimental arrangement an attempt was now made to investigate the velocity of the cathode rays produced. If one assumes that the electrons emitted from the incandescent wire pass through the wire grating with a velocity corresponding to the potential difference between hot-wire and wire grating, then no electrons can arrive at the outer cylinder when this has the same negative potential with respect to the grating as has the hot-wire. If the negative potential V_2 of the cylinder is now reduced by an arbitrary small amount then the total number (of electrons) passing through the grating should reach the cylinder. In the neighborhood, therefore, of this potential, the number of electrons reaching the cylinder should increase with extreme rapidity and maintain the same value with further lowering of the potential. It is here assumed that the electrons pass through the wire grating at right
[171] angles to its surface. The execution of the experiment gave the following results:

With very careful evacuation with the Kaufmann

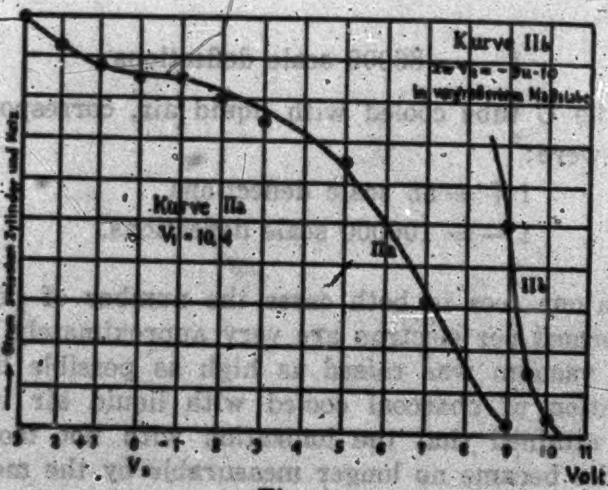


Fig. 4.

pump and cooling with liquid air of the connected U-tube, one obtained at $V_1 = 10.4$ a very sharp increase in the current i between cylinder and grating between $V_2 = 10.4$ and 9.0 volts. The curve II^b (Fig. 4) represents the characteristic of i from $V_2 = 9$ to $V_2 = 10.6$. It was noticeable that in the neighborhood of $V_2 = 10$ the current i was significantly affected by the kind of evacuation. For example, with evacuation by the mercury pump alone there was a deflection of six scale divisions for $V_1 = 10.4$, $V_2 = 10$, while the cooling of the U-tube with liquid air permitted the deflection to rise to 50 scale divisions, at which point the current sent out from the incandescent wire remained approximately constant. This showed that the electrons, which in this case had very small velocities in the neighborhood of the cylinder, were deflected, without the production of appreciable ionization, by the readily condensible part of the gas content, therefore in particular by the vapors of mercury and oil.

With a further decreased negative potential of the cylinder, however, the number of electrons caught by the cylinder constantly increased in the same measure; a constant value could not even be reached with a positive potential of about 4 volts. The characteristic is shown in curve IIa (Fig 4) in the region from $V_2 = -9$ to $V_2 = +3$. One may only conclude from this investigation that a small part of the aggregate rays pass through the wire grating with a normal velocity V_1.

The increase of the effect between $V_2 = 10$ and $V_2 = 0$ can be interpreted differently. One may assume that a considerable part of the electrons in passing through the grating experience a deflection by reason of the complicated character of the field in the neighborhood of the grating. A part of the electrons which with large retarding fields would be driven into the grating, will with small or accelerating fields pass through the meshes without striking the wires, reach the cylinder and thereby explain the increase of current.

Another possibility would be that the particles passing through the grating do not possess equal velocities. In this case, the particles must be given out not from the oxide cathode but from the gas residue, as is often assumed with visible cathode rays. In our case this is very improbable, as then ionization must have made itself noticeable.

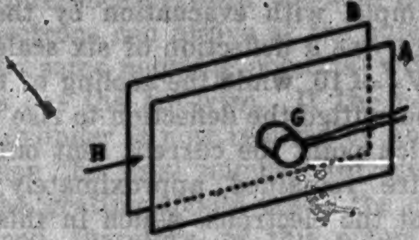


Fig. 5.

Finally one might assume loss of velocity on the part of the electrons by collision with gas particles. Lenard[11] in this way has explained observations of a similar character. In contradistinction to his research where the path of the rays was long (7.7 cm.) and the vacuum not very high (0.0025 mm.), in the investigation here described the path of the rays is only 1 cm. and the vacuum raised to the highest possible value with liquid air so that the departures in every case are not possible of explanation by this assumption alone.

To eliminate now as much as possible the influence of the wire grating, this was replaced by a diaphragm with which the inclination of the rays with respect to the surface of the diaphragm was as well defined as possible. For this purpose the incandescent electrode was placed in a hollow tube C (Fig. 5), the base of this tube was 2 mm. thick and was pierced with a few openings of 1 mm. size. This base lay on the middle of an [172] 8 cm. square brass plate A, and in the plane of

A. Finally there stood at 4 mm. distance an equal sized brass plate B, which corresponded to the external cylinder of the previous arrangement. As regards changes in the potential of the plate B, this investigation gave the same results as those of the foregoing part. With this arrangement, in case the rays were not influenced by the diaphragm, the rays passing through the diaphragm could proceed at most in a cone of about 54°. If one assumes that the rays of greatest inclination in every case had the velocity corresponding to the potential drop V_1, then the normal velocity component of these rays was v cos 27°. It would follow from this that these rays must reach the plate B in case V (the negative potential of B with respect to A) lay under $0.8 V_1$.

IV. *Secondary Rays: bzw. Reflection.*

With the last arrangement other disturbing phenomena appeared which admit of explanation, just as in the above described investigation, if one assumes a scattering of the rays by the metal particles encountered. Indeed, scattered rays were always present in the space between the plates A and B. Finally the effect, which has been already described by Thomson[12)] was of such a character that a weak magnetic field in the direction of the arrow (see Fig. 5) which could not noticeably affect the primary rays, yet caused a strengthening of the stream flowing from B. If one assumes a scattering of the rays by impact on B, the observed phenomena are simply explained by the bending back of the scattered rays which have a smaller velocity, at least normal to the impacted surface, than the rays striking the surface, and therefore are more easily influenced. In general hitherto a secondary radiation, reflection by metal particles, at the anode potential has not been known to exist for such slow rays.[13)] Lenard has found such secondary rays at velocities corresponding to 100 volts upward with a maximum effect occurring at 400 volts.

It was therefore necessary to devise an experimental arrangement which permitted of the certain detection of the presence of these secondary rays, bzw reflection. The experimental arrangement is shown in Fig. 6. In a cylindrical discharge tube, which was oriented in the direction of the earth's field, a brass tube A was placed. This tube was closed by a brass plate, in whose center a narrow brass tube B was placed (of 5 mm. diameter). The ring-shaped space between A and B contained a ring of brass foil which was insulated therein. At the top the ring-shaped space was closed by a wire grating C. This rendered it possible to impart to the ring an arbitrary potential difference with respect to its surroundings. D is a circular brass plate which may be lowered and raised. The cathode rays are emitted from the spirally wound platinum wire E, pass through B,[14] and fall upon D. The reflector D and the cylindrical member A are at the same potential with respect to the hot-wire. In order to permit the maximum possible rays passing through the grating C to reach R, the ring R is maintained at a positive potential with respect to C of the same value as that between A and E. If secondary rays or reflection is present, then an increase in

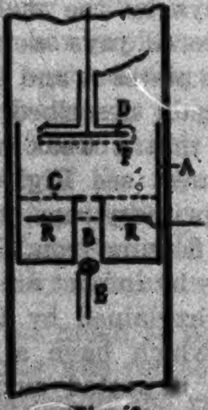


Fig. 6.

the number [of electrons] caught by the ring R must be capable of detection when the reflector is brought closer to the wire grating.15)

Once the current was measured between the ring R and A, in other cases between D and A. When by evacuation for many hours and the continuous application of liquid air the pressure was reduced to the lowest limit, and the rays had become fairly constant, the meas- [173] urements of the number [of electrons] falling on the reflector and on the ring for two separations of the reflector from the net C of about 17 and 7 mm. gave the following results:

TABLE II

Velocity of the primary rays in volts. (Potential difference between E and A)	Current in scale divisions between D & A		Current in scale divisions between R & A		Separation D — A in mm.
[illegible]	82	84	72	74	7
	85	89	62	67	17
4	66	65	98	93	7
	68	66	77	78	17
2 16)	14	—	38	—	5
	19	—	19	—	10

From this table one sees the following: The part of the rays reaching the reflector is approximately constant for the separation investigated. This shows that there is present no noticeable scattering of the rays by the gas residue. In any case at greater reflector separations the loss by scattering could be cancelled by the rays from the surrounding tube A. That this, however, could not be the case in any considerable degree follows from the fact that the quantity falling on D showed no marked diminution at very large separations up to 4 cm.

The current flowing from the ring R is in every case increased by the approach of the reflector D. This proves that the reflector is the source of rays.17)

If the separation between reflector D and grating C is further increased, the current flowing from the ring R does not further decrease in any considerable degree. As this is hardly to be explained by scattering of the rays by the gas residue, one must assume that the rays passing out of B which are considerably scattered by reflection on the inner walls of B, in their further course strike on the walls A, are there reflected, and so reach R.

Whether one has to do with secondary rays or diffuse reflection does not yet admit of decision. The same must be said of the question whether the observed phenomena proceed from the metal itself or from a gas film on its surface. Yet it may be established that the rays falling on the ring are of the same order of magnitude at the same velocity as the primary rays.

The increase of the current flowing from R is, in comparison with that flowing from D, larger with smaller primary velocities of the rays which signifies that the reflected number increases with decreasing primary velocity. If one compares this with the results of Lenard(18) who found a maximum of the secondary rays at a velocity of the primary rays corresponding to about 400 volts, then my research seems to say that one has here to do with another phenomenon. It appears that here a kind of diffuse reflection occurs, that is, change of direction of the moving particles by collision with molecules. In the latter investigation the cathode rays entered a space free from electric forces, so that the rays thrown back could move away from the reflector without any further agency. Furthermore, in the presence of an electric field which tends to retard the reflected rays, the reflected rays can cause disturbances under certain conditions.

If, for example, we place an incandescent oxide cathode at negative potential opposite a positively charged plate, in any case the rays reflected from the positive plate can not return to the cathode, since they possess at most a velocity corresponding to the potential difference between anode and cathode. If, however, the surroundings, for example the walls of the vessel, are raised to a positive potential with respect to the cathode, a part of the reflected rays can be intercepted and be incapable of detection. This is the reason why one can obtain true saturation curves only when one reduces the lateral deflection. So serviceable measurements with incandescent wires can be conducted only with an arrangement such that the incandescent wire is placed in the axis of a cylindrical tube whereby lateral deflections are negligibly small.

Lenard in his measurements has used a magnetic field in the direction of the rays to avoid lateral radiation. As one sees, thereby the influence of the herein described reflection is limited to the lateral diffusion. In any case, in the investigation of the photo-electric effect the matter is somewhat more complicated, as the [174] electrons so produced possess in considerable numbers noticeable initial velocities. Consequently a part of the number reflected from the anode may be returned to the cathode even with external accelerating fields.

Reflection must result in significant departures in all cases where the primary rays are retarded by an external field. In this way I believe that the departures from the results to be expected, as described in Part III, admit of satisfactory explanation.

V. *Avoidance of Reflection.*

The question now arises as to how this reflection is to be avoided. There are altogether three possibilities.

1. Application of an auxiliary field to restrain the reflected number (of electrons).
2. Application of the Faraday cage.
3. Selection of a suitable material.

I have adopted the method stated under 1 in that 2 mm. in front of the reflector D a fine wire grating F (0.15 mm. wire, 1.5 mm. mesh) was arranged which could be moved simultaneously with the reflector. While the grating was maintained at the potential of the surrounding [cylinder] A, the reflector could be brought to any desired potential. It was to be expected that with increasing positive potentials of the reflector D with respect to the wire grating F, the current flowing from reflector to A would increase up to the point where the auxiliary field sufficed to restrain the number of electrons reflected at D. In fact, the measurements showed a significant increase in the current up to a potential difference of 40 volts between the reflector and wire grating. That ionization in the space between reflector and wire grating did not here occur could be easily established by the fact that with a negative charge of 40 volts on the reflector with respect to the wire grating, no current flowing from the reflector could be detected.

From the measurements of the current flowing from D with and without the auxiliary field the ratio of the reflected to the arriving number [of electrons] could be approximately determined. Let i be the current flowing from the reflector without a field between grating and reflector, and i_1 the current in the presence of a field of such magnitude that a further increase (of the field) caused no further increase of the current. The practical part of the rays passing through the grating which is thrown back by the reflector in the absence of the field is then,

$$\frac{i_1 - i}{i_1} = r$$

The measurements gave:

TABLE III.

Velocity of the Primary Rays	i	i_1	r	
6 volts	9	52	0.83	Potential Difference between plate D and grating = 40 volts
	10	68	0.85	
8 volts	31	144	0.78	
	28	129	0.78	
16 volts	54	185	0.71	
	48	178	0.72	
	40	158	0.75	

From these measurements it follows that a considerable number of the rays arriving at D are reflected. The values found for the reflection factor r furnish a criterion for the magnitude of reflection. They can hardly be quantitatively correct as the sources of error were present in these measurements.

1. The reflection factor r gives in these cases the ratio of the number reflected at D to the number passing through the grating. One will therefore obtain the correct value when that part of the aggregate number which is absorbed by the grating is equal with and without the auxiliary field. This is not here the case as a part of the electrons, which without the field strike the wires of the grating, will in the presence of the field be bent away from the wires of the grating and reach the reflector through the meshes. Consequently the apparent value of r will be too large. The errors thus caused can, however not be large. For the part of the aggregate rays coming from the incandescent cathode which strikes the grating may be approximately calculated from the dimensions of the wire and mesh of the grating. It contributes in this case about ⅕ of the on-coming number [of electrons]. If one assumes the most unfavorable case, namely that this entire part reaches D in the presence of the auxiliary field, then $\frac{i}{i_1} = 1 - r$ comes out about ⅕ too small. For r itself there result these corrections in Table III.

For 6 volt rays r = 0.80 instead of 0.83
For 16 " " r = 0.68 " " 0.73

2. The second source of error to be considered is the disturbing field which exists such that the lines of force of the field between reflector and grating reach out into the space outside the grating.

This field will so act that those rays, which in the absence of this field reach the walls of the tube by rea-

[175] son of scattering by metallic particles or by the gas residue, or also by the formation of carriers, strike on the grating and the reflector. To avoid this source of error as completely as possible two diaphragms were placed in the tube of 2 mm. opening and 5 mm. separation. The result was that the scattered rays which arrived at the ring R were reduced to the tenth part of the number caught by the reflector, whereas in the previous investigation both numbers were of about the same order of magnitude. It was still necessary to determine by investigation the magnitude of these errors. For this purpose the reflection factor was determined for different separations of the reflector while the grating was moved simultaneously with the reflector.

The measurements gave for 10 volt rays:

TABLE IV.

Separation between grating and diaphragm	$\frac{i_1 - i}{i_1}$	i
3 mm.	0.74	88 scale divisions
8 mm.	0.70	97 " "
16 mm.	0.79	72 " "

From these numbers it follows that the quantity $\frac{i_1 - i}{i}$ is on the whole constant within the separations investigated. Still one recognizes that with very small separations, the disturbing field brings out rays from the space within the diaphragms whereby the reflection factor is apparently increased. With increasing separation this effect decreases. At the same time a still further increased separation results again in an increase in r, which is explained by the fact that with the application of a field between grating and reflector, rays, which in the absence of the field do not reach the grating, are drawn thither by the lines of force external to the grating, which in effect of course again conditions an apparent increase in r. The numbers given in Table III are based on a separation of about 8 mm.

Velocities of the rays under 6 volts could not be used in these investigations, since then the intensity was too small to measure on account of the diaphragm in B (Fig. 6). In the investigated interval between 6 and 16 volts, different values were obtained which show one significant phenomenon; for small velocities larger reflection factors. In accordance with the foregoing considerations one could trace this back to the stronger scattered rays with smaller velocities. From the previous investigations, which in this particular aspect are free from ambiguity, it likewise results that the reflected number increases with decreasing velocity, so that such an increase is established beyond question. As mentioned above, this is in agreement with the view that one has here not to do with secondary rays, as in Lenard's investigation, but with a simple scattering as has been also shown for gases.

VI. *Repetition of the Experiment under III with Avoidance of Reflection.*

In the measurements given under III of the velocity of the cathode rays, it was already mentioned that the presence of reflection would considerably influence the measurements. It was interesting, therefore, to investigate for such a case the effect conditioned by the suppression of reflection. Such an investigation was undertaken with the arrangement last described, in which a variable retarding potential was impressed between the grating and the outlet diaphragm. Whereas in the previous investigation with increasing retarding fields from a zero field up a systematic decrease of the current flowing from the intercepting plate resulted, now an entirely different characteristic curve appeared. In curve 8 (Fig. 7) the original velocity of the rays is 10

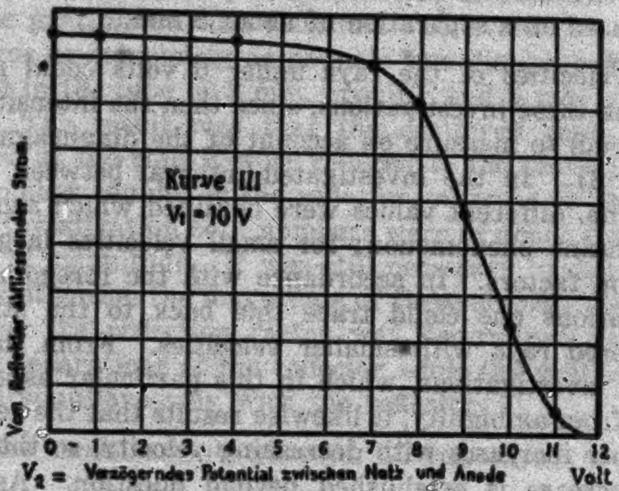


Fig. 7.

volts. As one sees, the number of rays striking the reflector remains constant, when the negative potential V_2 of the grating with respect to the diaphragm increases from 0 to 8 volts. Here begins a more rapid decrease of intensity up to $V_2 = 11$ volts. This interval, which is still considerable, in which the velocities of the rays appear to lie, cannot be traced back to an actual non-homogeneity of such magnitudes. Rather in explanation of this phenomenon the circumstance suffices that in this experimental arrangement neither the plate [176] D nor the grating is of infinite extent. For this reason rays which are emitted in a direction not exactly normal to the diaphragm but which with weak retarding fields between the grating and the diaphragm still arrive in the region of the grating with stronger retarding fields are forced off and laterally deflected.

The research herewith described has established the presence of a phenomenon similar to reflection with slow cathode rays. There is still required searching investigation to determine how this reflection depends on the material, the angle of incidence and above all the velocity of the primary rays. The determination of the velocity and specific charge of slow cathode rays will be improved on the basis of the views here given.

Berlin, Physikalische Institut der Universitat.
(Eingegangen, 19. October 1908.)

NOTES.

1. Abstracted from the Verh. d. D. Phys. Ges. (10) 96, 114, 1909.

2. J. J. Thomson—Phil. Mag. (5), 48, 547, 1899.

3. Ann. d. Phys. (14), 2, 355, 1900; (8), 149, 1902; (12), 449, 714, 1903; (15), 485, 1904.

4. Wehnelt, Ann, d. Phys. (4), 14, 425, 1904.

5. Wien. Ber. (97) 2a, 1175, 1888.

6. This is the so-called Edison effect in incandescent lamps.

7. Also in the cases when it is not mentioned in the description of investigation.

8. Lenard, l. c.

9. These large deflections are not directly observed, but calculated from the deflections with properly chosen shunt resistance.

10. Stark—Phys. Zeitschrift 5, 51, 1904.

11. Lenard, Ann. d. Phys. (4), 12, 726, 1902.

12. J. J. Thomson, l. c.

13. The known phenomenon that cathode rays as such are reflected from a plate has here no bearing. This appears when the plate has the potential of the cathode and is to be explained by electrostatic deflection.

14. The diaphragm shown inside B in the figure had to be omitted in order to attain the necessary intensity.

15. The arrangement is similar to that used by Stark (Ann. d. Phys. (4), 3, 75, 1900). While, however, with the arrangement of Stark only that part of the rays conditioned by scattering was influenced by displacement of the reflector, while the reflected number remained constant, on the other hand with the above arrangement a change in the quantity of electricity flowing from the ring R with change of position of D is only to be explained by the presence of secondary rays or reflection.

16. The measurements at two volts velocity had to be conducted at small separation on account of the feeble intensity.

17. By a special investigation it was established that the auxiliary field between the ring R and the net C conditioned no sources of error by its action outside the net. For this purpose the net C was completely removed and the ring given the same potential as the surrounding. The measurements gave qualitatively the same results.

18. Lenard, Ann. d. Phys. (4), 15, 485, 1904.

DEFENDANT'S EXHIBIT No. 23.

UNITED STATES PATENT OFFICE.

CHARLES J. THATCHER, OF UPPER NYACK, NEW YORK.

METHOD OF EXHAUSTING VESSELS.

1,028,636. Specification of Letters Patent. Patented June 4, 1912.

No Drawing. Application filed March [illegible], 1910. Serial No. [illegible].

To all whom it may concern:

Be it known that I, CHARLES J. THATCHER, a citizen of the United States, and a resident of Upper Nyack, in the county of Rockland and State of New York, have invented a certain new and useful Method of Exhausting Vessels, of which the following is a specification.

The process which constitutes this invention relates to the exhaustion of any vessels whatsoever in which it is desirable to rapidly and economically attain high vacua. It may be used either for exhausting electrical apparatus which are permanently provided with electrical conductors or terminals, such as incandescent lamps, vacuum tubes, etc., or for exhausting non-electrical apparatus provided with suitable conductors or terminals only for the purpose of exhaustion.

The object of this invention is therefore to attain high vacua in any vessel requiring complete exhaustion, and the invention consists in effecting this in a rapid and economical manner without introducing into the vessel, or otherwise employing, any gas absorbing substance.

It is well known that complete exhaustion of vessels to high vacua by mechanical pumping alone is a slow and somewhat costly procedure. The difficulty lies in the exhaustion of the last traces of gas.

My invention relates more particularly to the rapid removal of these last traces of residual gases remaining after mechanical exhaustion.

At the present time, so far as I am aware, the only process of rapid exhaustion is that used in the manufacture of incandescent lamps and set forth in U. S. Patent #537,693 to Arturo Malignani. Three steps are essential to the operation of this process. They are the preliminary mechanical exhaustion of the lamp to a pressure of about 2 mm. of mercury; the intensive incandescence of the filament of the lamp in this attenuated atmosphere and at a sufficient intensity to produce a characteristic faint bluish haze throughout the interior of the bulb; and lastly, the vaporization of a suitable solid substance, such as arsenic, iodin, sulfur, phosphorus, etc., previously deposited in some convenient locality within the interior of the lamp bulb. The process of said patent also comprises additional elements or steps which I consider tributary to the three fundamentally essential elements above referred to. These tributary steps have been modified in Letters Patent, and in commercial practice to some degree, as regards the means employed for carrying them out and the sequence of their performance. Otherwise the modern practice of incandescent lamp exhaustion is substantially identical with that devised by Arturo Malignani in 1894 and disclosed in his Letters Patent. In all of these modified procedures as well as in the Malignani process itself, the extraneous solid substance deposited within the lamp combines with and precipitates, when it is vaporized, practically all of the gases in the lamp interior, accompanied by the disappearance of the blue haze.

My process, as applied to incandescent lamps, differs from that just considered in that I secure a high vacuum without the use of any such extraneous solid substance. I extend the preliminary mechanical pumping so that a vacuum is obtained which is generally higher than that proscribed by Malignani or than that attained by mechanical pumping in the practice of his process. I then institute the intensive incandescence, proper, of the filament, whereupon a decrease of pressure which is equal in extent and rapidity to that produced by the Malignani process at once occurs.

The exhaustion of lamps from 2 mm. down to say 0.2 mm. is therefore effected by my process merely by the continuation of mechanical pumping instead of by the use of vapors of solid substances as by Malignani. The completion of exhaustion, i. e. from 0.2 mm. down is effected by the same means in both processes, namely by the intensive incandescence of the filament for the same length of time and with the same result, as has been shown by investigation. Operating in this manner, the use of suitable substances as disclosed by Malignani may be entirely dispensed with and an equally high vacuum is obtained in substantially the same time—or even less as I will later show. Since this method of procedure does not vary in any manner the degree or duration of the intensive incandescence of the filament as now employed in the exhaustion of incandescent lamps, it is obvious that the filaments will not undergo any changes which do not occur in the [illegible] exhaustion now universally employed, and that they are therefor not injured by the practice of my process.

It has been demonstrated that filaments which are ordinarily used in incandescent lamps have initially a certain ability to precipitate gases in comparatively high vacuum, but lose this ability after they have been incandesced for a period, particularly at voltages above those they are designed for. The ability of these filaments to precipitate the gases in comparatively high vacua is limited, moreover, as to the amount of gas which they are able to remove. There exists, in other words, a certain proportionality between the size of a filament and the amount of gas which it will precipitate; at all events, this is borne out by the fact that a rapid reduction of pressure to very high vacua occurs with certain small and limited quantities of gas at certain low pressures, but does not with larger quantities at higher pressures. In view of these considerations it is apparent that the practice of this process in vessels containing solid conductors requires the use of a conductor or filament which has not previously been lighted for any appreciable time, particularly at intensive incandescence, and requires also a suitably extended preliminary mechanical exhaustion of the vessels. It was the realization of the necessity of these conditions and the practical application thereof to the exhaustion of vessels without the use of extraneous suitable substances which enable me to devise the herein described process. This limited precipitating power of electrical conductors may be termed their normal, intrinsic precipitating power, for it represents that normal quantity of gas which can be rapidly removed from a rarefied atmosphere without any pronounced or recognizable disruptive effects on the conductor itself, and which removal is occasioned by phenomena which are intrinsic to an electrical conductor during the passage of a current. This normal, intrinsic precipitating power can be readily ascertained by a few appropriate trials with any suitably arranged apparatus. By decreasing, step by step, the pressure in the apparatus before the current is first passed through the conductor in each trial, a certain pressure will finally be reached in which a decrease of pressure down to a very high vacuum occurs with great rapidity. The normal, intrinsic precipitating power will always vary, naturally, with the size and nature of the conductor, the intensity of the current passed therethrough, and, apparently, with the nature, condition and size of the walls of the vessel. In view of these many factors, it is impossible to specify the maximum quantity or pressure of gas which can be exhausted from any certain piece of apparatus, but by means of the directions above set out, any one skilled in procedures of this nature will readily ascertain the normal, intrinsic precipitating power of a conductor during the passage of a current of a suitable high intensity.

In lamps containing carbon filaments it has been customary to attach the filament to the leading-in wires by means of what are technically known as clamps. These latter are composed usually of a paste composition containing carbonaceous materials which decompose when the filaments or clamps become red hot, and evolve gas in considerable quantities thereby. For this reason the carbon filaments of the lamp have to be "worked" as it is termed, either during the final stages of mechanical exhaustion or immediately thereafter. A very high vacuum cannot be attained or maintained in any incandescent lamp containing such or similar clamps until these gases have been evolved.

In carrying out the herein described process which constitutes my invention, with vessels containing solid conductors and clamps of this character, it is obviously necessary, in order not to destroy the normal, intrinsic precipitating power of the filament, to effect the working of the clamps without any considerably extended incandescence of the filament. I may employ any means to effect this result, but have found in practice that the carbon filament of an incandescent lamp is still able to precipitate gases at a pressure of 0.3 mm., more or less, provided the working of the clamp has been carefully and rapidly executed. That is, the filament is not injured for the practice of my process providing the clamps are worked by first turning on the current after the pressure has been reduced to about one millimeter, or preferably less, by mechanical pumping, and while the same is continuing then increasing the current rapidly to the minimum intensity which will cause the clamps to become red hot in a few seconds. I maintain the filament and clamps at this degree of incandescence for a few seconds longer and then immediately shut off the current and continue the pumping down to the necessary low pressure corresponding to the normal, intrinsic precipitating power of the conductor. In carrying out this working, I must emphasize, it is advantageous to initiate it at a tolerably low pressure, something less than one millimeter, for the clamps then more readily acquire and retain a red heat.

After practically all the gases contained in the filament and clamps have been thus evolved, and the lamp has again been brought down to a suitable low vacuum by continued pumping, I institute the intensive incandescence of the filament proper, that is I bring the current voltage up to a sufficient intensity to produce the blue haze phenomenon, and maintain the same until the blue haze disappears and the desired almost perfect vacuum is attained; 30 seconds more or less are usually sufficient. Any other means of evolving the gases from the filaments and clamps or any means which would obviate the necessity of such a procedure may be employed in combination with my method of removing gases at low pressures. In lamps containing filaments and clamps of any description which would not evolve gases in any detrimental amount upon the initial incandescence of the filament this working in the above described manner, or in any other, may be, of course, dispensed with. In a somewhat analogous manner, traces of residual gases may be removed from vessels by passing a suitable current through the gases themselves by means of terminals. The current must be sufficiently intense to overcome the resistance of the vacuous space, and to suitably ionize it and produce a pronounced luminous discharge in the vessel practically until the desired final gaseous pressure is obtained. In this modification, also, the amount or mass of residual gas within the lamp should not exceed the normal, intrinsic precipitating power of the electrically excited conductor, which value may be ascertained for any type of vessel by a few appropriate trials as before explained.

A treatment similar to the "working" before referred to may be carried out in vessels containing gaseous conductors, provided it is rendered necessary by the presence of substances, on or near the terminals or in other interior portions of the vessel, which might evolve gases either during the process of exhaustion or in actual use. Any vessel, indeed, exhausted by my process, should be previously heated by some suitable means sufficiently to drive off from the interior walls the films of water or gas which normally adhere to the surfaces of solids. After either or both of these treatments have been effected and the gas or vapor thus evolved has been pumped out until a suitable pressure corresponding to the normal, intrinsic precipitating power of the conductor has been reached, the process of exhaustion is completed by passing a current of suitable intensity through the vessel as before explained, and preferably after the pump has been shut off.

My process can of course be carried out by other means and in other ways than those specifically described. For example, the exhaustion of incandescent lamps can be effected by the passage of a suitable current, not through the filament of the lamp itself but through a supplementary solid conductor or even through the residual gases of the lamp, after the filament has been worked as before explained if necessary, and after the lamp has been exhausted by pumping or other means to a pressure corresponding to the normal, intrinsic precipitating power of the conductor used for this purpose. This procedure would be preferable in lamps containing very sensitive filaments, which would be damaged by even a brief period of intensive incandescence, and in low voltage lamps. My process may, indeed, be thus carried out with lamps of any description whatsoever, in which it is thought that the filament is unsuitable, or might be injured by reliance upon it, to effect exhaustion as herein set forth. Such a procedure entirely dispenses with even the period of intensive incandescence of the filament now employed in the exhaustion of incandescent lamps and obviates any damaging effects to the filament arising therefrom. One method of safeguarding the filament in this way would be to effect the exhaustion by the passage of a current through the gases of the lamp by means of suitably applied external terminals or auxiliary internal terminals.

It will of course be understood that I do not confine myself to the specifically described methods of passing electrical currents through exhausted vessels or suitably ionizing or electrically exciting the gases in their interior.

By exhausting vessels according to the herein described process certain practical and important advantages result. Thus it is economical to dispense with the use of a suitable gas-absorbing substance in exhausting incandescent lamps. Although the process of exhaustion now employed requires the use of a very small amount of a suitable substance such as phosphorus, the total cost of the same and of its deposition in the tubultures of large numbers of lamps is considerable. By my process the tubulture can be made shorter. The consequent saving in glass tubing amounts to a further considerable item.

Incandescent lamp exhaustion by my process is also more economical than the present practice in that it requires less attention on the part of the lamp operator and is, in reality, more rapid. A comparatively large number of lamps can be attached to each pump and the mechanical exhaustion can then proceed while the operator is attaching or attending to another series of lamps. After the proper vacuum has been reached, as ascertained if desirable by a reading of the gaseous pressure by means of a suitable gage attached to each series of lamps, the current can then be turned on in all of the lamps simultaneously and continued until the exhaustion is completed. A determination of the pressure common to all the lamps can now be made again and in a very few seconds by the said gage, to insure that the requisite high vacuum has been attained; or the disappearance of the blue haze may be relied upon to determine this point. By a suitable arrangement of gas jets the lamps may then be all sealed off simultaneously and the current finally turned off. With a fairly good pump, a vacuum of 0.2 mm. or less can be attained in considerably less than 2 minutes as contrasted with the 20 to 60 seconds of mechanical exhaustion now employed in the operation of the Malignani process. But then allowing as much as 5 minutes for mechanical exhaustion, during which time the operator's attention can be given to another series of lamps, the exhaustion of a bank of twenty or more lamps by my process will not occupy ten minutes altogether, or less than 1 minute per lamp. This method of procedure, rapidity of exhaustion and output per operator cannot be duplicated by the present practice of lamp exhaustion, as each lamp requires individual attention and treatment on the part of the operator during the critical portion of the exhaustion. In addition to these advantages the herein described process is superior to that now in use in that it more perfectly insures the continuance of a high vacuum in the lamp during actual use. The gases are precipitated by my process in a more stable and permanent combination than by the present practice. The substance, phosphorus, which is now used, and which hold the gas in physical combination as I have demonstrated, is vaporized in the lamp bulb at comparatively low temperatures. The temperature which will produce this effect is easily reached during actual use of the lamp, and upon vaporization of the phosphorus it liberates some or all of the gas with which it is combined. The conditions under which the combination of the residual gases with phosphorus originally occurred are not duplicated in actual use. This liberation of gas and impairment of the vacuum, when once started, is cumulative and results in a considerable reduction in the useful life of the lamp. This effect cannot occur when my process is used, for the gases are precipitated and permanently held in combination with practically non-vaporizing particles such as carbon, tungsten or the like.

I claim:—

1. The process of rapidly producing high vacua in vessels, which consists in subjecting them to a suitable preliminary mechanical exhaustion, and passing a suitable electrical current through the vessels to complete the exhaustion.

2. The process of rapidly producing high vacua in incandescent lamps, which consists in subjecting them to a suitable preliminary mechanical exhaustion and passing a suitable electric current through the lamps to precipitate the residual gases and complete the exhaustion.

3. The process of rapidly producing high vacua in incandescent lamps, which consists in subjecting them to a suitable preliminary mechanical exhaustion, and then bringing the filaments to intensive incandescence to complete the exhaustion.

4. The process of rapidly producing high vacua in incandescent lamps, which consists in subjecting them to a suitable preliminary mechanical exhaustion and then bringing the filaments to intensive incandescence to precipitate the residual gases and complete the exhaustion.

5. The process of rapidly producing high vacua in vessels containing an electrical conductor, which consists in mechanically exhausting them until the mass of gas within the vessels does not exceed the normal, intrinsic, precipitating power of the conductor, and then passing a suitable electric current through the conductor to precipitate the residual gases and complete the exhaustion.

6. The process of rapidly producing high vacua in incandescent lamps, which consists in mechanically exhausting them until the mass of gas within the lamps does not exceed the normal intrinsic, precipitating power of the filaments, and then bringing the filaments to intensive incandescence to complete the exhaustion.

7. The process of rapidly producing high vacua in incandescent lamps, which consists in mechanically exhausting the same to a pressure not exceeding two-tenths of a millimeter of mercury, and then bringing the filaments to intensive incandescence to complete the exhaustion.

Signed at New York, in the county of New York and State of New York this 29th day of March, A. D. 1910.

CHARLES J. THATCHER.

Witnesses:
Laura E. Smith,
Fredk. F. Schuetz.

DEFENDANT'S EXHIBIT No. 24.

C. A. FRIEDRICH.

METHOD OF PRODUCING HIGH VACUUMS IN X-RAY TUBES AND THE LIKE.

APPLICATION FILED OCT. 11, 1910. RENEWED MAY 27, 1913.

1,083,677. Patented Jan. 6, 1914.

Fig. 1.

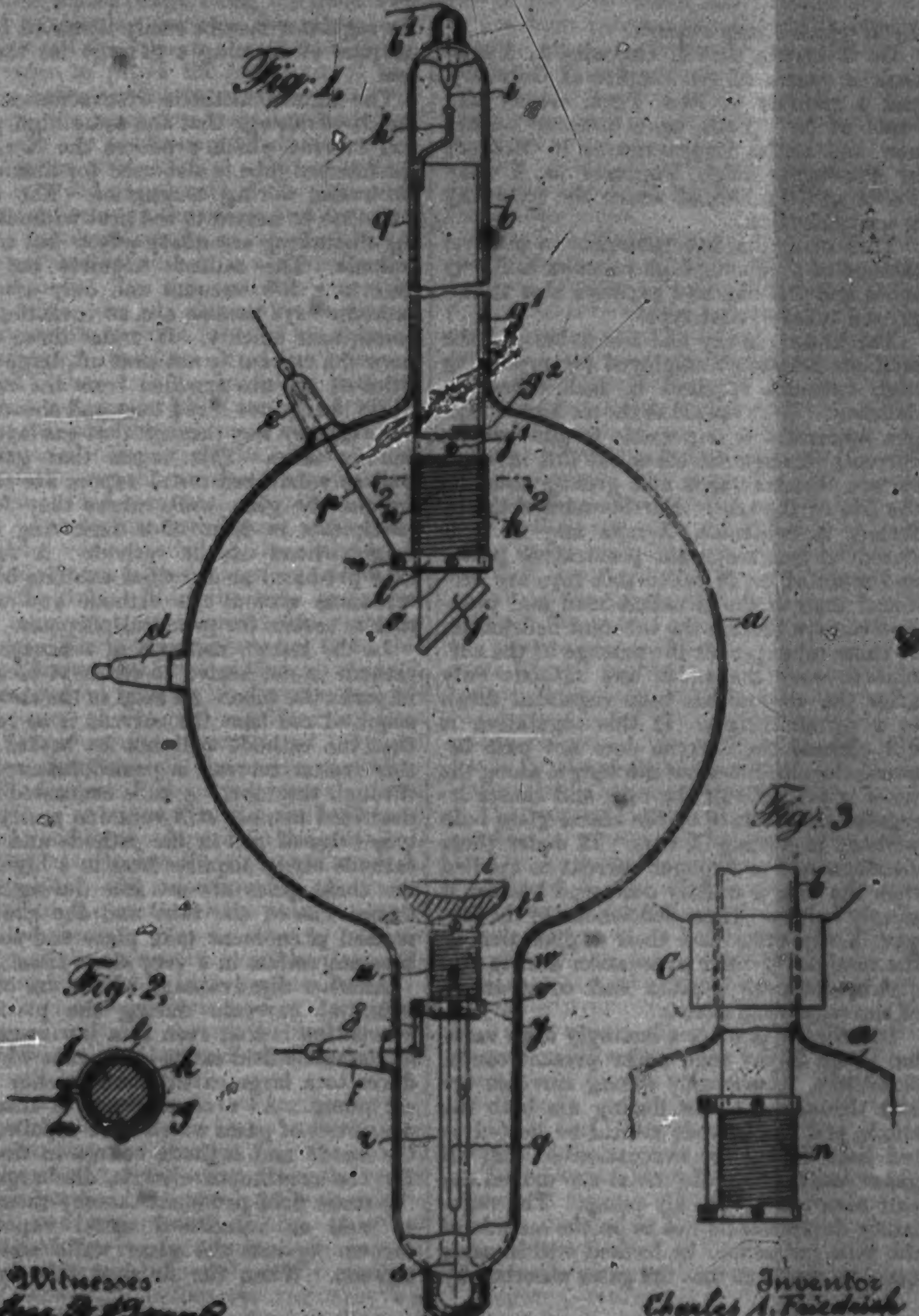

b1
i
k
q
b
g1
g2
e
j1
r
2
2
n
h
m
l
c
j
d
a
l
l1
u
w
v
y
s
f
x
g
o
d1

Fig. 2.

l
b
k
m
g

Fig. 3

b
c
a
n

Witnesses

Inventor

Charles A. Friedrich

By his Attorney

UNITED STATES PATENT OFFICE.

CHARLES A. FRIEDRICH, OF NEW YORK, N. Y.

METHOD OF PRODUCING HIGH VACUUMS IN X-RAY TUBES AND THE LIKE.

1,083,677. Specification of Letters Patent. Patented Jan. 6, 1914.

Application filed [illegible] 11, 1910, Serial No. 586,443. Renewed May 27, 1913. Serial No. 770,[illegible].

To all whom it may concern:

Be it known that I, Charles A. Friedrich, a citizen of the Empire of Germany, and a resident of New York, county and State of New York, have invented certain new and useful Improvements in Methods of Producing High Vacuums in X-Ray Tubes and the like, of which the following is a specification.

This invention has reference to a novel method of producing high vacuums in X-ray tubes and the like and pertains also to improved tubes of that type.

The known X-ray and like tubes and the methods heretofore employed for producing high vacuums required in such tubes are deficient. With the aid of the modern Roentgen apparatus it is possible to pass strong currents through the tubes but this involves certain disadvantages and greatly shortens the life of the tube. Furthermore with the former X-ray tubes, X-rays may be produced of but moderate penetrative power and more of the so called soft rays are produced than of the so called hard and penetrative rays because the inherent deficiencies of those tubes permit the passage of the current between the anode and cathode only after the vacuum has been regulated down to a certain height. If this regulation is not effected the current does not pass between the electrodes but discharges along the inner glass walls of the tube and causes irregular fluorescence of the entire glass bulb without producing X-rays. If under those circumstances a stronger current is applied then the tube is usually destroyed because it simply cracks. These deficiencies of the former X-ray tubes find their explanation in the method of their evacuation and in the disadvantageous location and construction of the regulating device.

In order to produce a lastingly high vacuum in an X-ray tube under present conditions when enormously strong currents are sent through the tube during use both the anode and the cathode should be heated to red heat during the evacuation so that all gases contained in the metal are driven out and removed by the air pump. The regulating device should not be on the outside of the tube but should be located within same near the center so that the gases absorbed by the regulator may be easily liberated for the purpose of forming a passage for the current.

The known methods of evacuation have the disadvantage that the same high potential current which produces the X-rays in the finished tube is also used for heating the electrodes during evacuation. The anode may thus be heated to red heat without causing disturbing secondary effects but not the cathode. The cathode acquires but little heat in a low vacuum and only after the cathodic rays become almost invisible it acquires heat quickly. If under those conditions the current is not shut off, large quantities of gas are expelled from the cathode while it acquires a red heat and the current finds an easy way through that gas layer and follows same. This causes that gases as well as volatilized metal vapors are thrown against the glass walls where they form a precipitate in form of a dark ring in the neighborhood of the cathode. A finished tube produced as described exhibits big disturbances around the cathode and such a tube is useless for practical purposes.

In the known methods of evacuation the cathode is not heated to red heat because it imperils the tube. As soon as the anode has acquired red heat the current is so reduced that the cathode will not be heated. For this reason current is passed interruptedly through the tube. A tube evacuated in the described manner still contains pretty large quantities of gas in the cathode and as the cathode easily acquires heat in a high vacuum these gases are set free during a continued use of the tube and the above described phenomena take place and the tube becomes useless in a very short time.

Another disadvantage of the use of high potential currents during the process of evacuation is that even at a low vacuum an electrostatic field exists in the tube which reduces to a large extent the efficiency of the air pump. As a consequence of this large quantities of gases which were expelled from the anode and cathode collect in the tube. By the continuous electric discharges and the static field produced thereby these gases as well as volatilized metal vapors are thrown against the glass walls and settle thereon. When the finished tube becomes cold this fine deposit on the glass walls absorbs part of the gases still contained in the tube and thus forms a fine gaseous layer on the entire inner glass wall. This explains why the current in a completely cooled finished tube passes easier along the glass wall instead of passing between the anode and cathode until the vacuum is regulated down.

In order to prove the existence of this fine gas layer on the inner glass wall reference may be made to a very simple method used years ago before regulating devices on X-ray tubes were known. When at that time a tube did not permit of the passage of the current between the anode and the cathode the tube was simply baked, that is, the tube was subjected to heat in a specially constructed oven. By this heat the gases absorbed by the deposit of metallic vapors on the glass walls were set free and accordingly the vacuum in the interior of the tube was reduced. Care had to be taken that the tube was not appreciably cooled off before current was sent through same otherwise the loose gases would partially be reabsorbed by the metallic deposit on the glass wall and no current for practical purposes would pass. As above mentioned gases and volatilized metal vapor settled on the cooler glass wall and when a high vacuum was produced the static field within the tube prevented quick excavation as required for practical purposes. The pump appears not to be able to draw the residual liberated gases through said static field in a higher vacuum and for this purpose an external regulator has been used. Such regulator consists of prepared asbestos, isinglass, or chemicals possessing a high degree of absorbing gases. After the process of exhaustion the residual gases are absorbed by the deposit on the glass wall and particularly by the prepared mass in the regulator. As a consequence of this the vacuum in the center of the tube is practically an absolute one, in other words the passage of the current between the electrodes is opposed in such a high vacuum by a tremendous electric resistance. For this reason it is easier for the current to find its way along the cooler glass wall where a thin gas layer still is found.

As above mentioned the regulating device on the tubes found in the market is in a disadvantageous location, on the outside and therefore too far away from the center of the vacuum. Such regulator is an encumbrance and necessitates a high auxiliary heating of the regulator mass. Such regulator on a former tube contains asbestos prepared separately before the regulator was fused to the tube and during handling the regulator it reabsorbs some vapors and moisture. Further when fusing the regulator to the X-ray tube water vapors are also formed from the blow pipe and the operator has to blow into the tube to join the regulator whereby more moisture is absorbed by the prepared asbestos therein. This absorption too has the bad effect of requiring a much longer evacuation. The regulator being outside of the tube causes that the vacuum will be too high between the electrodes for the passage of the current which passage is limited to a certain vacuum. This must be established by means of the regulator before the current will pass between the electrodes. It is however desired to obtain rays of greater penetration, that is, rays which are produced in a still higher vacuum than in the former tubes.

I have produced a novel X-ray tube and devised a novel method of producing a high vacuum therein by means of which high heating of both electrodes in a relatively low vacuum is effected without the use of high potential currents whereby all the deficiencies of the former method, secondary disturbing phenomena are eliminated and the glass walls remain clear and free from deposits. Furthermore there is no static field which prevents the continuous uniform action of the vacuum pump which with the new method can scope easily with the liberating gases from the electrodes in an unobstructed manner. To avoid deposits of metal on the glass wall no high potential currents are passed through the tube during the process of evacuation and the absorbent mass of the regulator is located near the center of the vacuum so that the passage of the current is not opposed by an almost absolute vacuum. The new X-ray tube thus made produces rays of higher penetrative power than those heretofore made.

The peculiar construction of my electrodes renders it possible to heat both the anode and the cathode simultaneously to red heat by means of the common current used for incandescent lamps. The absence of electrical discharges and the static field created thereby allows the pump to work with its full capacity whereby the liberating gases are quickly removed and cannot collect within the tube. Mercury vapors which formerly were produced within the evacuated space by the electrical discharges are accordingly not produced by my novel method and therefore not found in the finished tube.

To make the invention entirely clear reference is made to the accompanying drawing in which an X-ray tube is illustrated of my novel construction and exhausted according to my novel method and in which:

Figure 1 represents in elevation partly in section an X-ray tube embodying in desirable form the present improvements. Fig. 2 is a cross section on line 2—2 of Fig. 1, and Fig. 3 is a modification.

In the drawing *a* represents the glass bulb, *b* is a long glass tube for the anode integral with the bulb, *c* is a somewhat wider and shorter glass tube for the cathode also integral with the bulb and *d* is the remaining part or tip of the exhaust tube also sealed to the bulb by fusion. The anode passes through the long narrow tube *b* into the interior of the bulb and the cathode through the wider and shorter tube *c*. A terminal b^1 is formed at the top end of the tube *b* closing off same hermetically and a like terminal c^1 is formed at the bottom end of the tube *c* which closes off same hermetically. There are also two auxiliary terminals *e* and *f* whose purpose will be explained farther down.

The anode consists of a slotted steel tube *g* which has a longitudinal slot g^1 that extends through its greater length. At the end of the slot g^1 a lateral slot g^2 is formed. The slots are provided in the steel tube to impart some spring power so that the tube fits into and bears against the inner walls of the glass tube *b*. To the top end portion of the steel tube a metal wire, preferably a copper wire *h* is soldered to which the platinum wire *i* is fused which passes through the solid glass formed at the end of the tube and forms outside the anode terminal b^1. In the lower portion of the steel tube *g* there is the anode proper below the lateral slot g^2. The anode *j* is made of metal such as bronze or copper in the usual manner and secured to the steel tube by means of a screw j^1. Below the securing screw j^1 the steel tube is surrounded by an asbestos mantle *k* which is held in position by a metal ring *l* located on the bottom portion of the asbestos mantle and adapted to be tightened by a screw *m* passing through two side flanges of the ring as shown in detail in Fig. 2. Around the asbestos mantle the metal wire is wound preferably platinum wire *n* the one end of which is secured to the screw j^1 so that it is in electric contact with the steel tube *g* and the terminal for the anode. The second end of this wire around the asbestos mantle is secured to a short screw *o* which ends on the asbestos and therefore is not in electric contact with the anode *j*. As shown in Fig. 1 a conducting wire *p* leads from the tensioning screw *m* to the auxiliary terminal *e*. In this way a circuit may be established by means of the anode terminal b^1 and the auxiliary terminal *e* of which the high resistance metal or platinum wire forms a part and thus the wire *n* on the asbestos mantle may be heated by a low potential current without passing any current through the anode. As above stated street current or the common incandescent lamp current may be used for heating the high resistance wire *n* on the asbestos mantle and as may be seen from Fig. 1 both the asbestos mantle and the high resistance wire *n* are within the glass bulb near the center of the vacuum in the finished tube.

The cathode which is in the shorter and wider tube *c* opposite the anode consists of an aluminum rod *q* located in a narrow glass tube *r*. The bottom end of the aluminum rod connects with the terminal c^1 by means of a platinum wire *s*. The top end of the aluminum rod *q* is screwed into the cathode proper *t*. The cathode likewise is made of metal, cup shaped at the top and forms a thick rod t^1 below. The aluminum rod *q* is preferably screwed into the rod portion t^1 of the cathode while the glass tube *r* simply extends into an opening in the lower portion of the thick rod t^1. The glass tube *r* is fused to the solid glass portion through which the platinum wire *s* passes. Around the thick rod portion t^1 of the cathode *t* an asbestos mantle *u* is provided which is secured by means of a metal ring *v* adapted to be tensioned in the same manner as the ring *l* of the anode. High resistance or platinum wire *w* is wound around the asbestos mantle whose top end is secured to a screw *x* and thus in electric contact with the cathode. The bottom end of the platinum wire is secured by means of a short screw *y* to the copper ring *v* which screw ends on the asbestos mantle and therefore is not in electric contact with the cathode. In connection with the ring *v* is a small bar *z* which connects with the auxiliary terminal *f*. Thus a circuit may be established by means of the cathode terminal c^1 and the auxiliary terminal *f* of which the high resistance or platinum wire *w* forms part. In this manner the platinum wire *w* may be heated by common street current or the incandescent light current.

Assuming that the tube is in connection with the pump and is gradually exhausted then at a certain stage of the evacuation the platinum wire around the asbestos mantle is heated to incandescence. The asbestos mantle also gets hot and imparts heat to the anode below and after a certain time the anode proper acquires heat and becomes red. Simultaneously the cathode is heated in like manner. The gases contained in the metal of which the anode and cathode are made are gradually expelled and the liberating gases are at once removed by the air pump in an unobstructed manner because there is no static field within the tube. As both electrodes are heated in this manner no gases will be expelled from the finished tube when a high potential current is passed through same. No deposit is formed on the inner glass walls because there are no secondary disturbing phenomena within the tube under these conditions and there is no collection of gases as were retained in former tubes by the static field.

With the described construction of the electrodes in the tube and the novel method of evacuation a greatly improved tube is resulting whose glass walls remain clear from deposits. No gases can be expelled from the electrodes after the tube has been finished but over and above everything X-rays of higher penetrative power may be produced with such tubes.

When the finished tube made according to my novel method cools off the asbestos mantles naturally cool off too and as they are treated in the usual manner they absorb the residual gases within the bulb whereby an almost absolute vacuum is produced between the electrodes. If it is desired to use the tube current is passed through the platinum wire on the asbestos mantles whereby some gases are expelled right in the interior of the tube and almost in the path of the current. These expelled gases form so to say a conductive bridge for the high potential currents which then are passed through the electrodes proper.

In order to render the regulating device automatic the size of the platinum wire on the asbestos mantles is so selected that the strength of the current of the Roentgen apparatus is sufficient to heat that wire and thereby the asbestos mantles below same so that gases are expelled for the purpose of establishing a passage for the high potential current between the electrodes.

In Fig. 8 of the drawing a modification of the described device for heating the electrodes by low potential currents is illustrated. In this modified form the high-resistance or platinum wire on the asbestos mantle forms a closed circuit in itself and the heating of this wire and thereby the electrode is effected by induction from an outside primary spool of an induction coil C which fits over the glass tube *b*. The wire *n* then forms the fine wire of the induction coil and is heated when current is passed through the primary coil C. The platinum wire *w* on the asbestos mantle *s* of the cathode may likewise be heated by a suitable primary coil as described in connection with the platinum wire *n* on the asbestos mantle *k* of the anode.

I claim as my invention:

1. The method of producing a high vacuum in an X-ray tube which vacuum will remain constant during a single operation consisting in heating to red heat both the anode and the cathode during evacuation by means of low potential currents.

2. The method of producing a high vacuum in an X-ray tube which vacuum will remain constant during a plurality of operations consisting in heating to red heat both the anode and the cathode during evacuation by means of low potential currents.

3. The method of producing a high vacuum in an X-ray tube which vacuum will remain comparatively permanent consisting in heating to red heat both the anode and the cathode during evacuation in a relatively low vacuum by means of low potential currents.

4. The method of producing a high vacuum in an X-ray tube which vacuum will remain comparatively permanent consisting in heating to a cherry red heat both the anode and the cathode during evacuation in a relatively low vacuum by means of low potential currents, and expelling thereby all gases contained in both the anode and the cathode.

5. The method of producing a high vacuum in an X-ray tube which vacuum will remain comparatively permanent consisting in heating to high heat both the anode and the cathode during evacuation in a relatively low vacuum, expelling thereby all gases from the anode and cathode, and removing said gases as they are set free.

6. The method of producing a high vacuum in an X-ray tube which vacuum will remain comparatively permanent consisting in heating a regulating device on each electrode within the tube near the center of the vacuum in an independent circuit by low potential currents during evacuation in a relatively low vacuum, and expelling thereby the gases from both the anode and cathode.

7. The method of producing a high vacuum in an X-ray tube which vacuum will remain comparatively permanent consisting in heating a regulating device on each electrode within the tube in an independent circuit by low potential currents in a relatively low vacuum, expelling thereby the gases from both the anode and cathode and removing same as they are set free.

8. The method of producing a high vacuum in an X-ray tube which vacuum will remain comparatively permanent and expelling gases from regulators and both the anode and the cathode in one operation consisting in heating a regulator on the anode and one on the cathode within the tube in a relatively low vacuum by means of low potential currents in an independent circuit, expelling thereby gases from the regulator and the anode and the cathode, removing said gases as they are set free until a high vacuum is obtained, allowing the sealed off tube to cool and the residual gases to be absorbed by the cool regulator.

9. The method of expelling gases from the cathode of an X-ray tube and the like during evacuation consisting in heating a regulating device on the cathode by means of low potential currents in an independent circuit in a low vacuum whereby the gases contained in the cathode are gradually expelled.

10. The method of expelling gases simultaneously from both the anode and cathode

of an X-ray tube and the like consisting in heating a regulating device on each of them by low potential currents in separate circuits which are independent from the circuit of the electrodes, heating thereby gradually the anode and the cathode in a relatively low vacuum and expelling the gases contained therein and removing said gases.

11. The method of evacuating and automatically operating an X-ray tube and the like consisting in heating both the anode and the cathode in a low vacuum by means of low potential currents in independent circuits expelling thereby the gases from the anode, cathode and regulators removing same as they are set free until a high vacuum is obtained, allowing the sealed off tube to cool and the residual gases to be absorbed, and expelling the absorbed gases partially by the current of the Roentgen apparatus.

12. An X-ray tube comprising an anode and a cathode, and an electric heater on the anode and one on the cathode within the tube for the purpose of heating the anode and the cathode during manufacture.

13. An X-ray tube comprising an anode and a cathode, an electric heater on the anode in an independent circuit, and an electric heater on the cathode in an independent circuit, both within the globe.

14. An X-ray tube comprising a globe with central tubes thereon, an anode having an electric heater near its inner end within the globe, an auxiliary terminal for establishing an independent circuit, a cathode with electric heater near its inner end, and an auxiliary terminal for establishing an independent circuit.

15. An X-ray tube comprising a globe with central tubes thereon, an anode in one tube extending into the globe, a layer of asbestos near its inner end, high resistence wire thereon connecting with one end with the cathode and an auxiliary terminal connecting with the other end of said high resistance wire, a cathode, an asbestos layer near its inner end, high resistance wire on the asbestos connecting with one end with the cathode, an auxiliary terminal connecting with the other end of said high resistance wire so that independent circuits may be established for the purpose of heating the anode and cathode simultaneously but separately by low potential currents.

Signed at New York, N. Y., this 23rd day of September, 1910.

CHARLES A. FRIEDRICH.

Witnesses:
CORINNE MYERS,
THOMAS DONNELLAN.

DEFENDANT'S EXHIBIT No. 25.

[TRANSLATION]

Annalen der Physik.
Vol. 32 (1910)
PP 673-738

CONDUCTION OF ELECTRICITY IN EXTREME VACUUM.

By J. E. LILIENFELD.
(Leipzig Habilitationsschrift.)

[678]

CONTENTS.

I. Introduction.
II. The Fluorescence Colors of the Glass in the Positive Column.
III. The Experimental Arrangement.
  1. Production of the Vacuum.
  2. The Discharge Tube.
  3. The Cryostat.
  4. Arrangement for Making the Electrical Measurement.
  5. Method of Diagrammatic Representation of Results. Tables.
IV. Results of Observations.
  1. Relation between Potential Gradient, Current and Vacuum.
  2. Influence of Geometric Conditions on the Potential Gradient.
  Spectral Observations.
V. An Interpretation of the Results.
  1. General Considerations.
  2. The Independence of Cross-Section of Tube.
  3. Derivation of the Law of the Characteristic.
VI. Summary of Results.
  1. Experimental Results.
  2. General Conclusions.

In the fall of 1906 my attention was attracted to a remarkable phenomenon, the investigation of which afforded the substance of the following paper.

This phenomenon—a red fluorescence obtained under certain conditions along the path of the electric discharge in vacua—was soon found to be something accidental and of minor importance compared with the new relationships to which the investigation of this phenomenon in high vacuum led. It was found that the potential gradient in the positive column of a luminous discharge does not, as was assumed on plausible grounds and found experimentally by Hertz,1) decrease without limit with decrease in gas pressure and approach zero, but that this holds only down to a certain maximum pressure, from which on the potential gradient increases again very rapidly with decreasing gas density.2) [674] The remarkable thing about it was that the mean free path of the charged particles carrying the current increases with decreasing pressure, and that consequently the obstruction to the current transportation should become less the better the vacuum.

If one works with a Wehnelt cathode,3) to simplify the matter technically and to avoid too high voltages, and finds that from a maximum pressure down the voltage across the terminals of the tube show a marked increase, one would be misled to conclude4) that in this region the oxide cathode does no longer show the property of reducing the cathode fall. An exploring electrode measurement shows, however, that there is no change in the behavior of the oxide cathode; that, on the contrary, a marked potential gradient accompanied by an intense heating of the glass walls in the positive column, appears when the gas pressure is reduced.

With this was given the substance for investigation: The highest possible vacuum was to be produced. In this vacuum a discharge was to be established with a current greater than a definite minimum value. The conditions were to be investigated in regions as far as possible away from the electrodes.

One can formulate more generally the conditions of high vacuum and large current density as follows: The production of a state *in which the volume density of the electrons carrying the current is as large as possible compared with the density of gas molecules, in which there exists, therefore, a tendency for the formation of the maximum possible space charge in the path* [675] *of the current.*[5)]

Under the conditions thus defined phenomena manifested themselves which formed the basis of my above mentioned publications and which pointed to the existence of positive carriers of small mass. I could not reproduce these phenomena since in a satisfactory way. In view of their importance they were primarily the spur to a thorough investigation of the discharge of electricity in extreme vacuum, in order to know and understand the conditions which were initially very variable. The results of this study form the substance of the present paper.

Even if a direct proof of the existence of positive electrons is not given by the following results, one nevertheless finds a number of relations which can be explained in a simple way on the assumption of the existence of positive carriers having a constant ratio of charge to mass, i. e., more specifically positive charges which exist independently of matter.[6)] The question regarding the existence of positive electrons may therefore, as far as my experiments go, be left unanswered, especially also because investigations of other experimenters and closely allied to my publications leave the question open. In fact I do not see a decision on the question either by the repetition of part of my experiments by Gehrcke and Reichenheim,[7)] Bestelmeyer and Marsh,[8)] which gave a negative result, or in the experiments of Jean Becquerel[9)] which gave an affirmative answer to the question of the participation of positive [676] electrons in gas discharge and in emission of light.

II. THE FLUORESCENCE COLORS OF THE GLASS IN THE POSITIVE COLUMN.

Before taking up the substance proper of the following investigation I want to give a summary of the most important observations made in my former investigation on the red fluorescence which was first made by me at the outset of these investigations.

The fluorescence appeared in the course of another experiment.10) I used a tube of the form shown in Fig. 1. The glass bulbs G_1, G_2 containing the cylindrical electrodes C — and C + were connected with the tube U (13 mm. wide). D consists of a glass rod and serves to support the structure; R is the connection to the pump. When this tube was filled several times with [677] oxygen prepared from potassium permanganate and evacuated while a discharge was passing it happened that when the pressure was below 0.01 mm. Hg. and the current about 20-30 milliamperes a red patch could be produced at any point of the tube U by the approach of a steel magnet. When the vacuum became

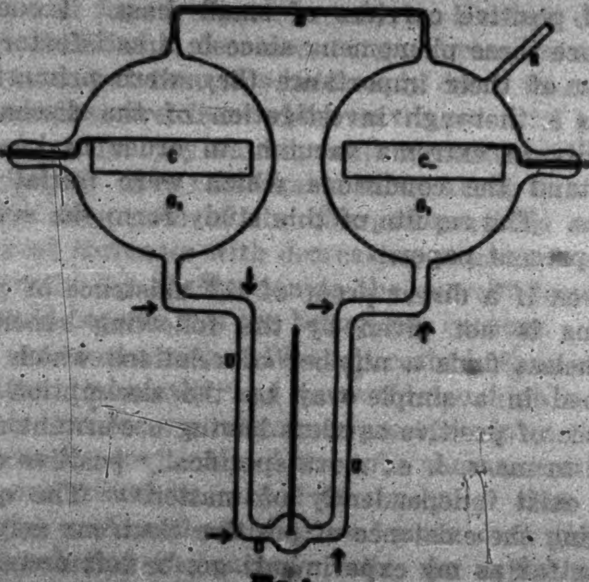


Fig. 1.

better cherry red patches appeared at the places marked with arrows, which could be distinguished from such as are produced by canal rays. The spectrum was found to be continuous in the red region.[11]

The position of the patches showed that they were produced by carriers passing from cathode to anode. In order to study the phenomenon in a higher vacuum I replaced the aluminum electrode C— by an oxide cathode. When, for example, this cathode was placed in the tube marked with — (Fig. 2) and the desired vacuum produced the red patch appeared at R. From a deflection experiment I concluded "that the negative corpuscles alone cannot account for the red fluorescence but that it was also conditioned by another factor."

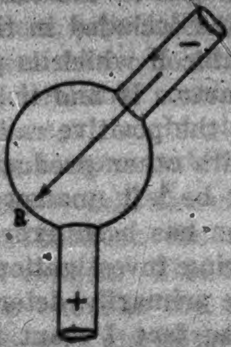


Fig. 2

I suspected that this second factor was due to positively charged carriers. At the same time I intimated that the minimum potential gradient mentioned in the introduction, which is established at a definite pressure "indicated that it is not only the electrons emitted from the oxide cathode which, as is often assumed, cause the discharge in high vacuum, but that the condition of electricity under the conditions mentioned depends very much on a second factor, which is perhaps made visible [678] to the eye by the red fluorescence."

In the next publication (No. 7) the red fluorescence and other fluorescence colors of the glass were mentioned for the last time as follows: "It appears on glass and quartz in a very high vacuum but not in most extreme degree of vacuum. If the vessels are freed from gases occluded in the walls by continued discharge the original cherry red fluorescence in the case of glass becomes red-violet to blue with a few sky blue places; in the case of quartz, however, the fluorescence becomes sky blue with a few green patches, and sometimes also other colors—which is due to the technical difficulties in the manufacture of quartz tubes.

"The red fluorescence consequently appears to depend on the residual gas in the tube, or what is more probable, with the gas occluded in the walls. The blue may be due to the silicon which is present both in the glass and in the quartz. If and in how far this fluorescence is caused by the positive radiation or rather by their joint action with other products of the discharge may for the present be left unanswered."

Since the opinion has been expressed by others, as well as in the following investigation, that the color of the fluorescence was primarily determined by the condition of the glass surface I want to say here briefly that from the beginning I have held the view that the fluorescence colors observed by me were due to a special kind of excitation of which I did not say anything definite except that it was not conditioned by cathode rays alone. In support of this view I pointed out in my first publication that the ordinary green fluorescence can be produced as well as the red by bringing a magnet close up to the bulb of Fig. 2. It is also possible by the use [679] of an auxiliary electrode to superimpose the ordinary yellow green fluorescence upon the pale blue,—especially in the case of the less marked bluish fluorescence which appears on glass walls that have been very well denuded of gases, and, after the red fluorescence had disappeared after a long continued discharge. Of the many possible ways of performing this experiment may be mentioned the one in which the platinum wire ring Z of Fig. 6 is connected with the cathode through a high resistance (electrolytic or the secondary of an induction coil): the upper opening of the narrow tube

E_2 immediately becomes filled with the ordinary Roentgen tube fluorescence.

In contrast to my experience and views are the following publications: Gehrcke and Reichenheim[12] ascribe the excitation of the fluorescence colors to the impact of cathode rays and regard simply the difference in velocity of the cathode rays as the deciding factor; slow cathode rays were supposed to give the red and presumably also the blue, and fast cathode rays the ordinary green fluorescence. This view was afterwards modified by Reichenheim[13] in that he supposed that the new fluorescence colors, especially the blue, were caused by the intensive emission of primary or secondary cathode rays. Reichenheim considered the possibility that also ions (canal rays) might play a part in the excitation—thus tending to some extent to favor my views.

Lastly, Goldstein[14] held the view that there might be some connection between the red fluorescence and gas mixture rich in oxygen. This fluorescence is indeed best produced when one fills the tube, during the discharge several times, as I did initially, with pure oxygen and evacuate. A red fluorescence is obtained especially when the tube has been previously filled with pure oxygen, and then also with much higher pressures than [680] when oxygen has not been used. And it seems that with oxygen the pressure can be increased without limit, provided that the current be large enough to give sufficient energy at the higher pressures to cause the red fluorescence.

It is, however, possible to also obtain the red fluorescence, without washing with oxygen, as follows: If the tube is evacuated for several hours during which the glass walls are strongly heated and during which time the absorption vessels give off hydrocarbon gases under strong heating in accordance with the method of evacuation described below, gases are introduced into the discharge vessel, which presumably do not contain oxygen in appreciable quantities and which indeed give a hydrocarbon spectrum. When now one of the absorption vessels be immersed in liquid air for some time and the discharge passed, one observed the red fluorescence with a persisting hydrocarbon spectrum, although this fluorescence is then not obtained in the same intensity as when the tube is washed with oxygen.

Also other facts to be mentioned in the course of this paper indicate that washing with oxygen and simultaneously discharging point out, as I have surmised in the first publications, the value of this method of purification of the walls of the vessel—a purification which could, however, also be obtained by an intense heating of the tubes in thermostats, although not so well as when both methods are combined.

In this connection it must be remarked that Konen[15] observed the red fluorescence in tubes which gave a pure helium spectrum.

Finally it may still be remarked that when one obtains the highest degree of evacuation which has only lately become possible the fluorescence of the glass walls assumes a peculiar grayish tint and that in general no appreciable change in the tint takes place when the tube is immersed in liquid air.
[681]

III. EXPERIMENTAL ARRANGEMENTS.

1. *The Production of the Vacuum.*

In the course of the work it was found that the principle on which the production of the vacuum is based if one tries to obtain extreme rarefication of the gas, can be put in a form as instructive as it is simple; the discharge tube itself must be kept, as far as possible, from the very commencement of the pumping at a considerably higher temperature than the connecting tubes, etc., especially if heated wood-charcoal, stop-cocks and joints tightened with fat, etc., are present in the connecting tubing. In fact it is apparent that these conditions prevent the distillation of all kinds of impurities from the sources mentioned. Consequently if the discharge tube is at room temperature, a part of the tubing which should be located if possible between the discharge tube and the joints, should be immersed in liquid air. If, however, the wood-charcoal tubes are deprived of gas by heating to a high temperature, then it is absolutely necessary to bring the discharge tube to at least as high a temperature; and on the other hand it is desirable to cool part of the tubing in liquid air.

The coconut charcoal which is used as an absorbtive material, must be heated to over 400° C. every time a vacuum is established and must be freed as far as possible from the gases given off by pumping for several hours with a rapidly working air pump (Gaede's Mercury air pump). I found it desirable, however, after operating the Gaede pump for several hours, to pump for some time with an air pump which draws less from the atmosphere (Neesen's mercury air pump as manufactured by R. Burger & Co., Berlin). Not till then is use made of the combined absorption process by filling with oxygen and evacuating.

The apparatus used is as follows: thermostats of [682] different sizes and of the form shown in figure (3) are used for heating the tubes, both the absorption

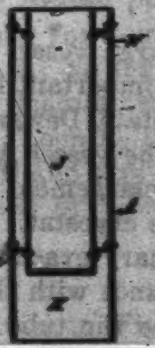


Fig. 3.

and the discharge tubes. An external iron tube A, covered with asbestos is open at both ends and has inside it an iron tube J supported by brackets W, which is open above and is closed by a plate below. There is an air space between the two metallic walls. In the space H there is a suitable heating flame (gas burner, etc.). It is considered to be a practical way of proceeding when working with such thermostats to construct the instruments to be heated so that their main expansion will be as much as possible in a vertical direction.

The vacuum tubing is shown in Fig. 4. The cocks H_3 and H_4, indicated diagrammatically, lead to the Gaede and Neesen pumps respectively. The absorption tubes A_1 and A_2 are constructed on the plan of a wash bottle, in order to precisely separate the parts of the tubing in front of the discharge vessel from those behind it, and yet have the discharge vessel in the form of a figure of rotation; this is important in connection with fitting vessels into thermostats, Dewar flasks and cryostats, for various reasons. The vessel A_2 differs from the vessel A_1, in having an enlargement E in the upper part for inserting it into the cryostat. The tube A_1 is used for [683] the preliminary evacuation of the entire system of tubing in accordance with the principle mentioned in the beginning, while the tube A_2 is joined to the discharge tube by a connecting tube about 25 to 30 mm. wide and as short as possible and serves to maintain the vacuum during the actual experiments. The exhaustion is carried out as follows: in the beginning the tubes A_1 and A_2 and the discharge tube are heated to over 400° C.

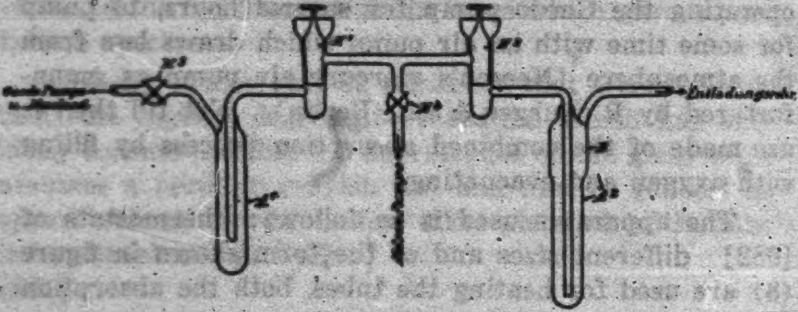


Fig. 4.

and the Gaede pump connected to the entire system of tubing. In the very first stage of the exhaustion the Wehnelt cathode is also raised to a red heat in order to deprive it of gas as far as possible at the outset. When the partial pressure over the heated wood charcoal is of the order of magnitude of 0.0001 (a Macleod manometer is connected with the Gaede pump) the Gaede pump is disconnected, the stop-cock H_3 closed, H_4 is opened and the Neesen pump set in operation. After a period of from one to two hours the tube A_1 is allowed to cool and is immersed in liquid air. The Neesen pump is disconnected, and the remaining traces of gas allowed to be absorbed in A_1 during a period of about three hours. Then the stop-cock H_1 is also closed and after the tube A_2 has been allowed to cool, the discharge tube is removed from the thermostat and is at once heated by an intense discharge current.[1] The whole system of tubing and vessels is filled several times with oxygen from the potassium permanganate vessel attached to the Neesen pump up to a pressure of several millimetres, then gradually evacuated with the Neesen pump and the last traces of gas removed each time by opening H_1 and absorbing in A_1. After the walls of the tube have been cleaned in this way, a condition which can readily be perceived after long experience, the Neesen pump is disconnected, the stop-cock H_1 is opened for some time and the remaining gas absorbed in A_1 as far as possible, a continuous discharge being maintained through the discharge tube all the while. Then A_2 is immersed in liquid air, the cock H_2 is closed and now the final degree of evacuation can be attained by a correspondingly long discharge.

[684]

The permanganate tube in Fig. 5 consists of the glass bulb G containing the permanganate; the capillary hook H serves to keep back the coarser dust during the heating of the permanganate, while the very fine dust is retained in the tube A, which is constructed like a wash bottle. The action of the tube is chiefly to retard the velocity of flow; its effectiveness may be increased by filling the space between the capillary tube K and the wall with glass wool and by putting in a capillary spiral S. Moreover the tube A may be cooled in liquid air if it is desired to retain the moisture which may be liberated by heating the permanganate. But this has no greater effect than the cooling of the part of the actual tubing between the ground joints and the tube A_2 in Fig. 2 by means of liquid air during the filling with oxygen. For this reason this complication is usually omitted.

---

[1] At this stage the red fluorescence mentioned on p. 680 can be observed in the absence of 0.

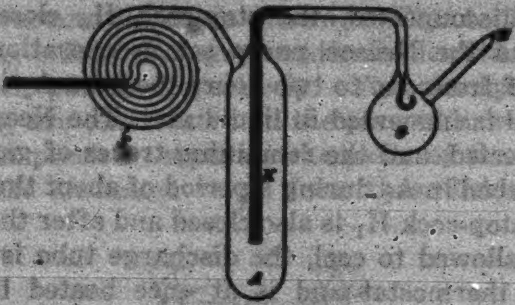


Fig. 5.

2. *The Discharge Tube.*

The construction of the discharge tube is based on the following considerations: *Firstly,* its expansion should be mainly in a vertical direction as mentioned in the description of the thermostats. This permits the tube not only to be heated but also to be cooled to the temperature of liquid air. *Secondly,* in order to save [685] the liquid air during the cooling, the heat generated at the Wehnelt cathode by the heating current should as far as possible be given off outside the liquid air bath. The light from the glowing cathode must be screened as far as possible in such a way that the spectral observations of the discharge can be carried on without hindrance. *Thirdly,* the oxide cathode should

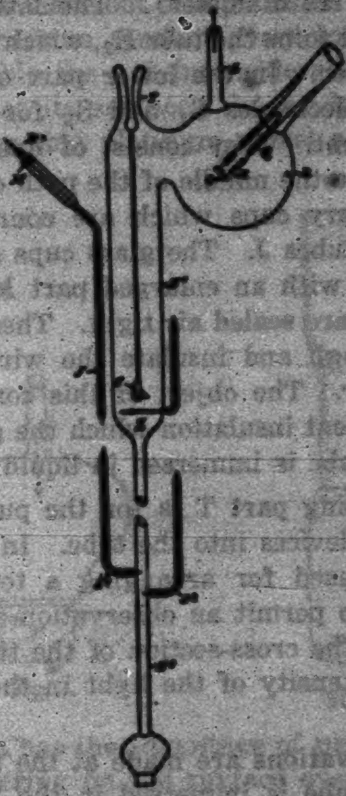


Fig. 6.

however, be connected as near as possible to the absorption tube, and, in contrast with this, should be separated from the part where the actual measurements are carried out by tubes as long and narrow as possible, in order that a dynamical equilibrium may be attained in which the gases given off by the cathode and absorbed by the wood charcoal diffuse as little as possible to the point where the observations are taken. These three considerations are the reason for the unsymmetrical retort-like shape of the discharge tube in Fig. 6. The bulb R, which is about 12 cm. in diameter, is connected on one side to the tube L, which leads to the absorption tube, and on the other side to the wide discharge tube E_1, (about 50 mm. in diameter). The latter is gradually constricted till it joins the tube E_2, which is about 10 mm. internal diameter. In the lower part of this tube are the exploring electrodes S_1 and S_2 for measuring the potential gradient. They consist of fine platinum wire which extends to the middle of the path of the discharge and have mercury cups which are connected with the long fine glass tubes J. The glass cups are provided at [686] the top with an enlarged part M, in which the amber pieces B are sealed air tight. These amber pieces are bored through and insulate the wire D leading to the electrometer. The object of this construction is to utilise the excellent insulation which the glass walls possess when the tube is immersed in liquid air.

The projecting part T is for the purpose of introducing various devices into the tube. In the figure, for instance, it is used for arranging a totally reflecting prism F so as to permit an observation of the distribution of light in the cross-section of the tube and also to integrate the intensity of the light in the entire length of the tube.

When observations are made at the temperature of liquid air, the tube is immersed in the liquid air to a depth of some centimetres above the prism.

The platinum ring Z serves as a starting electrode.

The following may be said concerning the electrodes. The cathode, which is the most sensitive part of the whole apparatus, has the peculiar form shown in the figure; the heating current is introduced through the mercury contacts Q. I have found that this method of construction not only makes the oxide cathode more durable than the usual methods, but the electrolysis of the glass which generates traces of gases is here prevented, as there is a piece of cold glass between the two wires. Copper wire spirals K are soldered to the two platinum wires and at the other small pieces of platinum wire connect with the platinum foil O. The latter is coated in the usual way with a layer of oxides of alkaline earths.

The anode is made out of a platinum vessel T shown in Fig. 7, in order to conduct away to the outside as readily as possible the not inconsiderable quantities of heat generated at its surface. In my last experiments I substituted for this platinum vessel a platinum tube (Fig. 8), which has the advantage of preventing impurities from gathering on the surface over which the discharge spreads. A further advantage in having the [687] anode a tube is that the discharge is spread out more uniformly over a part of the surface, whereas it is usually concentrated in the middle of that part of the anode which is at right angles to the axis of the discharge.

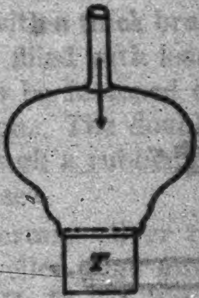


Fig. 7.

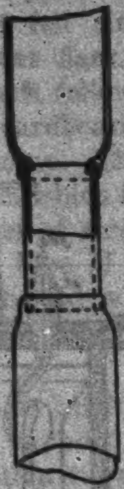


Fig. 8.

3. *The Cryostat.*

The cryostat, which not only enables the absorption tubes to be cooled to the temperature of solid air, but is also used for working with liquid hydrogen, is constructed on the principle of the cryostat of Kamerlingh Onnes[1] with of course the necessary modifications for the present purpose (Fig. 9). It consists of a wide brass

---

[1] H. Kamerlingh Onnes, Communications from the Phys. Lab. Leyden, No. 94f, 12, p. 32.

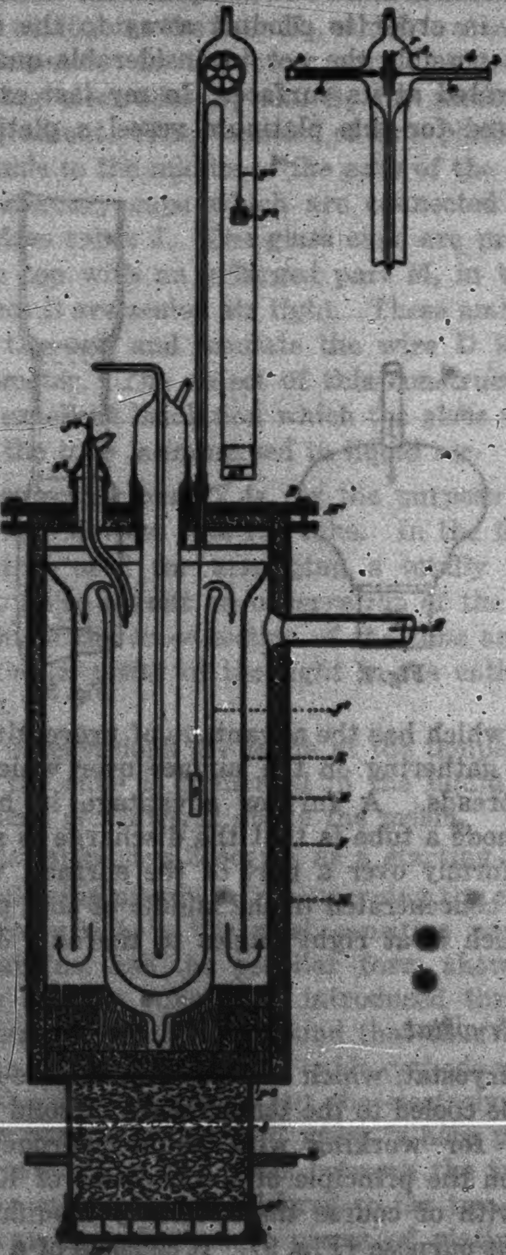


Fig. 8.

tube M, the inside of which is covered with a layer of felt, F, and a sheet of nickel, H. At the lower end the tube is soldered to a German silver tube S over which is stretched the rubber cap G_1. The latter is supported by a sieve-like plate, P. The German silver tube is filled with wadding and another sieve-like plate is provided on which are fastened a number of felt rings and a wooden base for supporting the Dewar flask D_1. The gases evaporating from the Dewar flask follow the path indicated by the arrows around the cardboard dividing wall through the tube E into the air pump. The cryostat is covered with a thick brass plate M, in which is a groove B, which is filled with lead. A number of screws enable the plate to be fastened down to the tube M in an air-tight fashion. The double walled tube J_2, which is inserted through a rubber cap G_2, is used to introduce the liquified gases.

The German silver ring R (B?) is inlaid with felt and its bevelled edge affords a firm support at the enlargement E, Fig. 4, for the absorption tube, which is likewise packed in with a rubber cap.

The float S, which, together with the cord F_1 and [689] weight F_2, serves to indicate the height of the liquid in the tube D_1, is placed in the glass tube which is closed with the rubber stopper G_3. The cross sectional view shows how the pully, r, in the glass tube s, is attached to the wire d, which passes through the tubes a, and is fastened to the brass discs b.

4. *The Electrical Measurements.*

The connection with the electrometer is made by means of the shielding arrangements shown in Fig. 10. As the distance of the electrometer from the discharge tube is frequently varied, it is convenient to so arrange the connections that their length can easily be varied. For this purpose the protecting tube consists of two parts R_1 and R_2, which are made to slide one over the other, while the actual connection with the electrometer

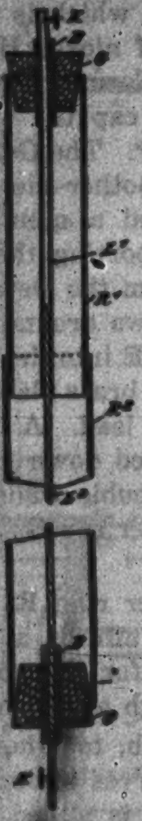


Fig. 10.

is established by means of the fine tube L_1, the wire L_2 which can be made to slide through it, and the binding screws K. The tubes R are closed by rubber stoppers G, through which pass insulating amber tubes B. In these latter the connecting parts L are fixed.

The potential differences were measured by a quadrant electrometer connected idiostatically. This was a Mascart-Carpentier instrument which was reconstructed for the measurement of the large potential differences (up to 400 volts) and provided with numerous alterations and amber insulation. The sensitiveness of the bi-filer suspension of platinum wire could be adjusted by varying the distance between the wires and by varying

the load. The damping arrangement, which is very im-
[690] portant where large couples are concerned, was a specially constructed air damping arrangement which enabled a periodicity to be attained in all cases.

Notwithstanding the unsensitiveness of the electrometer a careful electrostatic protection was indispensable mainly on account of the brush discharge from the connecting wires which occurred with high tensions. The electrometer, which was insulated, had to be set up inside an earth connected casing as the case of the instrument itself was at the potential of one of the exploring electrodes.

The galvanometer was a mirror instrument by Keyser and Schmidt (sensitiveness 10^{-8} amp.) and likewise carefully insulated. A series and shunt resistance enabled measurements in different ranges to be carried out.

Both instruments were read in an objective way so that both co-ordinates could be observed simultaneously on two scales one over the other.

As a source of current a high tension battery and a direct current generator were employed with like result. The resistances were metallic up to 11 megohms and from this up to 1,000 megohms amyl alcohol-cadmium iodide resistances.

5. *Description of Diagrams: Tables.*

The connection between current and potential gradient is communicated in the following diagrams and tables on the basis of the values of the current and the square of the potential gradient. The ordinates of the diagrams are the currents, whose absolute values in milliamperes are given when the corresponding ordinate is multiplied by the co-efficient 0.0572.

The absolute values of the abscissae are given by the following table in which the calibration of the elec-
[691] trometer is also communicated. This corresponds to the diagram of Fig. 11.

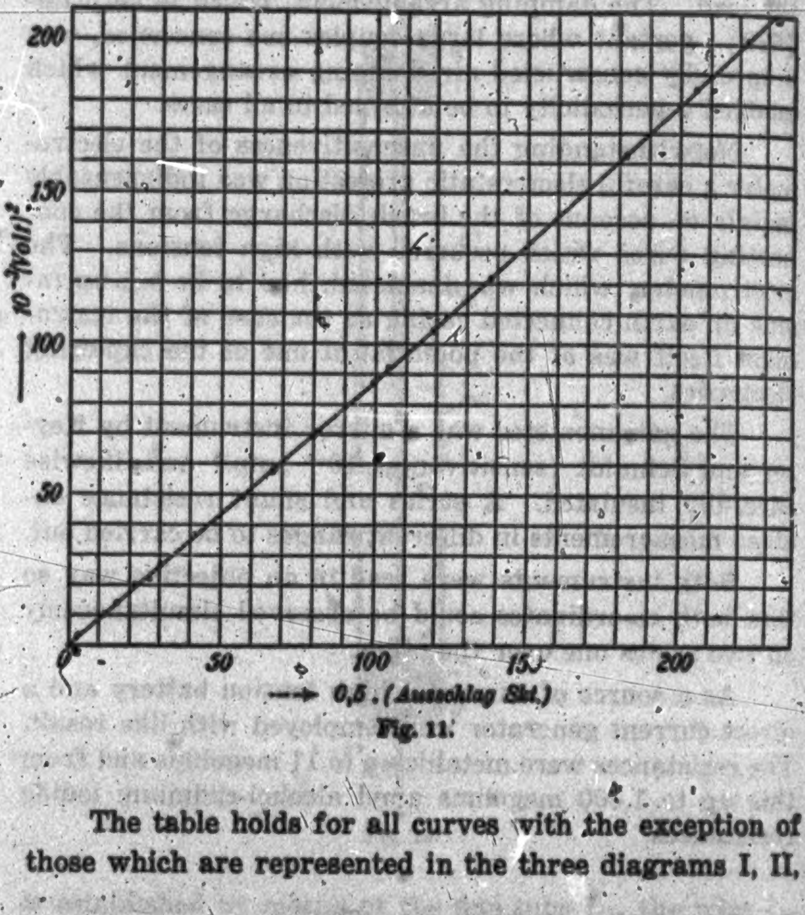


Fig. 11.

The table holds for all curves with the exception of those which are represented in the three diagrams I, II,

Deflection in Scale Divisions	Abscissae of the Diagram (Fig. 11)	$\frac{(\text{Volts})^2}{1{,}000}$	Volts
0	0	0	0
23.2	11.6	10.0	100.2
5.5	2.7	2.7	52.0
7.5	3.7	3.8	62.3
32.0	16	14.6	121.0
45.5	22.7	19.9	141
53.0	26.5	22.6	150.4
60.5	30.2	25.7	160.4

114.3	57.1	49.5	222.5
135.5	67.7	59.0	263.0
			44*

[692]

158.8	79.4	69.2	283.0
199.3	99.7	87.0	295.0
139.5	69.7	60.5	246.0
184	67	75.6	240.0
160.0	80	69.2	263.1
182.0	91	79.2	281.3
209.0	104.5	92.1	303.5
237.5	119.0	104.3	322.9
303.0	151.5	134.3	366.5
365.5	182.7	162.6	403.1
388.0	194.0	173.4	416.3
410.0	205.0	185.2	430.2
446.0	223.0	201.4	448.9
476.5	238.0	214.8	463.5
547	273.5	248.5	498.5

III; these were taken with a much greater electrometer sensitiveness, and their interest is of a more qualitative nature.

In the following tables the results of the observations are given which are graphically represented in diagrams 1-21. As regards the diagrams it should be remarked that, in order to facilitate comparison, the first curve on the left is referred to the actual system of co-ordinates, while each succeeding curve is referred to a system whose ordinate axis is displaced 10 scale divisions to the right relatively to that of the preceding curve. Finally practical considerations rendered it necessary to reduce the reproductions of the curves in the proportion of 2:5.

[698]

Date	10^{-3} (volts)^2	0.0572 10^{-3} Amp.	Date	10^{-3} (volts)^2	0.0572 10^{-3} Amp.
21/X	112.5	150.7	22/X	10.0	5.2
	106.0	142.2		10.0	2.7
Dia-	95.7	130.0	Dia-	116.5	143.5
gram	82.0	113.0	gram	138.8	167.5
1.	64.8	92.5	2.	75.2	100.7
	53.7	78.0		51.5	74.5
	42.5	62.5		46.6	67.5
	32.6	49.0		35.3	52.2
	24.5	36.5		23.4	34.5
	17.5	24.7		17.5	24.5
	14.5	17.0		14.0	17.7
	11.3	11.2		11.6	11.5
	82.[illegible]	111.0		8.4	0.2
	66.5	92.5		13.0	12.7
	33.3	48.0		140.1	167.5
	10.5	6.5		117.6	143.5
	33.3	49.0		52.4	73.7
	17.5	24.7		17.5	24.5
	11.0	8.0		9.8	2.5
	10.0	4.5		52.2	73.5
	17.5	24.5		17.5	23.5
	69.9	96.5		13.9	17.7
	53.6	77.0		11.3	11.5
	13.1	11.5?		9.8	5.2
	66.8	92.5		17.5	23.5
21/X	20.0	28.5		9.8	5.2
	16.5	22.5		11.0	1.5
Dia-	14.0	14.5		7.0	0.2
gram	33.0	48.5		10.5	7.0
1.	99.0	131.5		10.9	1.5
				52.0	74.0
				100.4	125.2
				118.0	143.5
22/X	59.0	82.2		140.6	167.5
	87.4	118.5		159.0	187.5
Dia-	120.2	148.0		52.3	73.7
gram	77.5	102.2			
2.	58.5	82.2	23/X	53.0	74.2
	46.6	77.5		143.5	167.7
	37.0	54.2	Dia-	119.5	143.7
	29.5	44.5	gram	64.8	74.5
	23.3	34.5	3.	51.0	61.7
	12.5	18.2		41.6	51.0

[694]

Date	10^{-8} (volts)^2	0.0572 10^{-8} Amp.
	28.8	36.7
	18.4	24.0
	11.7	13.2
	8.8	5.7
	8.0	4.2
	64.7	74.7
	123.0	127.2
	153.1	154.2
	177.0	174.2
	158.2	160.0
	105.0	113.5
23/X	75.2	87.5
	62.8	74.5
Diagram 3.	41.2	51.0
	17.0	23.7
	9.7	10.0
	11.7	3.7
	11.7	1.7
	64.7	11.7
	27.0	74.7
	177.0	174.5
	106.0	114.2
24/X	123.4	143.5
	110.2	127.0
Diagram 4.	95.0	112.5
	80.7	99.7
	67.3	86.2
	54.5	74.0
	45.7	61.5
	29.0	48.5
	23.4	36.5
	15.0	24.0
	12.2	17.7
	3.1	11.7
	13.0	11.0
	8.5	10.5
	0.5	10.2
	34.0	48.5
	14.9	23.5
	10.8	13.0
	14.9	11.2
	12.3	13.0
	16.0	10.2
	58.3	74.0
	143.0	164.0
	Ni	
9/XI	13.5	23.5
	20.0	36.0
Diagram 5.	27.1	49.0
	35.0	62.0
	42.5	74.0
	51.7	85.7
	61.0	99.2
	70.0	112.5
	80.2	123.5
	91.0	136.5
Diagram 5.	101.0	146.5
	109.2	161.0
	129.2	184.2
	90.5	136.0
	70.5	111.0
	51.5	86.0
	35.2	61.0
	20.9	36.0
	15.0	23.5
	11.0	11.0
	9.3	4.7
	8.5	3.5
	8.0	1.0
	7.5	0.2
	9.3	5.5
	Pt	
Diagram 6.	13.5	23.5
	19.0	36.0
	27.0	38.7
	34.5	61.5
	44.5	73.5
	52.5	86.5
	60.5	98.5
	61.5	99.2
	71.5	111.0

[695]

Date	10^{-3} $(\text{volts})^2$	0.0572 10^{-3} Amp.
	82.0	123.5
	103.5	148.5
	114.8	162.2
	120.5	174.0
	128.4	184.2
	13.5	23.2
	10.5	11.0
	10.0	3.5
	8.9	1.0
	8.9	0.5
	9.8	5.5
	15.7	23.5
	20.0	48.5
	45.3	73.5
	62.5	98.5
	82.0	123.5
	English Al	
9/XI	14.0	23.5
	21.3	36.0
Diagram 7.	27.[illegible]	48.5
	35.3	61.0
	43.5	73.5
	51.5	86.0
	59.5	98.5
	68.5	111.0
	79.2	123.5
	91.0	136.0
	101.8	148.5
	112.5	161.0
	122.0	173.5
	128.[illegible]	184.2
	36.5	61.0
	56.5	73.5
	51.5	86.0
	28.0	48.5
	16.3	23.5
	22.0	36.0
	13.5	11.0
	11.5	6.5
	9.8	1.5
	9.0	1.0
	12.0	7.0

Date	10^{-2} $(\text{volts})^2$	0.0572 10^{-3} Amp.
	Au	
Diagram 8.	17.5	23.0
	19.6	36.0
	30.0	48.0
	36.1	61.0
	44.0	73.7
	52.0	86.0
	61.5	98.5
	70.5	111.0
	80.0	123.5
	91.5	133.5
	102.5	148.5
	113.0	161.0
	123.0	173.5
	22.1	36.0
	35.5	61.0
	17.0	23.5
Diagram 8.	15.8	11.0
	13.9	7.2
	13.0	4.7
	11.0	1.5
	17.0	23.5
	English Al	
10/XI	9.8	11.0
	13.5	23.5
Diagram 9.	25.5	48.5
	42.0	73.5
	59.5	98.5
	80.4	123.5
	102.5	148.5
	130.5	148.2
	42.0	73.5
	25.5	48.5
	German Al	
Diagram 10*	80.3	123.5
	102.0	148.5
	59.5	98.5

[696]

Date	10^{-8} (volts)^2	0.0572 10^{-8} Amp.
	42.5	73.5
	13.0	23.5
	25.5	48.5
	11.0	11.0
	8.9	6.0
	7.5	4.0
	131.5	184.2
	8.5	8.0

English Al in liquid air

Date	10^{-8} (volts)^2	0.0572 10^{-8} Amp.
11/XI	32.9	57.7
	81.0	123.5
Dia-	62.5	98.5
gram	72.4	111.0
10.	82.8	123.5
	94.0	136.0
	117.9	161.0
	126.0	173.5
	136.7	184.2
	94.0	136.0
11/XI	72.4	111.0
	52.7	86.0
Dia-	44.0	73.5
gram	35.6	61.0
10.	28.0	48.5
	19.5	36.0
	13.5	23.5
	9.8	11.0
	8.5	6.7
	2.5	0.2
	2.0	0.0
	34.0	61.0
	60.0	98.5
	70.0	111.0
	103.8	148.5
	116.0	161.0
	126.4	173.5
	19.7	36.0
	87.6	184.0
	5.6	2.5

Pt in liquid air

Date	10^{-8} (volts)^2	0.0572 10^{-8} Amp.
Dia-	135.2	184.2
gram	12.0	23.5
11.	25.0	48.5
	42.5	73.5
	59.5	98.5
	80.5	123.5
	108.4	148.5
	125.7	173.5
	12.0	23.5
	8.0	11.0
	4.5	2.7
	17.5	36.0
	26.0	48.5
	34.0	61.0
	41.0	73.5
	50.4	86.0
	60.1	98.5
	12.1	23.5
	26.0	48.5

Ni in liquid air

Date	10^{-8} (volts)^2	0.0572 10^{-8} Amp.
11/XI	135.1	184.2
	126.0	174.0
Dia-	118.0	161.0
gram	106.0	148.5
12.	82.5	123.5
	61.5	98.5
	43.5	73.5
	28.0	48.5
	12.1	23.5
	9.0	11.0
	6.5	4.7
	5.0	1.5

German Al in liquid air

Date	10^{-8} (volts)^2	0.0572 10^{-8} Amp.
Dia-	135.0	184.0
gram	25.9	48.5
13.	11.5	23.5
	9.0	11.0
	6.5	6.0
	61.0	98.5
	103.5	148.0

[697]

Date	10^{-3} (volts)^2	0.0572 10^{-3} Amp.
Diagram 14.	Au in liquid air	
	135.0	184.2
	105.5	151.0
	61.0	98.5
	43.0	73.5
	27.0	48.5
	13.0	23.5
	9.5	11.0
	8.0	6.0
	5.5	1.0
	German Al	
17/XI	66.5	122.5
	62.0	115.0
Diagram 15.	57.5	107.5
	53.2	100.0
	45.3	85.0
	39.6	77.5
	35.3	70.0
	German Al	
17/XI	31.0	62.5
	26.8	55.0
Diagram 15.	20.0	42.5
	16.6	35.0
	12.5	27.5
	9.5	20.0
	5.5	12.5
	5.0	5.0
	4.5	1.2
	4.0	0.0
	67.0	122.5
	57.5	107.5
	65.0	122.0
	69.0	130.0
	In liquid air	
Diagram 16.	79.0	122.5
	66.5	107.5
	60.5	100.0
	57.0	95.0

Date	10^{-3} (volts)^2	0.0572 10^{-3} Amp.
	45.7	80.0
	42.5	75.0
	37.5	67.5
	35.5	65.0
	31.0	57.5
	26.8	50.0
	22.5	42.0
	18.5	35.0
	14.5	27.5
	11.0	20.0
	8.0	12.5
	5.5	7.0
	5.0	2.5
	79.0	122.5
	02.0	147.5
	124.0	172.5
	132.9	183.2
20/XI	31.0	80.0
	34.0	87.5
Diagram 17	36.5	95.0
	35.2	95.0
	27.0	73.2
20/XI	22.0	57.5
	16.7	42.5
Diagram 17.	9.0	27.5
	4.5	12.5
	3.6	2.5
	5.4	12.5
	In liquid air	
Diagram 18.	40.0	73.2
	43.0	77.5
	35.4	65.0
	26.0	50.0
	23.0	42.5
	19.2	350.
	13.5	22.5
	9.5	12.5
	43.0	77.5
	76.5	122.5
	128.0	183.0

Date	10^{-3} (volts)^2	0.0572 10^{-3} Amp.
	26.5	50.0
	44.5	77.5
	78.0	122.5
	128.0	183.0
6/XII	126.0	145.0
	116.0	132.5
Dia-	108.0	120.0
gram	90.5	107.5
19.	76.0	95.0
	64.0	82.5
	53.0	70.0
	43.0	57.5
	34.0	45.0
	24.5	32.5
	16.5	20.0
	12.0	5.5
	10.5	0.0
	17.0	20.0
	33.5	45.0
	53.0	70.0
	76.0	95.0
	102.0	120.0
	152.5	170.0
	173.5	195.0
Discharge tube in liquid air		
7/XII	11.3	1.7
Dia-	13.0	8.5
gram	17.5	21.0
20.	25.5	33.5
	34.5	46.0
	44.0	58.5
	53.5	71.0
	65.5	83.5
	77.5	96.0
	91.0	108.5
	103.8	121.0
	119.0	133.5
	131.5	146.0

Date	10^{-3} (volts)^2	0.0572 10^{-3} Amp.
	146.0	158.0
	151.5	171.0
	169.5	183.5
	182.5	196.0
	134.0	148.5
	79.9	96.0
	36.5	46.0
	14.0	1.0
Absorption vessel in solid air		
	104.0	121.0
	77.5	96.0
	55.0	71.0
	34.5	46.0
	17.5	21.0
	13.5	8.5
	10.5	0.5
	26.0	33.5
	65.6	83.5
	91.0	108.5
	113.0	133.5
	145.3	158.5
	Irregular	196.0
	78.5	96.0
	162	175.5
9/XII	19.5	33.5
	33.0	46.0
Dia-	119.0	146.0
gram	97.0	121.0
21.	133.0	96.0
	52.5	71.0
	33.0	46.0
	16.0	21.0
	11.5	1.0
	119.5	146.0
	159.5	171.0
	180.0	196.0

[699]

IV. RESULTS OF EXPERIMENTAL OBSERVATIONS.

1. *Relation between Potential Gradients, Current Density and the Vacuum.*

Even during the first potential measurements by means of sounds when the methods of evacuation had not yet been developed to the same extent as in the course of time, there was found to exist besides various irregularities and phenomena that always appeared in different form, a definite relation which could always be reproduced. It was found that when the discharge tube had been subjected to a proper previous treatment and the degree of vacuum mentioned in the introduction had been obtained, the relation between the current J and the potential gradient v could be expressed by (1)

$$J = a v^2 + b$$

where a and b are constants that will be more fully interpreted later.18) The condition for this law was, besides the one already mentioned, namely, that the proper degree of evacuation must be reached, that J should not have too small a value—with a tube diameter of 10 mm. about 1 milliampere. For current values greater than this, this law held so long until the heating of the glass walls in virtue of the discharge caused a marked addition to the pressure of the gas in the tube, because since an increase in the pressure of the gas caused a decrease in the potential difference for constant current, a heating of the glass walls caused a in equation (1) to increase and this corresponds to another vacuum. b which was held very small for the gas pressures dealt with in the earlier investigations could be neglected as a first approximation in these.

Whatever was said about the quadratic law holds for the better vacuum that could now be obtained with
[700] the help of newly installed equipment. Also here every reduction in the gas pressure up to the limiting region to be considered later on causes a diminution in

a. Furthermore, there are three peculiarities of the characteristic that always were found to exist. We shall, in order to avoid repetition, briefly state these here.

(a) Provided that we deal with variation in gas density within the region of the vacuum here investigated, the minimum current from which on the equation (1)

$$J = a v^2 + b$$

holds is always smaller for the larger pressure than for the higher vacuum.

(b) The b increases with a decrease in gas density, but generally remains small in comparison with the discharge current that came under observation.

(c) With the smallest currents that were observed current densities that lie very far below the region mentioned under (a) the potential gradient and the current strength cannot be connected by a definite relation, as can be seen from the lower parts of the diagrams where the points are scattered.

Contrary to the parts of the curve that strictly follow the equation (1), there were other parts for small currents which in the initial experiments were not so good. These parts, as already pointed out under (c), were not only different for different apparatus, but even for the same tube they varied. It often happened that it was not possible to get a satisfactory series of observations for this part of the curve. Diagram 1 gives the curve for a tube made out of Thueringer glass. As abscissae are given the square of the potential gradients and as ordinates the currents. The diameter of the tube [701] was 14 mm. It is seen the uniform upper part of the curve, which indicates a definite relation between current and potential gradient, is preceded by a curve which is different for increasing and decreasing currents, similar to what is found in the ordinary discharge of Geissler tubes, that the potential gradient decreases with increasing current. Besides this, there is a part of the curve for the smallest currents which indicates a potential gradient which is relatively very high. Diagram II

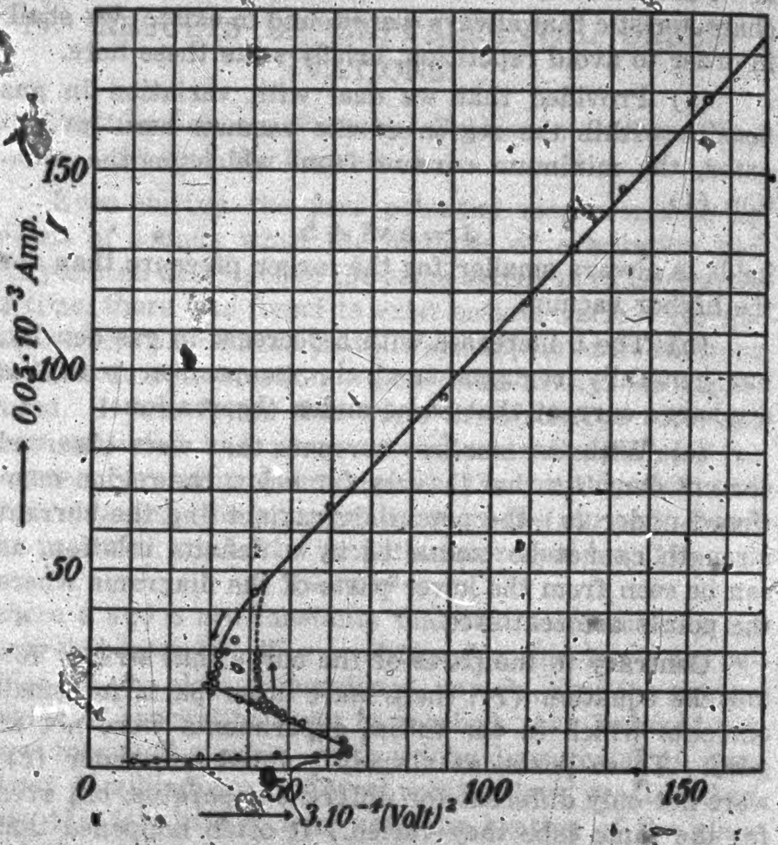


Diagramm I.

shows a part of the curve which is analogous to the last mentioned, and one which is quite marked here, but was only indicative in the tube of Diagram I. This part shows relatively high currents for small v^2. In the second diagram, however, the part of the curve which [702] indicates an increase in potential for increase in current was too unstable to be measured. Diagram II represents the results obtained with a tube made of Jena glass.

In the course of the investigation it was found that the lower irregular part of the characteristic became smaller and less marked, the more the walls of the vessel were freed from absorbed gases. This could probably

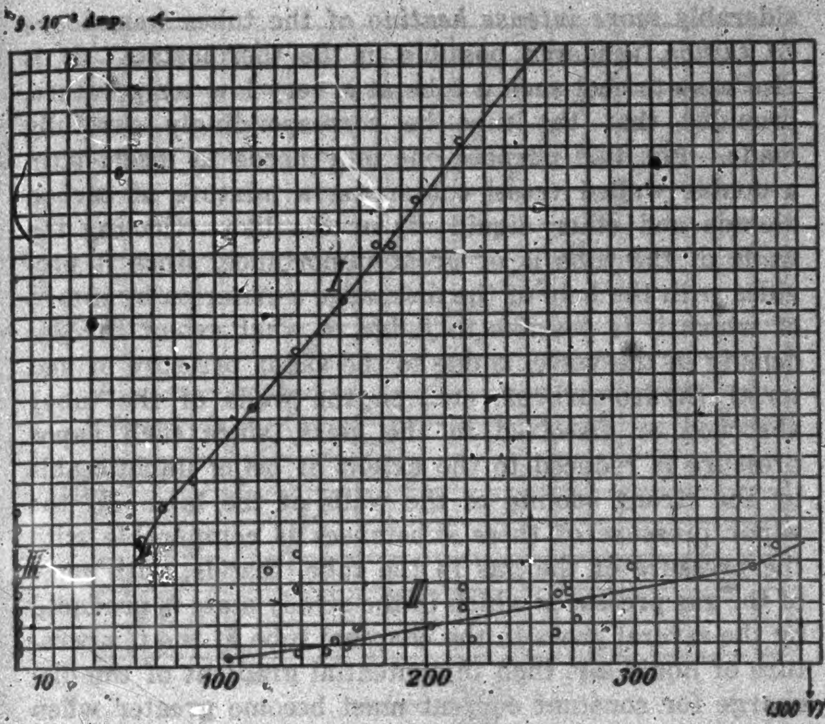


Diagramm II.

be taken to indicate the transition stage between discharge at higher pressures and the discharge in the vacuum worked with here. Since the separation of the important from the unimportant (insulation faults, gas peculiarities, residue formation, uncleanliness of all kinds) caused great difficulty due to the inconsistency [703] of the phenomena, the plan was adopted here to better the vacuum as much as possible in the hope of finding a uniform characteristic by producing well defined conditions and perhaps on the basis of an insight thus obtained to critically repeat prior observations.

For this purpose the tubes were thenceforth made of Jena glass to avoid impurities due to the sealing in with lead glass. Furthermore, I abandoned the original type of tube whose main expansion was in a horizontal plane and designed a form of tube which I referred to in Part III as the vertical type. Consequently a considerably *more intense heating* of the tubes was, *above all things*, rendered possible in the thermostats. It is also easy to cool such a tube at a very low temperature, provided that the tube be correspondingly carefully made. For this purpose one only needs to insert it in a double walled vessel containing a mixture of carbon dioxide and ether, liquid air or the like. Cooling the walls of the tube is of great importance, since it provides with the help of the discharge a criterion by means of which it is possible to judge to what extent the gas density in the vessel is due to the vapor pressure of material (hydro-carbons, etc., on the walls of the tube) absorbed or dissolved in the glass, since such vapor pressure is reduced to the extent of being unnoticeable by the strong cooling of the walls of the tube. If the vapor pressure of these substances is comparable with the pressure of the gas in the tube, that is, with some of the gas pressures which in the steady state is produced by the several gases in the charcoal tube at the temperature of liquid air, then the potential gradient of the discharge for constant current must become greater when the tube is cooled than in the ordinary case in which the tube hangs freely in the air and is strongly heated by the discharge current.

In fact it was found in the first experiments that by cooling the tube to —180° the potential difference [704] between sound wires was almost double. After that the thermostat was improved and given the form described above. The result is given in diagram 1 (continuous current) in which case the tube hung freely and was heated by the discharge. After long continued discharge this curve went off into the dotted one, which gave higher voltages for the same current, thus indicating a better vacuum. On the following day the curve given in diagram 2 was taken, which corresponds to a still better vacuum obtained with long continued absorption and discharge. The dotted part of the curve represents conditions in which a strong discharge caused so much heating (up to about 250°) that an increase in

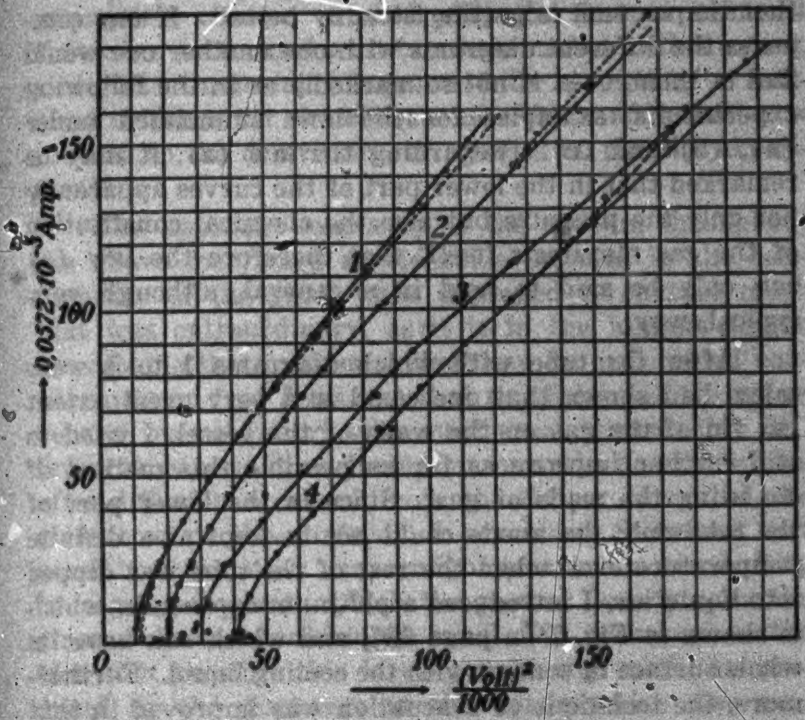


Diagramm 1—4.

vapor pressure on the glass walls becomes noticeable. [705] Diagram 3 shows a curve taken when the tube was dipped into the liquid air. In this case there is no deviation indicating higher pressure such as is given by the dotted line of diagram 2, even for higher potentials and large currents. The dotted curve gives the characteristic directly before immersion of the tube in liquid air. One sees that the improved method of heating the tube resulted in a very great improvement in these experiments over those in which the potential gradient was doubled as a result of cooling.

Diagram 4 gives a characteristic that was taken the following day without cooling. The broken curve has the same meaning as that attached to diagram 2; the dotted part gives for comparison the relation observed on the previous day without cooling. One sees that the vacuum is getting steadily better. If one compares the different diagrams with one another one would find in them, even if not so markedly as in the following experiments, examples for the laws enunciated under (a), (b) and (c). Regarding the law (a), it may be remarked that in the lower part of the curves apparently not only the pressure but also the chemical constitution of the gas manifests itself, that therefore the law (a) can only be said to hold in a general, although very typical, way.

After the tube with which diagrams 1 to 4 were taken had shown that one could to a very great extent get rid of the gas on the walls of the vessel, I tried to still further improve as far as possible this method of denuding the walls of gas. Since in the lower part of the tube only the anode could not be kept at a definite temperature even when the rest of the tube was dipped into liquid air, I introduced a platinum cap anode, which is shown in Fig. 7 on page 687, and which can have its whole surface in contact with the cooling liquid. Furthermore, the technique of evacuation was improved in that the method of pumping and the arrangement of the absorption vessels described on page 682 were used. Working now on the principle that in the earliest possible stages of pumping a part of the tubing was kept uninterruptedly at a very much lower temperature than [706] the discharge tube, I reached a degree of purity of the glass walls for which the part $J = a\,v^2 + b$ remains unchanged even for great temperature changes. It was, in fact, possible to proceed on the above mentioned principle of obtaining the vacuum even in the case of investigations lasting weeks at a stretch, since the liquefaction installation which had meanwhile been erected in the Institute gave large quantities of liquid air very reliably. In this way it was attained that, with a temperature change from about + 200 degrees corresponding to an uncooled tube through which a discharge was passing, down to — 185 degrees in a bath of liquid air, the coefficient of equation (1) underwent no perceptible change. I shall skip the first experiments that were performed with tubes evacuated to this extent, since later material (diagrams 5 to 14) will give sufficient evidence for the above contention, and I shall now proceed to the description of a series of parallel experiments.

The apparent constancy of the vacuum throughout the above mentioned considerable interval in the temperature of the glass walls appeared to contain much that was extraordinary, as it is in the highest degree improbable that a glass surface can be maintained continuously so free from gas that no change in the vapor density over it occurs with such great temperature differences, especially as during many weeks no appreciable after-diffusion occurred from the deeper layers of the glass toward the surface. I concluded therefore that possibly some other cause might produce a gas density by comparison with which the partial density over the glass wall was vanishingly small. So I arrived at the idea that possibly this large gas density might be produced by the discharge at the anode which was perceptibly heated.

In order to test this question experimentally five pot-shaped anodes of platinum were sealed into a glass vessel in the form of a very oblate ellipsoid (Fig. 11). The middle one was not inlaid but in each of the other four was placed an exactly fitting pot made of foil 0.3 mm. in thickness of nickel, gold, German aluminum and [707] English aluminum respectively. The inlaid pots had their edges turned over to prevent traces of the discharge from leaving the upper edge of the platinum. The two sorts of aluminum were chosen because of the well-known experience of Roentgen tube makers that German aluminum contains more sodium and consequently gives off much more gas (hydrogen) [19)] under the influence of the vacuum discharge. It is just *this* property which renders it more suitable for use in Roentgen tubes than the metal of English origin.

Everything was therefore so arranged as to make

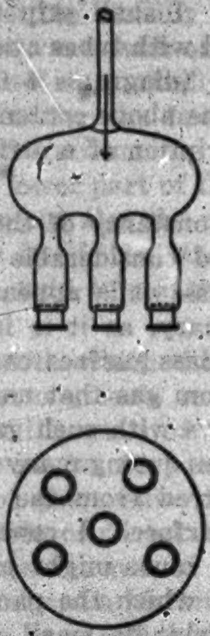


Fig. 11.

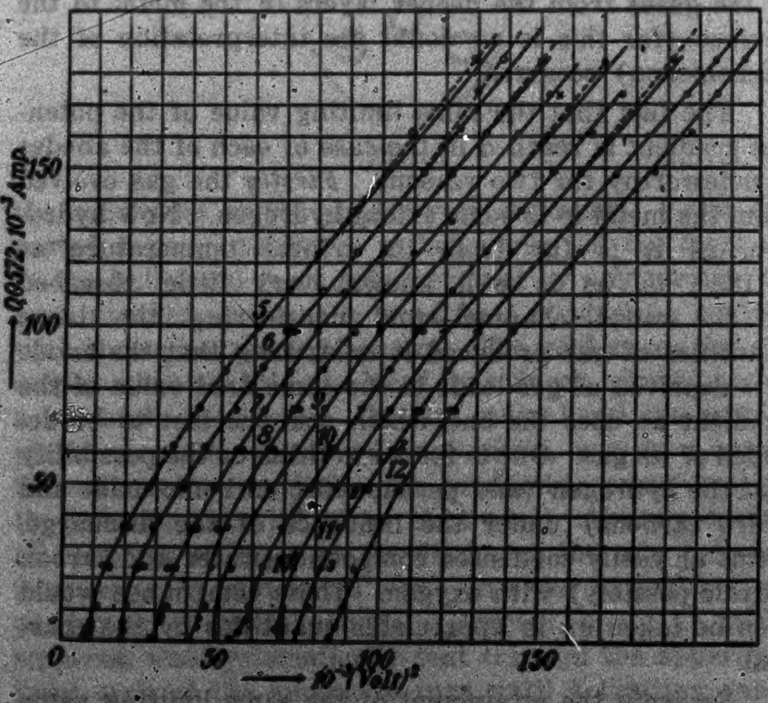
the conditions at the anodes very different. I also expected a great difference in behaviour, all the more so as the individual inset pots were not by any means—as was intended—in equally good heat conducting contact with the surrounding platinum. The gold anode for example, when slightly displaced by a knock, glowed under a moderate discharge. On the other hand the middle platinum anode which was not inlaid, was in a much more favorable condition for conducting away heat to the exterior than the other electrodes. Already during the removal of gases by the discharge the tube behaved in an entirely unexpected way. In order to enable comparison to be made a definite current, about 11 milliamperes, was systematically sent through the apparatus from each of the anodes in turn until a limiting value of the potential gradient was reached which remained unchanged for a considerable time (15 minutes). Now, contrary to all expectation, the same limiting value re-
[708] sulted for each anode, one after the other, as

for its predecessor which had just been deprived of gas, although different times were necessary to attain it. The time required to deprive the platinum, English aluminum, nickel and gold anodes of gas was 40 to 100 minutes in each case while the German aluminum anode required over 3 hours to reach the limiting value. It is of interest to note that, after the tube has been deprived of gas for the first time and is then left for 24 hours without any discharge, the limiting value does not set in immediately the discharge is switched on again, but some time, although a very much shorter period, must elapse before the limiting value is again reached. This can be repeated for several days, but the periods necessary to get rid of the gas get shorter and shorter till at last a stage is reached in which no after-diffusion of the gases from the deeper layers of the metal to the surface (for this is no doubt the interpretation of the phenomenon) occurred.

The fact that the same limiting value of the potential gradient is reached in the case of each of the anodes is noteworthy for two reasons. *Firstly* the gas evolved from the metal is to some extent hydrogen. Now hydrogen; as it is far from its critical temperature at —185°, is, as is well known, very little absorbed by the wood charcoal—and considering the large quantities of gas produced it is striking that the anode *first* deprived of gas leads to the same final value of the gradient as does the one which was the last to be denuded of its gas. One is forced to think of the possibility that the hydrogen (and perhaps also carbonic oxide and hydro carbons) under the influence of the discharge, forms an easily condensed compound (water and carbon dioxide possibly) with oxygen. These compounds would then be taken up in appreciable quantities by the charcoal.

Secondly the attainment of the same limiting value independently of the material of the anodes is also remarkable because, if we were to take this limiting value as a measure of the vacuum, it would amount to saying

[709] that the stationary equilibrium between the evolution of gas from the anode on the one hand and the gas absorption by the charcoal on the other leads to the same limiting value independently of the constitution of the electrodes. When we consider the great change in the evolution of gas which is produced by the slightest change in the materials used in the construction of vacuum tubes generally (also Roentgen tubes) we are forced to look for some way of avoiding the last conclusion, especially when we remember the large quantities of energy liberated at the electrodes in my experiments. One would first think of the possibility that the vapour density given off from the glass walls is great in comparison with that given off from the anodes. Now



Diagrams 5—12.

it follows from the diagrams that the vapour density over the glass walls is not perceptible at all. The diagrams 5, 6, 7 and 8 show the characteristics taken on the 10th November 1909 with the nickel, platinum, English aluminum and gold anodes respectively. It will be seen that these curves in the part $J = \alpha v^2 + B$ correspond [710] with one another exactly as regards α, that is they have all the same inclination. In the case of the last curve, Diagram 8, the vapour pressure over the glass wall has been reduced to such a degree by the preceding exhaustion that the same constants α and B still hold with heavy discharge currents, whereas the preceding diagrams show deviations at the corresponding part in the sense of an increasing pressure. In so far as the differences in B do not lie within the limits of error mentioned below (p. 724) it can be concluded from them and especially from the course of the curves for small currents (cf. (a) and (b) p. 700) that notwithstanding the agreement for big currents, the vacuum was not the same in all the experiments; it was best for instance in the case of the English aluminum. On the following day the determination in the case of the last mentioned anode was repeated (Diagram 9) and the German aluminum anode was freed from gas and the characteristic $J = \alpha v^2 + B$, which was likewise in agreement with the others, taken (Diagram 10*).

On the next day the investigation of the tube in a bath of liquid air took place. It will be seen from the carefully determined curves 10 and 11, and also from the more widely separated measurements which give 12, 13 and 14 that there is a complete agreement, not only with one another, but also with the curves 5-9 in the rectilinear part, and only in the parts corresponding to smaller currents was it just possible with the help of (a) (p. 700) to recognize in some cases an improvement of the vacuum as compared with the process of exhaustion with the discharge and no cooling. It follows that the constancy of the measurements was not due to the vapour density over the glass wall far exceeding the evolution of gas from the anodes. There remains therefore a last possibility, if we question the objective uniformity of behavior of the anodes, namely that the gases absorbed by the charcoal give rise to a total gas density which is great in comparison with gas densities from other sources.

It was therefore time to investigate whether a lowering of the temperature of the charcoal would produce an appreciable rise in the potential gradient.

As the liquid hydrogen reducing plant of the Insti-[711] tute was at the time being extended and reconstructed I had, for the time being, to be content with cooling the absorption vessel to the temperature of solid air. For this purpose, after a number of experiments with the tube just described which were not quite free from objection, and to which I shall refer again later, a tube of the ordinary form, but with a cylindrical anode (cf. Fig. 8, p. 687) was evacuated with special care for

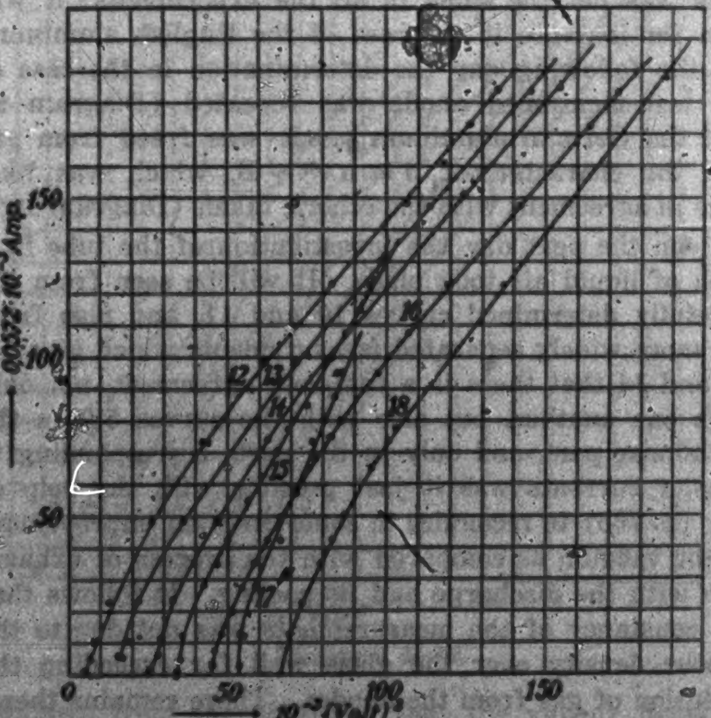


Diagramm 13—19.

days on end, so that its characteristic in a bath of liquid air was not to be distinguished from that obtained without cooling. Then the liquid air around the absorption vessel was allowed to vaporise under a pressure of 10 mm. of mercury for 4 hours at a time, at first with the tube free in the air and later cooled with liquid air. The result was that not the slightest change could be perceived, not even when the discharge tube was run for [712] hours on end with a heavy discharge current during the experiment with solid air, so that the conditions were favorable for still further freeing the walls of the discharge tube from absorbed gases.

Diagram 19 shows the characteristic when the absorption tube is in liquid air (about —185°) while the discharge tube is not cooled.

Diagram 20 shows the characteristic of the same tube, indicated by circles, where both discharge tube and

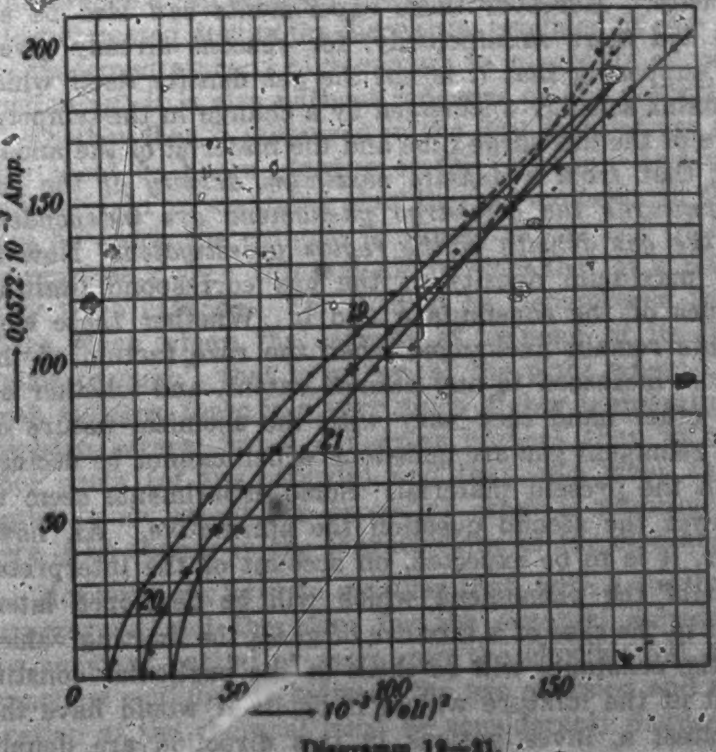


Diagramm 19—21.

absorption tube are cooled to — 185° and then the curve, indicated by crosses, for which the absorption tube was in solid air (about — 220°, as with the small pressure of 8-10 mm. the oxygen is also almost on the point of solidifying) and the discharge tube again in liquid air. [713] Most of the points coincide, since, as on other occasions, the function was taken by giving the current a definite value and then reading the electrometer deflexion. There is no perceptible difference here. As however a lowering of the temperature by about 35° must at these low temperatures[20)] considerably increase the absorption by the charcoal, it follows also that the lowering of the gas density has no influence on the conduction of the current in the high grade vacuum within the range of current strengths investigated.

For the previous experiments had shown that the other causes present do not produce any perceptible gas density. Moreover these experiments can also be explained more satisfactorily, for reasons already given, by supposing that it is not the gas density itself which remains sensibly unchanged by a change in the temperature of the discharge tube and the material of the anode, but that *from a definite maximum density of the gas downwards the discharge phenomena are independent of the gas density in the region investigated.* Now to the maximum density of the gas correspond limiting values of the constants a and b. Whether these constants remain unchanged when the rare faction of the gas is increased to any desired extent, and whether on the other hand they vary with the chemical nature of the remanent gas are questions which cannot be decided with the present material. Some experiments seem to answer the second question the affirmative. As, however, it is to be expected, on account of the interpretation of the phenomena which will be developed later, that in the case of a mixture of gases the limiting values of the constants will be those of the particular constituent of the mixture which, if by itself would have the greatest a, investigations in this direction are doubly difficult to carry out and can only yield reliable results on the basis of an extraordinarily comprehensive amount of material. For it does not seem to be easy, on account of the probable oxidation of all the remanent gas mentioned on p. 708, to have, in a steady state, any gas, and yet a strictly defined gas, through which to pass the discharge.

It might possibly be thought that the continuous [714] emission of gas from the oxide cathode is sufficiently great to completely push into the background all the factors dealt with above which influence the gas density. This idea, however, is contradicted by every day experience, for it obviously means that the potential gradient must necessarily vary greatly with the constitution of this cathode.

Now as a matter of experience it not only makes no difference at all whether the cathode is very strongly or feebly heated during the discharge, provided of course that its temperature is high enough to ensure its proper functioning; it is also without influence on the potential fall whether that is measured in the first hour of use or after about 60 hours glowing of the cathode. And we shall be right in assuming that the gas emission in the cases in which the cathode is almost at the end of its life must be a very different affair from that of a relatively fresh cathode. For it must be remembered that at the place where the cathode at the end of its life "burns through", that is to say, at the place where the break appears, there is a very much higher temperature (perhaps several hundred degrees higher) than in the other parts (of the cathode) and that even when thus heated to an extent for exceeding what is admissible, there is no change in the characteristic of the discharge.

Moreover we have to consider that, with a constant temperature, and therefore for the eventual existence of a constant partial pressure over the glowing foil, the dynamical equilibrium between the gas emission and absorption at the charcoal must be considerably displaced according as the cathode is a fresh one or has been in use for many hours, since the velocity with which the gases are given off must diminish in course of time.

If the evolution of gas from the same cathode is to be regarded as changing in course of time, we should expect it to be very different indeed with different cathodes as their condition varies very appreciably from one case to another. Notwithstanding this, when a new cathode is introduced into a new tube no change can [715] be observed in the limiting value of the potential drop (gradient). And even with *different discharge tubes* we arrive at *exactly the same limiting value*[21)] provided we take into consideration the way in which the characteristic varies with the geometrical features of the tube, on the basis of the laws given further below. So the behaviour of the cathode is a very important reason for the assumption of the existence of a maximum value of the gas density from which downwards the potential drop remains unchanged rather than one which is in conflict with this assumption.

Finally, when the temperature of the absorbing substance is lowered appreciably, an essentially different dynamical equilibrium of the gas density must set in between the evolution of gas at the cathode on the one hand and the absorption of gas at the charcoal on the other. But this, as we have seen, produces no change at all in the characteristic.

The diagrams 15, 16, 17, 18 as well as 21 are rather more distantly, though still very closely, related to the subject discussed above. The first four diagrams were taken with the tube with 5 anodes, in connection with the experiments already described, after intentionally violating the principle of exhausting mentioned on p. 681;—that a portion of the connecting tubing should always be maintained at a much lower temperature than the discharge tube. This was done by keeping the absorption vessel for a time, about an hour, at room temperature. Curve 15, taken after this, shows, when compared with diagrams 5-14, that a considerable contamination of the glass walls was immediately caused. Curve 16, which was taken with the discharge tube immersed in liquid air, shows that the cooling completely dispels the effect of the impurities and gives the characteristic the form it has in the case of an uncontaminated tube which is not cooled. At the same time the curves 15 and 16 furnish clear illustrations for the laws (a) and (b) p. 700.

[716]

It may be remarked by the way, that, with curve 15, even with a moderate discharge only, under which the glass walls would in other cases show no trace of the sodium spectrum, the emission of a line of an extraordinarily great intensity coinciding with the sodium D lines was observed with a simple spectroscope. As such a spectral phenomenon does not appear with uncontaminated tubes, that is with small gas densities, not even with much heavier discharge currents, and as it is probably to be ascribed to the formation of diffuse canal rays, this observation may provide some insight of fundamental importance into the formation of canal rays. As simultaneously with the appearance of the D line and the contamination of the tube an intense hydrocarbon spectrum appears it is natural to suppose that a casual connection exists between the two phenomena. This fact may be related to one observed by J. J. Thomson that in high vacua canal rays always have a ratio of charge to mass corresponding to hydrogen. This way of explaining Thomson's experiments seems all the more likely as no sufficient precautions were taken in his experiments to get rid of the partial pressure of hydrocarbons over the glass walls.

Diagram 17 was obtained after heating the walls of the absorption tube at room temperature for a longer period. A further deterioration of the vacuum as compared with curve 14 will be recognized. Curve 18 was taken after this with the discharge tube cooled in liquid air. The vacuum was now so badly defined that even this intense cooling did not quite suffice to bring the gradient (drop) back to the old limiting value. At the same time a preliminary experiment of cooling the absorption tube by solid air was carried out, the result of which did not differ appreciably from curve 18. On account of the contamination and the consequent appreciable vapour density over the glass walls this experiment is indeed not any more convincing and is therefore not mentioned again.

[717]

Curves 17 and 18 also furnish illustrations for the laws (a) and (b) p. 700. Diagram 21 was obtained with the same tube as diagrams 19 and 20 under circumstances similar to those under which curves 15 and 17 were obtained with the tube with five anodes. We also find illustrations for laws (a) and (b) in comparing 21 with 19 and 20.

In order to get the law of the lower part of the characteristic, that is, of the part which extends from $J = 0$ to the region where $J = a v^2 + b$ is valid, we may use the curve of diagram 20 in the following way. A parallel displacement along the horizontal axis is carried out so as to make the curve pass through the origin of coordinates. This happens when v^2 is replaced by $(v^2 - 11)$. Logarithms are now taken of $(v^2 - 11)$ as well as of J for the whole curve. If we, for the sake of convenience, subtract 0.70 from log J in the following table and introduce therefor log J — 0.70, and if we further multiply both this quantity and log $(v - 11)$ by 100, we obtain the following:—

I	II	III	IV
1	5	0	0
2.5	10	40	30
4.5	15	65	47
6.8	20	83	60
9.5	25	98	70
12.6	30	110	78
17.2	35	124	84

19.7	40	129	90
23.7	45	137	95
26.8	50	143	100
34.8	60	154	108
42.9	70	163	114
51.9	80	171	120
62.0	90	179	125
72.0	100	186	130
92.5	120	197	138
114.0	140	206	145
135.0	160	213	150
156.0	180	219	155
176.5	200	225	160

Column I contains the quantity 10^{-3} (volts)$^2 - 11$
" II " " " 0.0572×10^{-3} Amp.
" III " " " $10^2 \log_{10} (v^2 - 11)$
" IV " " " $10^2 \log_{10} (0.0572 \times 10^{-3}$ Amp.$) - 0.70$

[718] Columns III and IV are represented graphically in diagram 20a. The points from the origin of coordinates to the bend indicated by the arrow undoubtedly lie on a straight line which corresponds to the curved portion of diagram 20a. The equation of this straight line is if we take as a first approximation for the tangent of its angle of inclination to the horizontal axis the value $\frac{3}{4}$, $\log J - 0.70 = \frac{3}{4} \log_{10} (v^2 - 11)$
and therefore

$$J = 10^{0.70} (v^2 - 11)^{3/4}$$

The part of the curve above the bend indicated by the arrow corresponds to the straight part of the curve of diagram 20, $J = a v^2 + b$, and is consequently likewise a straight line. A superficial examination might give the impression that this part of the curve is determined by too few points. In reality the
[719] accuracy of its determination by far exceeds that which can be reproduced by the method of diagram 20a, as the curve corresponding to the anti-logarithms of the coordinates is itself a sharply defined straight line.

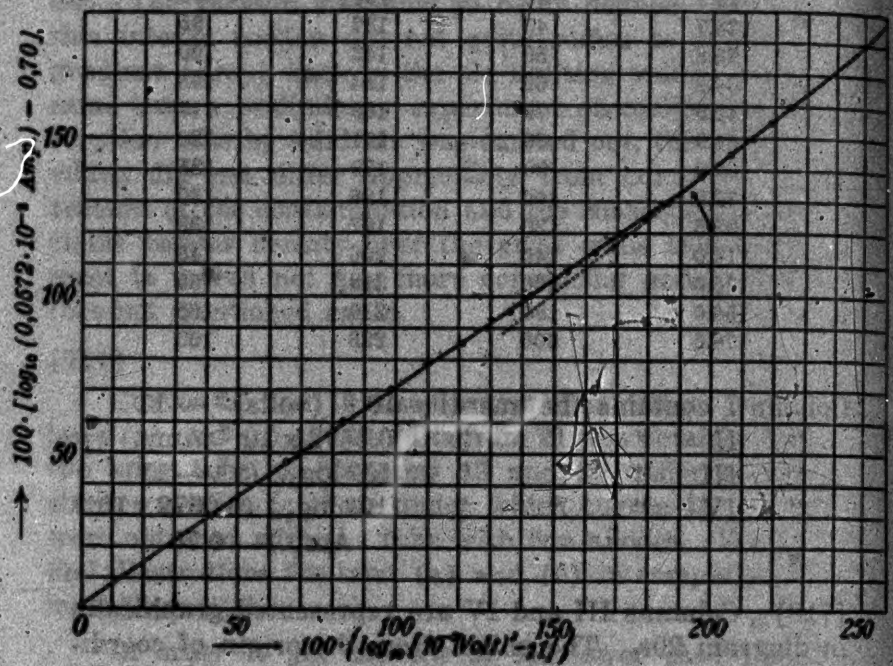


Diagramm 20 a.

The bend which has been mentioned, therefore possesses undoubtedly a real meaning, namely that in its neighborhood the exponent of the potential drop (gradient) in the characteristic increases by about 25% of its initial value.

More exactly formulated; *the characteristic consists of two parts. In the first part the potential drop (gradient) increases as $J^{2/3}$ in the second as $J^{1/2}$. In both parts the connection between J and v is represented simply by a power.*

A few remarks may be made here concerning some diagrams which are apparently determined by few points, and also concerning the general accuracy of the measurements. For technical reasons one generally endeavours to work as quickly as possible. For if we intend to carry out with an apparatus a long series of connected measurements we have to take into consideration that the life of a tube and especially that of the cathode is limited. The circumstance that each new apparatus not only causes expense but also much trouble and loss of time during exhaustion and getting ready for measuring is not without importance. Of necessity therefore a method of working must be chosen which, before all things, leads as rapidly as possible to the end in view. Setting the current for definite values and observing the resulting electrometer deflexion is obviously such a method. It is a relief to the observer, whose attention is in any case greatly taken up by the whole apparatus, if the apparatus is frequently set for the same few well marked points in preference to taking many observations in a continuous way one after the other, especially as any disturbances are at once noticed in this way and can be removed. Therefore those curves which are determined by less numerous points are not of less value, at any rate for our present purposes, than some of those determined by continuously distributed points.

[720]

As regards the accuracy of the measurements, it is, as the diagrams prove, generally very satisfactory, especially when we consider that every disturbance in the exterior circuit (especially in the running of the high tension machines) directly affects the *first power* of the potential drop between the terminals of the tube, while it is *the square* of the potential drop (gradient) which is measured and represented in the diagrams. It can be seen from some of the curves that the accuracy could be uniformly and considerably increased in case of need, though this, as has been said, would not be of utility for our present purposes—for the constancy of the phenomena is in itself very great. It would then be necessary of course to relieve the actual observer from the supervision of the working of the apparatus, and, especially, to arrange for the high tension machines to be driven always from the battery of the Institute during measurements. As a rule the measurements last too long for the capacity of the Institute's battery to suffice;

so that it is preferable to work with the town supply generally—which naturally reduces the accuracy of the measurements—rather than that the attention of the observer should be taken up by frequently switching on and off the current driving the high tension machines.

2. *Influence of the Geometric Conditions on the Potential Gradient; Spectral Observations.*

Along the discharge tube the potential gradient is distributed as follows: At the oxide cathode it is a few volts—according to the condition of the cathode. An increase in the vacuum over that which is usually obtained with air pumps causes no change here. The proof of this is given, as is easily conceivable, by introducing an exploring electrode in the neighborhood of the cathode.

Along the axis of the discharge column the potential drop, within the limits of validity of the law $J = av^2 + b$, is linearly distributed. With bigger gas densities, that is at the beginning of the region of investigation, it increases in the direction from the cathode to the anode and when the vacuum is improved to some extent it very soon attains a linear distribution—the [721] cross-section being supposed constant, of course. This can be proved simply by a row of exploring electrodes placed one behind the other, this fact appears to furnish the justification—which at the outset is not at all obvious—of speaking of a positive column in the extreme vacuum.

At the anode there is no exceptional drop in the gradient, at least as long as the anode is sufficiently large.

The determination of the distribution of potential gradient perpendicular to the axis cannot be carried out with the same method. If, however, the tube with the totally reflecting prism (Fig. 6) be used there is seen, as long as the vacuum is not so good that the characteristic remains unaltered, a well marked thread along the axis of the tube, which emits the cathode ray band spectrum of oxygen besides the carbohydrate and perhaps also the hydrogen spectra. One would be inclined to conclude from this that the current density is by far the greatest in the immediate neighborhood of the axis.

As the vacuum gets better, however, this thread shrinks together more and more and finally vanishes,—and with it every trace of a discontinuous spectrum vanishes; at least as far as can be seen with an ordinary spectroscope. There only remains then a uniformly distributed luminescence, which gives a continuous spectrum. This fact and the law derived below, that the characteristic is determined by the current and is independent of the dimensions of the tube speaks against the assumption that the current density is greatest in the center of the tube. On the contrary, the inner discontinually glowing thread seems rather to be a phenomenon closely related to striction canal rays, which also is connected with the apparent emission of the D-light (p. 716) and then vanishes in very high vacuum, in which obviously the possibility of the existence of canal rays is greatly reduced.

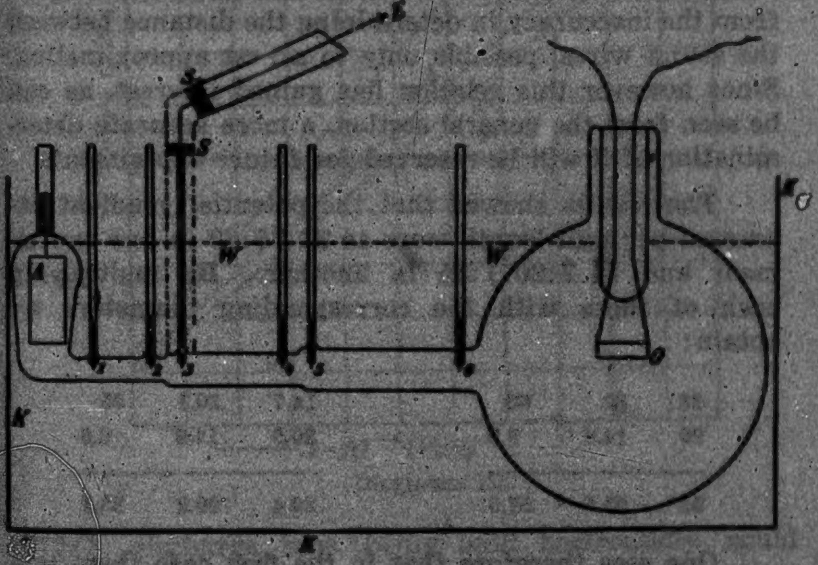


Fig. 13.

The dependence of the potential gradient on the cross section of the current path, for constant current, [722] i.e., on the current density, was studied with the horizontal type of tube shown in Fig. 12. Three cross sections were used. The diameters (20.0, 14.6, 9.5 mm.) were measured after the tube had been taken apart,[23] and so also the distances between the sounds. This was done in order not to introduce errors due to irregularities in the glass walls. The distances between the sounds (630, 500, 315 mm.), were so chosen with the help of previous experiments, that the potential difference between the several pairs was about the same for the same current, so that the potential difference between them could be determined with the same sensitivity of the electrometers.

It is to be remarked that on account of the wires sealed into the tube and of the changes from one diameter to the other, the tubes were not perfectly cylindrical. Moreover, the diameter of glass tubes about 20 mm. [723] inside diam. varies about 5 to 10%. Consequently the determination of the dependence of the characteristic on the cross section of the tube is, apart from the inaccuracy in determining the distance between the sound wires, possible only to a first approximation. Since however this relation has gained interest, as can be seen from the general section, a more accurate determination of it will be reserved for future experiments.

The results showed that the potential gradient expressed per unit length were as 28:36:60 in one experiment and 14.7:20.1:35 in another. By multiplying each of these with the corresponding diameters we obtain:

28	36	60
20	14.6	9.5
56	52.5	57.0

14.7	20.1	35
20.0	14.6	9.5
29.4	29.2	33.1

One sees therefore that in the first case there is a very good constancy and in the second, in view of the above mentioned sources of error, a marked constancy. Although I give preference to the first row of measurements, which were taken in the quickest possible succession, still the second may also be taken as representing a large number of observations.

Expressed verbally this result is: The potential gradient is, for constant gas density and current, inversely proportional to the diameter of the tube. If the potential gradient for two tubes of radii r_1 and r_2 be v_1 and v_2 then:

$$v_1 : v_2 = r_2 : r_1$$

It would be interesting to make a comparative determination of the current-voltage characteristic for tubes of different cross sections. Since, however, the

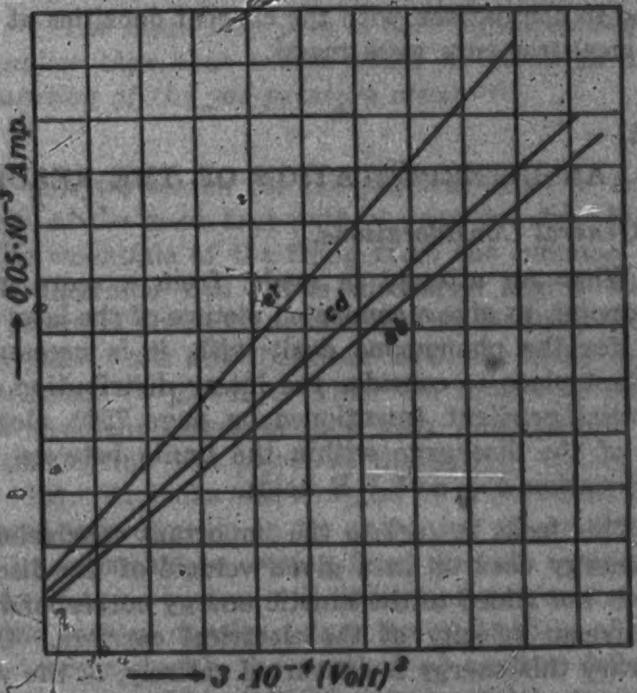


Diagram III.

[724] discharge tube, being built horizontally, could not be heated high enough in the furnace, and conse-

quently the curves did not remain constant during a longer discharge, they are not adapted to a closer discussion in this direction. However, a rough diagram may be given here showing curves which approximately obey the equation $J = a v^2 + b$, and which have been extended to intercept with the J axis to show how b is changed by a cross section. As is seen, every change in the zero point strongly modifies b and this is another source of error which makes it impossible to obtain an exact law by which b can be determined.

One thing is certain, viz., that b increases markedly with increasing diameter of the tube.

The above mentioned errors in b do not exert much of an influence on the measurement of the variation and potential gradient with the current, since it can be neglected in comparison with the current densities at which the measurements were made.

[725]

V. AN INTERPRETATION OF THE RESULTS.

1. *General Considerations.*

When an attempt is made, from a more general standpoint, to give a connected picture of the laws which hold for the phenomena dealt with, it is necessary in the first place to consider the linear distribution of the potential gradient (mentioned on page 720) along the axis of the discharge within the limits between which the equation $J = a v^2 + B$ holds.

This leads in fact to the important conclusion that the energy used up in a given volume of the discharge tube is *not* added to the kinetic energy corresponding to the stream velocity of the electrical carriers. On the contrary this energy is converted entirely, in the volume in question, into the energy of agitation of the molecules (heating of the walls of the vessel). For it must be remembered that we are dealing with a space occupied by an extremely rarefied gas; if therefore the energy were employed to an appreciable extent in accelerating the carriers of electricity we should expect, in consequence of the great mobility (great free path) of the negative electrons, the potential gradient to diminish considerably towards the anode, while at first with bigger gas density it increases in this direction rather than otherwise and then becomes precisely linearly distributed along the axis. The question then arises: "Why should great quantities of energy be used up in producing irregular motion of agitation in maintaining a current in an extremely high vacuum in which the mean free path of the electrons might be expected to far exceed the dimensions of the tube?"

In this connection it is hardly more than a description of the facts when we summarize as follows:—

> *"The mean free path is here incomparably smaller than that which would be given as a function of the gas pressure alone.*[24]

[726]

If now we search for the physical cause of such a decrease of the mean free path, we can get some insight into the essentials of the thing from the common form of the diagrams 1-21. The discharge begins with a small potential gradient, determined no doubt by charges on the glass walls and therefore as a rule badly defined (cf. sentence C. p. 700). Then the square of the potential gradient increases at a very much bigger rate than that of the first power of the current density (cf. page 719). It looks therefore as if the current itself produced impediments in its path, and if we think of those impediments as coming from discrete centres, the number of these centres will, it is clear, increase rapidly with the current density (since the probability of a collision increases with the number of centres deflecting the electrons). This rapid increase will then continue until a certain limit for the ratio of the density of the electrons from the cathode to that of the gas is exceeded (cf. the deduction on p. 731, and also the description of the subject of investigation p. 674). From this point onwards the increase will be slower and, in the interval within which the law $J = \alpha v^2 + B$ holds, constant. That the formation of these impeding centres is connected with the gas density follows from the fact that the greater the gas density the sooner the greatest attainable value of the ratio of the number of centres to the electron density is reached for a given gas density. This is indeed just another way of expressing the experimental result (A) on page 700. Now the simplest hypothesis which suggests itself is that these centres are ions which are formed by the impact of electrons or some similar cause, and which, on account of their large inert mass, scarcely come into consideration so far as the conduction of the current is concerned. It is evident in fact that in an extremely high vacuum the increased attractive force that an ion, as compared with a molecule, exerts on the cathode rays will cause an appreciable increase in the statistical mean value of the number of collisions.

We arrive therefore at the conclusion that the extraordinary reduction of the mean free path of the nega-[727] tive electrons in extreme vacuo is caused by a suitable electrical excitation of the gas in such a way that the large radius of action of an ion (as compared with that of a molecule) on (slow) electrons can make itself felt by the augmentation of the statistical mean value of the number of collisions.

In what follows the laws of the discharge will be considered more closely, partly in the sense which has just been sketched in a general way, and partly by putting them in such a form as to strengthen the interpretation given above.

2. *The Independence of the Cross-Sectional Area of the Tube.*

Let J_1 and J_2 be the currents corresponding to the given potential gradients V_1 and V_2 in two cylindrical tubes with the radii r_1 and r_2 respectively (Fig. 18) the following laws hold

$$(1) \qquad \begin{cases} J_1 = \alpha_1 v_1^2 + B_1 \\ J_2 = \alpha_2 v_2^2 + B_2 \end{cases}$$

and for

$$(2) \qquad \begin{cases} J_1 = J_2 = J \\ V_1 : V_2 = r_2 : r_1 \end{cases}$$

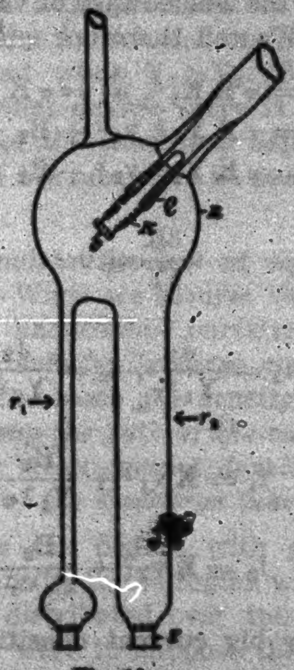


Fig. 18.

Where α_1, α_2; B_1, B_2 are in general functions of the cross-sectional area of the tubes, the nature of the walls of the tube, the gas density or any other peculiarity of the space through which the discharge passes.

If in (1) we put $J_1 = J_2$ and subtract both sides of the equations from one another, we get

$$\alpha_1 v_1^2 - \alpha_2 v_2^2 = B_2 - B_1$$

or

$$\frac{\alpha_1 v_1^2}{\alpha_2 v_2^2} = 1 - \frac{B_1 - B_2}{\alpha_2 v_2^2}$$

If this relation holds as is actually the case for currents for which

[728] $$\frac{B_2 - B_1}{\alpha_2 v_2^2} \text{ is small compared with 1,}$$

we have

$$\alpha_1 : \alpha_2 = v_2^2 : v_1^2 = Y_1^2 : Y_2^2$$

Now since α is independent of the current this relation will hold for the whole range of values for which (1) and (2) hold. We can therefore quite generally write

(5a) $$\alpha_1 = \pi K K_1^2,\ \alpha_2 = \pi K K_2^2$$
$$J_1 = \pi K Y_1^2\ v_1^2 + B_1$$
$$J_2 = \pi K Y_2^2\ v_2^2 + B_2$$

where

(3) $$\frac{\delta K}{\delta Y} = 0$$

Let us now put

(4) $$i_1 = \frac{J_1}{Y_1^2 \pi},\ i_2 = \frac{J_2}{Y_2^2 \pi}$$

and we get

(5) $$i_1 = K v_1^2 + \frac{B_1}{Y_1^2 \pi}$$
$$i_2 = K v_2^2 + \frac{B_2}{Y_2^2 \pi}$$

Consequently for big current densities, where $\frac{B}{Y^2 \pi}$ is small compared with i we have the general result

(6) $$i = K v^2$$

independent of the cross-sectional area of the discharge.

For current densities where $\frac{B}{Y^2 \pi}$ cannot be neglected by comparison with i the relation between current density and potential gradient will be independent of the dimensions of the tube if

$$\frac{B_1}{Y_1^2 \pi} = \frac{B_2}{Y_2^2 \pi} = B$$

that is to say, when

$$B_1 = Y_1^2 \pi B, \ B_2 = Y_2^2 \pi B$$

In this case we should have the general result

$$i = K v^2 + B \tag{6a}$$

It was not until this investigation reached the [729] stage immediately preceding this publication that the values of B acquired a definite meaning, in consequence of the connections developed on pp. 730-731, for the explanation of the processes. From the material previously collected only one definite conclusion can be drawn, namely that when $Y_1 > Y_2$, $B_1 > B_2$ (p. 724). Whether and in what degree there is a constituent of the form $Y_2 \pi B$ for the functional dependence of B on the cross-section of the tube must be reserved for further investigation.

We may formulate the law of equation (6) once more as follows:—When we assume the validity of the laws (1) and (2) and confine ourselves to currents J_1 and J_2 which are sufficiently large compared with B_1 and B_2 then, for the same gas density *the distribution of the potential along the path of the current is uniquely determined by the mean current density, independently of the dimensions of the discharge tube.*

From this we can deduce with great probability that the current density, in the region where (6) is valid, is homogeneously distributed over the whole cross-section. Since if we were to suppose the current density to be greatest in the axis of the tube, as is frequently the case with discharges through gases, it would only be possible to establish equation (6) by the very questionable assumption that the distribution of the current density is rigorously similar in tubes of different diameters while from the nature of the case suggests a considerably more homogeneous distribution with small cross-sections than with great.

When we compare the law (6) with those which have been found, for example, for the positive column in gas pressures such as those in Geissler tubes, we find that its simplicity is not the only astonishing thing about

it. Its independence of the cross-section of the discharge must appear remarkable when we remember the current views according to which the mean free path of the molecules as well as that of the electrons must many times exceed the dimensions of the vessel. We can therefore consistently regard equation (6) as furnishing strong confirmation of the assumption that in the case of the discharge phenomena which have been dealt with, the mean free paths must be considered as vanish-
[730] ingly small by comparison with the dimensions of the vessel, that in fact we must speak of an extraordinary augmentation of the radius of action of the centres distributed through the empty space.

We see further that any pair of the three equations (1), (2) and (6) is sufficient and necessary to determine the third. This is interesting from a physical point of view, when we also take into consideration the fact that, from a certain limiting value of the degree of evacuation onwards, with decreasing gas density but with a constant current, or, as we may now say, with a constant current density the potential gradient remains unchanged. This gives in consequence of equation (6), if we denote the value of k thus defined by K

$$(7) \qquad \begin{cases} i = Kv^2 \\ \dfrac{\delta K}{\delta N} = 0 \end{cases}$$

where N denotes the gas density. We have further from equation (8)

$$(8) \qquad \frac{\delta K}{\delta r} = 0$$

Therefore K is possibly in consequence of what has been said when the function k was introduced, only a function, in the first place, of the chemical nature of the molecules of the gas used to fill the vessel and in the second place of any remaining features of the space through which the discharge passes. In what follows both these variables will be discussed, so far as the existing material permits. Before proceeding to this we shall attach a physical meaning to the connections mentioned at the beginning of this paragraph. The independence of K from the gas density enables us, as will appear from further considerations, to conclude that K is, first and foremost, a factor which depends on the electron density necessary to break off positive charges from the molecules, and it is due to its independence of N that the negative space charge cannot be increased beyond a certain maximum value. From its very nature therefore we should expect K to be independent of the boundary of the discharge space. From this point of view it would have been very perplexing if it [731] had turned out that the coefficient K in the equation $i = K v^2$ was determined, to any extent by the cross-section of the tube, that is to say, in other words, if the characteristic of the discharge were independent of the pressure and yet a function of the (obviously much less essential) dimensions of the discharge tube.

In this sense the fact of the existence of a limiting value of K, independent of N, may be associated with the fact, which forms the foundation of equations (1), (2) and (6), that the characteristic of the discharge is given by the current density and not by the strength of the current combined with a complicated dependence on the shape of the discharge tube. And vice versa if one were to deduce in this way from equation (7) that the current density is the only thing that determines the characteristic, that is to say, that equation (6), or equation (6a) also, is valid, then we should be able by using one of the equations (1) or (2) to deduce the other.

8. *Deduction of the law of the characteristic.*

The law

$$J = a v^2 + B$$ 28)

can be deduced, with the aid of certain assumptions, from the usual notions concerning the conduction of electricity in gases and, more especially, the causal connection between the volume density of the electrical carriers, the potential gradient and the strength of the current. The volume density N — of the negative electrons emitted from the oxide cathode must be regarded as the primary factor. The density N + of the positive charges, which we may ascribe to processes similar to ionization, is assumed—and this is the essential point—to be proportional to N — throughout the range of validity of the law $J = \alpha v^2 + B$

[732] $$\frac{N-}{N+} = a \quad (a > 1)$$

Where a other things being constant, is a function of the gas density N. It is easily seen, if we assume, as is usual, that the positive charges originate from matter, that a will diminish with increasing gas density, therefore

$$\frac{\delta a}{\delta N} \overline{<} 0$$

a result which is confirmed by the augmentation of the potential gradient with diminishing gas density.

It is further assumed that N — (and also N +) is proportional to the number of carriers—for which a special symbol is unnecessary—actually engaged in the conduction of the current; so that therefore all these other quantities are connected with N_- in a linear way.

Let J be the total current when a steady state has set in. A change d J of the current will be, according to what has been stated above, associated with a change dn_- of the density N_-. Consequent N_+ changes by an amount $dn_+ = \frac{1}{a} dn_-$.

Then it is likely, and is rendered more probably by the validity of equation (6), that the distribution of the charges which determine the special distribution of the potential remain geometrically similar to themselves during such a change, that in fact the change in the potential gradient can be taken as proportional to the change in the space charge

(9) $$dv = p\,(dn_- - dn_+)$$

$$= p\left(dn_- - \frac{1}{a}\,dn_-\right)$$

$$= p\,\frac{a-1}{a}\,dn_-$$

Now the change d J of the current depends not only on the number of the carriers of electricity but also on their velocity. Here too there is proportionality. As, however, the velocity is on the other hand proportional to the potential gradient we shall have, with the assumptions that have been made

(10) $$dJ = b\,v\,dn_-$$

Where (b) is a factor which depends mainly on the mobility of the electrical carriers. If we substitute for dn_- the value given by (9)

$$dn_- = \frac{1}{p}\,\frac{a}{a-1}\,dv$$

we get

(11) $$dJ = \frac{1}{p}\,\frac{ab}{(a-1)}\,v\,dv$$

If we put

(12) $$\frac{1}{p}\,\frac{ab}{(a-1)} = 2\,\alpha$$

[733] and integrate (11) we get

(1) $$J = \alpha\,v^2 + B$$

Where B is a constant of integration.

From the above deduction with the help of the equations

(7) $$K = \frac{\alpha}{v\,Y^2}\,\frac{\delta K}{\delta N} = 0$$

we get certain information concerning the functions a and b.

From (12) we have

$$K = \frac{1}{2\,r^2\,p\,v}\,\frac{ab}{a-1}$$

When we remember now that r and p are by their nature independent of N, we see that $\frac{\delta K}{\delta N}$ means essentially

$$\frac{\delta\left(\frac{ab}{a-1}\right)}{\delta N}=0$$

When we carry out the differentiation we get

(14) $$\left(1-\frac{1}{a}\right)\frac{\delta b}{\delta N}-\frac{b}{a^2}\frac{\delta a}{\delta N}=0$$

as $a > 1$ we have also

$$1-\frac{1}{a}>0$$

Since in the region of validity of K the potential gradient does not change as N is varied, therefore

$$\frac{\delta v}{\delta N}=0$$

and consequently also

$$\frac{\delta\left(\frac{\delta v}{\delta n}\right)}{\delta N}=0$$

This becomes, when we remember that p is independent of N and make use of equation (9)

$$\frac{\delta\left(\frac{a-1}{a}\right)}{\delta N}=0$$

therefore

[784]

(15) $$\frac{\delta a}{\delta N}=0$$

and by (14)

(16) $$\frac{\delta b}{\delta N}=0$$

Equation (15) expresses the independence of

$$\frac{N_-}{N_+}=a$$

of N, that is to say: *from a certain maximum value of the gas density downwards the number of positive charges formed per negative charge, i.e., per negative electron is independent of the gas density.*

Since we usually regard positive charges as originating from molecules (or atoms) we can put this result in the following form: *the number of positive charges per molecule increases continually with diminishing gas density in the region of validity of the function K which is independent of the gas density provided other conditions (the potential gradient) are kept constant.*

Always regarding the negative electrons as the primary factor, we must think of the formation of the positive charges as the result of the effects which are conditioned by the electron density and the number and energy of their collisions; and consequently we must conclude that the intensity of these effects, i.e., the amount of energy communicated to a molecule or ion cannot exceed a definite limiting value without the production of a positive charge. Whether these charges are to be regarded as uniting with the molecules to form complex ions, or whether we are to ascribe to them an independent existence in space may be left for the present an open question.

The manner in which we have to regard the formation of positive charges by the action of the electrons on matter, in the case where we have a small gas density on the one hand and a large electron density on the other,[26] does not seem to me to be determined by the kinetic energy of the *individual* electrons, as would be the case according to the usual views of ionization. We must consider rather the space density, the *frequency* and collisions of the electrons in case these collisions are sufficiently frequent to communicate their energy additively to the molecule during the split-
[735] ting off of the positive charges. Obviously it is necessary for this purpose that the frequency of the collisions should be commensurable or of a higher order

of magnitude than the frequency of vibration of the positive charge attached to the molecule and which is to be split off. A related phenomenon has been observed by Kunz (Phil. Mag. 14, p. 614) in the case of the excitation of fluorescence by canal rays. Kunz found that the limiting value of the velocity necessary for the excitation of the fluorescence is smaller when the beam of canal rays is richer in ions.

We can, on the other hand, adopt the view that since the number of positive charges produced (other things being equal) is independent of the number of molecules, there is no causal connection (from the above-mentioned maximum gas density downwards) between the positive charges and matter. This means that these positive charges arise and continue to exist in empty space (in the ether) outside the molecules.

If it were technically possible (cf. p. 713) to vary the chemical nature of the traces of gas in the high grade vacuum in a definite way, we should be able to decide experimentally between these two assumptions. It would then appear whether the quantity K which is independent of the gas density, is a function of a general character or is dependent on the chemical nature of the gas.

A few conclusions can also be drawn from equation

$$(16) \qquad \frac{\delta b}{\delta N} = 0$$

As b was characterised as essentially dependent on the mobility of the charged particles this equation means that the mobility of the electrical carriers is independent of the gas density. The assumption suggests itself that the mean free path of the negative electrons remains unchanged, as the diminution in the number of molecules is compensated by the increase in the radius of action of the remaining ones.

If we were to regard the above conclusion as plausible when extended to positive charges we should be led to a contradiction so soon as we were to suppose these [736] charges to be associated with matter. For the mobility of a multiple-valued ion is greater than that of a single valued one of like mass. We should then have to resort to the possibility that the multiple-valued ions in consequence of their great inert mass or very small free path do not play an appreciable rôle in the conduction of the electricity.

Evidently we could also introduce other hypotheses here. *The problem would be solved in the simplest way if we could establish the existence of free positive charges with a constant ratio of charge to mass, and independent of matter.*

Finally we may point out that the law (p. 719) according to which the potential gradient, for small values of the current density, varies as $J^{2/3}$, can be deduced with similar assumptions and its independence of the pressure similarly interpreted as in the case of

$$J = \alpha v^3 + B.$$

Although such a deduction would support some of the views developed above and more especially the hypothesis of the production of positive charges in space which are independent of matter, it will be left over for the present. For we have seen already that in the discussion of equations (15) and (16) the experimental material at our disposal begins to fail. It is clear that this material can be supplemented in several directions.

Firstly, it is hoped to clear up many points by an improvement in the vacuum by replacing liquid air by liquid hydrogen in the experiments.

Secondly, it would be of interest, as already mentioned, to work out methods for the introduction of chemically well defined gases into high grade vacuum and the investigation of the behaviour of the latter.

Thirdly, the question whether the mean free path of electrons of *known* velocity in the luminous column [787] admits of measurement can be dealt with, as this would give us some idea of the gas density which at present cannot be estimated.

Finally, the question, which was again brought to the front by the last results, as to the nature of the positive charges must be dealt with, especially as some of the earlier experiments in this direction, while not having the force of proofs, have nevertheless not been refuted and still await explanation.

VI. SUMMARY.

1. *Experimental Results.*

(A) Provided that the current density is sufficiently great it is still justifiable to speak of a part of the discharge sufficiently far from the electrodes which at much higher pressures is ordinarily called the positive column (cf. p. 721).

(B) In the region of the investigation for current densities exceeding a certain minimum value the following relation holds:—

$$i = K v^2 \tag{6}$$

Where K is a factor independent of the form of the tube [pp. 727 to 731, especially p. 728, equation (3)].

The connection between current intensity and potential gradient is independent of the shape of the discharge in the sense which is more fully dealt with in the text (p. 729).

(C) From a certain maximum value of the gas density downwards the characteristic of the discharge is entirely independent of the gas density (p. 713), and therefore we have more especially for the factor mentioned under B

$$\frac{\delta K}{\delta N} = 0 \text{ (p. 730).} \tag{7}$$

(D) If the gas density is sufficiently small, we find for current densities between 0 and the regions of B and C the law that the potential gradient varies as J ⅔ (p. 719).

2. *General Conclusions.*

(E) The laws mentioned under B and C can be [788] deduced and interpreted from a more general point of view in which the phenomena of the discharge are associated with the production of positive charges by the negative electrons (pp. 781-783). The conclusions reached in this way led to the consideration of the existence of positive charges which are independent of matter (pp. 783-786).

(F) From the facts summarized under A we have concluded that in the region of investigation the mean free path of the electrons is much smaller than that observed with the same gas density outside the electrical discharge in the positive column.

The materials and apparatus for these investigations were provided to a large extent by a fund connected with the Haertel foundation which was most obligingly placed at my disposal for this purpose by the *Royal Society of Sciences in Leipzig.*

The experiments described were carried out in the Physical Institute of the University of Leipzig. I wish once more to express my heartiest thanks to Geheimrat Prof. Dr. O. Wiener for his support in a work which has required such large resources. I also wish to thank Prof. Dr. Th. Des Coudres for the interest he has taken in the investigations.

NOTES.

1. H. Herz, Wied. Ann. 54, page 49, 1898.

2. Compare three successive publications by the writer, "On Glow Discharge," Verh. d. Deutsch. Phys. Ges. 8, Nov. 10, 1906; March 22, 1907; Ber. d. Math.-Phys. Klasse d. Kgl. Ges. d. Wissensch., Leipzig, 9, July 20, 1908; finally also a publication under the title "Wehnelt Cathode in High Vacuum," Phys. Zeitschr. 9, 1908.

3. I have always pointed out very definitely that these phenomena can also be obtained with the help of ordinary metallic electrodes of large surface. Compare, for example, Verh. d. Deutsch. Phys. Ges. 9, page 126, 1907.

4. This view was submitted by Fred Soddy, Phys. Zeitschr. 9, page 1, 1908. Compare my reply, Phys. Zeitschr. 9, page 193, 1908.

5. Verh. d. Deutsch. Phys. Ges. 9, pages 127-8, 1908, regarding large electron density and its action on matter. Compare pages 55-57 of this paper.

6. On a similar, although differently meant, presumption of J. J. Thomson; compare page 37.

7. E. Gehrcke and O. Reichenheim, Verh. d. Deutsch. Phys. Ges. 1907, page 593.

8. A. Bestelmeyer and S. Marsh, Verh. d. Deutsch. Phys. Ges. 1907, page 758.

9. J. Becquerel—see number of publications in Le Radium, 1907 and 1908, especially 1908, page 193.

10. Verh. d. Deutsch. Phys. Ges. 8, page 11, 1906. "A Method of Determining the Temperature and the Direct Conductivity of the Positive Column." Also Verh. d. Deutsch. Phys. Ges. 8, page 23, 1906, "On New Phenomena in the Positive Column of a Glow Discharge."

11. Verh. d. Deutsch. Phys. Ges. 9, page 134, paragraph 7, 1907. Gehrcke and Reichenheim (Verh. d. Deutsch. Phys. Ges. 1907, page 593) photographed the spectrum of fluorescence and found two lines between 654 and 620 with maxima at 650 and 630.

12. E. Gehrcke and O. Reichenheim, Verh. d. Deutsch. Phys. Ges. page 593, 1907.

13. O. Reichenheim, Verh. d. Deutsch. Phys. Ges. 1909, page 45.

14. E. Goldstein, Verh. d. Deutsch. Phys. Ges. 1907, pages 598 to 605.

15. H. Konen, Verh. d. Deutsch. Phys. Ges. 1907, page 704.

16. In this stage the red fluorescence mentioned above was observed in the absence of oxygen.

17. H. Kamerlingh Onnes—Communications from the Physical Laboratory of Leyden, No. 94f, 12, page 52.

18. Compare the last two publications given in foot note No. 2.

19 Compare also R. V. Hirsch and F. Soddy, Phil. Mag. 14, page 779, 1907.

20. J. W. McBain (Phil. Mag 1909, page 108, 930) finds that the adsorption of hydrogen has a high temperature coefficient, large changes being obtained with the differences of temperature of liquid air of different combinations.

21. So the diagrams which were taken with three different tubes coincide very well when one makes allowance for the unavoidable variation in the distance between the sounds, 28-32 mm. and the diameter of the tube, 9 to 10 mm.

22. J. J. Thomson, Phil. Mag. 13, page 561, 1907; 16, page 657, 1908; 18, page 821, 1909. Compare also W. Wien, Phil. Mag. page 212, 1907.

23. The tubes were taken apart only after the last publication; I am therefore in position to give here for the first time more accurate values.

24. Compare Ber. d. Kgl. Sächs. Ges. d. Wissensch. 60, July 20, 1908.

25. Compare the simplified derivation which is analogous to that given here (Ber. d. Kgl. Sächs. Ges. d. Wissensch.—16, pages 219-220).

26. Compare Verh. d. Deutsch. Phys. Ges. 9, page 133, 1907.

DEFENDANT'S EXHIBIT No. 25-A.

Leipziger Berichte
Vol. 63 (1911)
pp. 534-539
[TRANSLATION]

THE CONDUCTION OF ELECTRICITY IN EXTREME VACUUM

By J. E. LILIENFELD

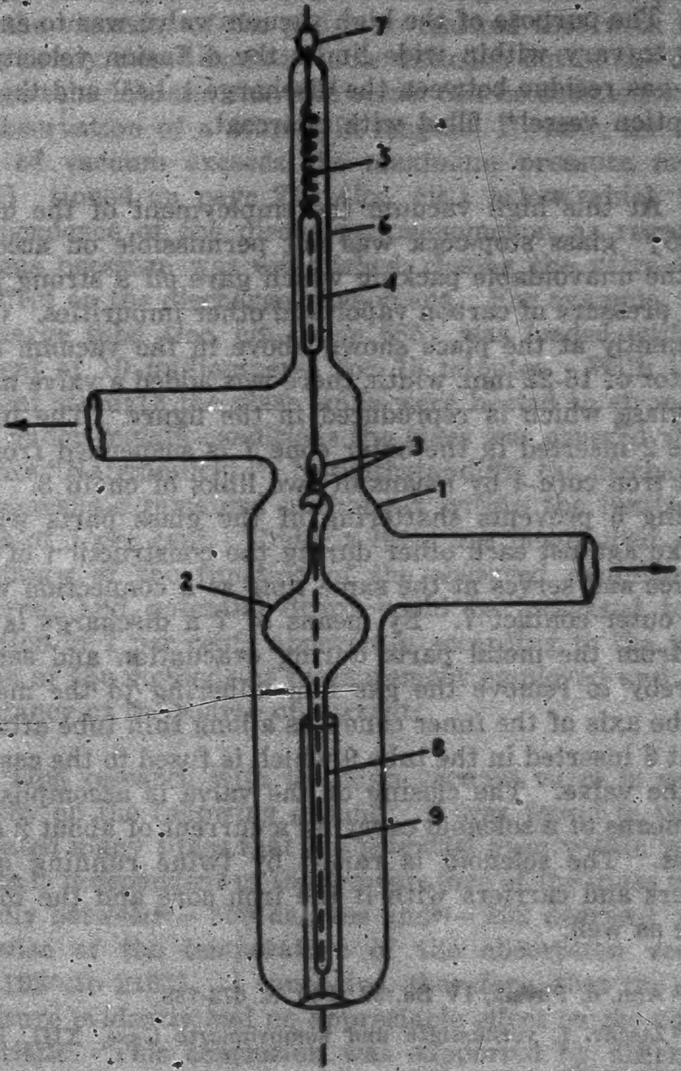
[534]

I.

In my last publication[1] on this subject, a series of general formulæ were collected. In the first place among others there was given the function

$$J = \alpha v^2 + B$$

expressing the relation between the current strength J and the potential drop v at very low pressures obtained by the application of liquid air. It was found, furthermore, that from a definite pressure downward in the region then accessible are independent of the gas density. On the basis of some consequent considerations directions were given on page 736 to 737 for the further investigation of the region dealt with. The present communication concerns itself with the above mentioned improvement of the vacuum which was made possible by the apparatus of the physical institute for the liquification of large quantities of hydrogen[2] which I installed in the mean time, as well as by the employment of the novel high vacuum valve described in the following.



II.

The purpose of the high vacuum valve was to enable one to vary within wide limits the diffusion velocity of the gas residue between the discharge tube[3] and the absorption vessel[4] filled with charcoal.

At this high vacuum the employment of the usual [535] glass stop-cock was not permissible on account of the unavoidable packing which gave off a strong partial pressure of carbon vapor and other impurities. Consequently at the place shown above in the vacuum conductor of 16-22 mm. width, there was added a valve made of glass which is reproduced in the figure. The inner cone 2 inserted in the outer cone 1 is suspended from a soft iron core 4 by means of two links of chain 3. The spring 5 prevents shattering of the glass parts which strike against each other during the construction of the device and serves at the same time as a connection with the outer contact 7. By means of 7 a discharge is set up from the metal parts during evacuation and serves thereby to remove the gas film adhering to the metal. In the axis of the inner cone 2 is a long thin tube attachment 8 inserted in the tube 9 which is fused to the casing of the valve. The closing of the valve is accomplished by means of a solenoid carrying a current of about 2 amperes. The solenoid is raised by twine running over rollers and carriers with it the iron core and the inner cone as well.

---

[1] Ann. d. Physik, IV Bd. 32 1910, S. 673-738.

[2] Ztschr. f. verflussigte und komprimierte Gase, XIII, Heft 11 u. 12.

[3] Ann. [illegible] Phys., loc. cit., S. 685.

[4] S. 6[illegible]

Obviously the valve does not provide an absolute barrier to the gas. However, at the high vacua in question the viscosity of the gas is so marked that with the valve firmly closed no noticeable diffusion out of the discharge tube into the charcoal vessel can be detected with an observation of a minute in length. If, now, the degree of vacuum exceeds the maximum pressure men- [536] tioned on page 718 (loc. cit.) below which the independence of the discharge phenomenon as regards the gas pressure was established, closing the valve has no effect on the discharge phenomena. For example, the discharge tube (loc. cit., page 685) was loaded with a current of 10 milliamperes for 15 minutes. With this current strength the glass walls were heated so strongly that under certain conditions the glass was covered with intense "Natriumlicht." Notwithstanding, the discharge characteristic remained unchanged within the limits of error of 1 per cent. Under a little less heavy load, the constancy of the function of the observed magnitudes (current and potential drop) could be increased to a fraction of 1 per cent; apparently according to the precision of the methods of measurement employed and the constancy of the source of current.

This research with the high vacuum valve is noteworthy on the following ground. It was found in work repeated many times that the potential drop within wide limits is independent of the temperature of the glass wall (easily between + 300 degrees and — 192 degrees) and likewise of the temperature of the absorption vessel (— 183° to 215°). I concluded, therefore, that the gas pressure evidently had no appreciable effect on the characteristic. This conclusion was supported by different extensive observations such as its independence of the anode material and of the temperature of the oxide cathode. So the obvious objection that the gas pressure had remained constant in spite of all these changes was robbed of its force since it depended substantially only on the diffusion velocity of the traces of gas evolved from the glowing cathode and by the discharge. By the employment of the high vacuum valve which practically stops the diffusion to the charcoal vessel without otherwise changing the discharge, the non-existence of each of the possibilities considered above was proved beyond all doubt.

III.

The improvement of the discharge characteristic was further effected by the application of a bath of liquid hydrogen about the charcoal vessel and also hydrogen solidified in vacuum (— 259°). The experimental means which served for this purpose and in particular the Kryostat, are described on page 688 (loc. cit.). The results [537] may be summarized in the statement that in this markedly extended range, the discharge phenomena were proved independent of the gas pressure by observations lasting hours and repeated in the course of many weeks, which will be given again in a publication planned for the future. The temperature of the charcoal during these experiments varied between — 182° and — 259°; the temperature of the discharge easily between + 300° and — 192°, and the diffusion velocity from the discharge tube to the charcoal vessel varied between approximately 0 and that which took place in a tube of 25-30 cm. in length and cross-section of 18 mm. Furthermore, the temperature of the oxide cathode could be varied between red glow and bright white glow.

It is of interest to add that although the above parts of the discharge tube were often replaced, the same piece of tube with the same exploring wires was used for the exploring wire measurements for several years. The limiting function of the potential drop between these exploring wires and the accompanying discharge characteristic always remained the same with great exactness.

IV.

In the course of the present investigations a light was thrown on the independence of the experimental results as regards gas pressure over such an extremely wide range. For the interpretation of the foregoing results, the following may be remarked.

Along the axis of the discharge tube a linear distribution of potential was experimentally found (loc. cit., page 720).

From the general appearance of the discharge it was concluded that the current was homogeneously distributed in planes *perpendicular to the axis* (page 721). Further it was shown on page 729 that independently of the form of discharge tube, a definite current I was always related to the definite potential drop v. If one designates in general the current strength by J, the cross-section of the discharge path q, and if in two different discharge paths whose cross-sections are q_1 and q_2 at the constant potential drop v, the currents are J_1 and J_2, then

$$J_1 = a\, q_1\, v$$
$$J_2 = a\, q_2\, v$$

[538] in which a is a constant. It therefore follows

$$\frac{J_1 - J_2}{q_1 - q_2} = \frac{J}{q}$$

or if we write $J_1 - J_2 = \Delta J$ and $q_1 - q_2 = \Delta q$ then

$$\frac{\Delta J}{\Delta q} = \frac{J}{q}$$

It follows, therefore, in case at the constant potential drop the discharge cross-section is gradually increased, in every new cross-section element the same current flows, that is to say, the current density i is uniformly distributed over the whole cross-section.

In the light of the unique relation between the potential drop and the current density which is independent of the form of the tube, the potential drop cannot be otherwise than uniformly distributed in cross sections normal to the direction of the current. Therefore, the two vectors, the potential drop and the current density, have everywhere constant values and their direction parallel to the axis of the tube. It follows, therefore, as regards the potential function δ

$$\Delta^2 \delta = 0$$

An expression showing that *in the discharge path there is present no volume density of electricity.*

However, it was shown on page 723 (loc. cit.) that in the discharge path there exists an irregular motion of negative electricity which represents an enormous amount of energy in comparison with the regular motion of current conduction and that consequently, the mean free path of the electrons is very small. Therefore, there is a large volume of density of negative electrical carriers present. On the other hand, we are forced to conclude from the above formulæ that a positive volume density exists which is equal to this negative density, the lines of force originating on the negative charges ending on the positive charges; furthermore, these positive charges must stand in causal relation with the unusual diminution of the free path of the negative electrons.

One would perhaps be inclined in view of the fact that the energy necessary for the production of the positive charges is independent of the gas pressure within such wide limits, to conceive of the charges themselves as existing independently of the material.
[539]

On the other hand, one must remember that there are possible explanations which are contradictory to the foregoing. For example, an unlimited independence of the characteristic as regards gas pressure with decreasing gas pressure could be simulated by the following arrangement. From a certain maximum number of molecules m_1 per unit volume to a number of m_2 m_1 the characteristic might be independent of m. For still smaller gas pressures, however, a law might hold that as long as m is less than m_2, a partial gas pressure, independent of the temperature of the electrodes and walls of the vessel, is produced in addition by the discharge until again the limiting function for the relation of the current to the potential drop comes into force. As regards the way and manner in which this compensating partial pressure originates, and likewise as regards the origin of the molecules, nothing further can be said. In any case, it is enlightening that the foregoing observations were exactly as though from a density m_2 downward the unlimited independence of the gas pressure held.

The region dealt with here is, however, capable of a so many sided further investigations that it appears at present to be too early to formulate any definite opinions concerning the facts which are based on the collected experience.

DEFENDANT'S EXHIBIT No. 26.

Verhandlungen der Deutschen Physikalischen Gesellschaft
Vol. 13 (1911) pp. 601-606

[TRANSLATION]

ON A METHOD OF PRODUCING VERY SOFT ROENTGEN RAYS IN THE HIGHEST VACUUM

By H. DEMBER

(Entered July 19, 1911)

[601]

1. According to the quantum theory, a certain minimum amount of energy is necessary for the production of a Roentgen impulse. In the following a method is described which makes it seem possible to measure such amount of energy directly. At the same time this arrangement makes possible the production of X-rays over a great range of hardness.

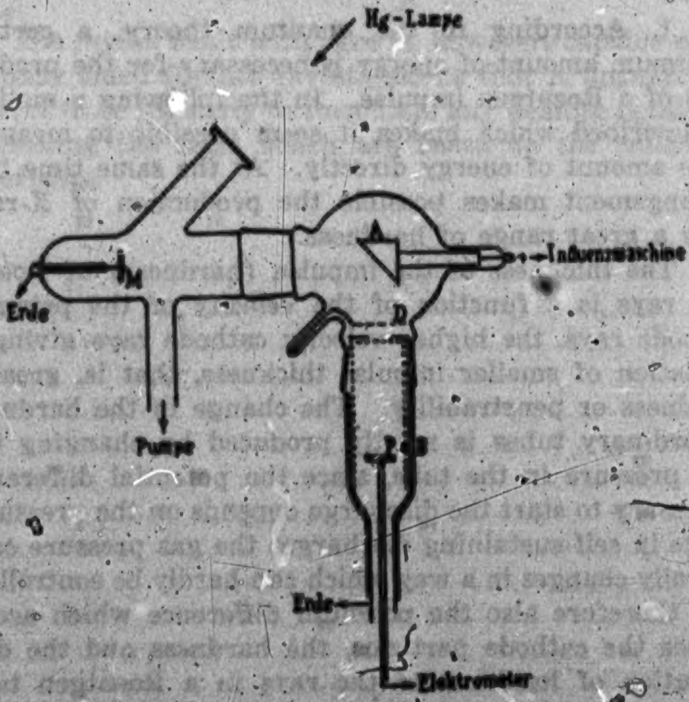
The thickness of the impulse (hardness) of Roentgen rays is a function of the velocity of the primary cathode rays, the higher velocity cathode rays giving a radiation of smaller impulse thickness, that is, greater hardness or penetrability. The change in the hardness in ordinary tubes is mostly produced by changing the gas pressure in the tube, since the potential difference necessary to start the discharge depends on the pressure. Since in self-sustaining discharges the gas pressure continually changes in a way which can hardly be controlled, and therefore also the potential difference which accelerates the cathode particles, the hardness and the distribution of hardness of the rays in a Roentgen tube is very variable.

Experiments with the Roentgen rays of constant or single thickness of pulse or with a range of constant distribution of hardness are therefore exceedingly difficult and can only be made in an unsatisfactory way by using selectively absorbing filters.

The photo-electric action gives a means whereby cathode rays can also be produced in the utmost vacuum, and therefore an attempt was made to increase the velocity of the photo-electric electrons to such an extent [602] that they can produce Roentgen rays when they bombard the anti-cathode. The proof of the existence of the harder rays was done with a photographic plate; the very weak rays could be tested for by the action of Roentgen rays to emit electrons from matter and the consequent generation of positive electricity.

2. *Experimental Arrangement.*

The photo-electrically sensitive magnalium or copper plate M (see figure) was submitted to the light from



a quartz mercury vapor lamp, the light passing through a quartz plate which was cemented to the tube. In order to accelerate the liberated electrons a potential difference was applied between the cathode M and the anti-cathode A which was coated with platinum foil. The Roentgen rays produced by the bombardment of the photo-electric electrons passed through a wire net of 1.8 sq. mm. mesh, and thus reached the adjoining tube B. In this adjoining tube a suitable aluminum box was placed which con- [603] tained the photographic plate. As a source of potential a 20-plate Toepler influence machine was used. The voltage applied to A could be varied between 100 and 10,000 volts and kept constant for hours with the help of a Gray point shunt and a variable liquid resistance. The fluctuations in potential were so small that they could hardly be noticed on the Braun electrometer which was used to measure the potentials.

3. Since there was a possibility of cathode rays reflected from the anti-cathode getting into the adjoining tube, there was placed in order to prevent this a grounded net D opposite the positive anti-cathode, so that the electrons entered a retarding field. For the evacuation was used first a Gaede pump and then charcoal which was dipped into liquid air.[1)] In the final experiments the pressure was less than 10^{-5} mm. Hg.

4. *Experiments.*

With the help of the photographic plate which was wrapped with the light-tight black paper used in packing the plates, a picture of a lead strip .2 mm. thick and 1 to 2 mm. wide which was attached to the plate could be obtained with a difference of potential of 6000 volts, and an exposure of two hours, and so also with 4000 volts. On the other hand, with 2000 volts no impression was obtained on the photographic plate after an exposure of several hours. This same result was obtained with magnalium as well as copper as cathode. Also, when the photographic plate was covered with two light-tight aluminum foils of 0.00035 cm. thick instead of the black paper, no definite blackening was produced with an exposure of two hours. Only when the very thinnest aluminum foils were used, such as is used for making [604] the most sensitive leaf electrometers, a potential difference of 2000 volts showed a uniform blackening of the plate besides the blackening due to the action of the ultra-violet light through the pores of the aluminum foil.

5. The latter experiment gave the suggestion to further follow by means of another method these soft Roentgen rays, and to determine the lower limit of the potential difference necessary to accelerate the primary cathode rays.

For this purpose use was made of a phenomenon discovered by P. Curie and G. Segnac[2] and quantitatively investigated by E. Dorn,[3] that Roentgen rays emit negative secondary rays. When Roentgen rays fall on a metal plate it becomes charged positively. This is a phenomenon which is in many respects analogous to the photo-electric effect. For example, the velocity of the emitted electrons is found to depend in such a way on the hardness of the Roentgen rays which cause their emission that the electrons of highest velocity give rise to the harder rays.[4]

6. In order to prevent positive ions formed by collision ionization of the residual gas from entering the adjoining tube M and so charge up the plate positively, the wire gauze D was connected to the positive anticathode by means of a sealed-in platinum electrode. The metal plate from which the Roentgen rays were to emit electrons consisted of a polished platinum disc P, 2.2 cm. diameter, which was inserted through amber insulation in a brass cylinder blackened with soot. This was lined according to von Baeyer with a wire net blackened with soot (see figure). Both the brass cylinder and wire net were blackened with soot. Furthermore, at the opening to the cylinder was placed a lead diaphragm with 1.5 cm. opening. The distance of the platinum plate P [605] from this diaphragm was 5.6 cm. It was chosen so large to prevent electron reflection inside the cylinder.[5]

To measure the positive excitation, a Lutz string electrometer was used which was very suitable for this purpose on account of its low capacity (4.4 cm.). The electrometer was used with string connection and its sensitivity was so chosen with the help of the string voltage and that of the auxiliary battery that 1/10 volt could be read with certainty. All connections to the electrometer and grounding key were carefully shielded in the usual way from electrostatic disturbances.

7. The following table gives the potentials acquired by the plate P in relation to the potential difference which accelerated the photo-electric electrons. The cathode used here was a magnalium disc.

Velocity of Photo-Electric Electrons Volts	Velocity of Roentgen-Electric Electrons Volts
9500	3.6
6000	2.0
4000	1.35
1000	1.1
500	0.95
250	0.7

For velocities of the primary rays below 250 volts, Roentgen rays could not be noticed with certainty with this method, since the charge acquired by the plate as the result of the ultra-violet light also increased to 0.7 volt. For measurements above 250 volts the actions of the Roentgen rays and ultra-violet light could be separated by observing the rate of accumulation of charge.

From these experiments it follows that Roentgen impulses can still be produced by electrons of energy of $4.69 \,.\, 10^{-10} \frac{250}{300}$ erg. $= 3.9 \,.\, 10^{-10}$ erg. Furthermore, [606] these results also show that excitation, i.e., the velocity of the secondary electrons depends on the hardness of the Roentgen rays.

It is not in place on the grounds of the measurements made thus far to compute a quantitative relation between the hardness of the Roentgen rays which were produced by photo-electric electrons and the velocity of the secondary rays, since the small charges acquired by the plate depend on the gas occluded in the excited metal and this was not considered here.

Dresden,
Phys. Institut d. Techn. Hochschuler.
July 10, 1911.

NOTES.

1. I wish to express my thanks to Prof. Dr. Mollier and Prof. Dr. Naegel for the liquid air.
2. P. Curie and G. Sagnac, C. R. 130, 1013, 1900.
3. E. Dorn, Arch. Neerl. 2, 5, 595, 1900.
4. R. v. Lieben, Phys. Zeitschr. 4, 469, 1903; K. Hahn, Ann. d Phys. (4) 18, 140, 1905.
5. O. v. Baeyer and A. Gehrts, Verh. d. Deutsch. Phys. Ges. 12, 870, 1910.

GI
BT

DEFENDANT'S EXHIBIT No. 27

Annalen der Physik
Vol. 36 (1911)
pp. 995-1026
[TRANSLATION]

REFLECTION AND SECONDARY RADIATION OF PHOTOELECTRICALLY LIBERATED CATHODE RAYS.

A. GEHRTS.

Extract from Berlin Dissertation.

I. *Proof of a Reflected and Secondary Radiation of Photoelectrically Produced Cathode Rays.*

[995]

1. The secondary radiation produced in gases and solid bodies by photoelectrically liberated cathode rays is investigated in detail by Lenard[1] in a series of works. Lenard used essentially a phosphoroscopic method and obtained the following results:

(a) *For gases:* "If the primary velocity is below 11 volts, no noticeable secondary radiation takes place. From 11 volts up the number of secondarily liberated electrons suddenly increases rapidly, being at first almost proportional to the velocity excess over 11 volts; later this increase must be slower. The secondary radiation reaches a maximum in air at about 300 and in carbonic acid at a primary velocity of about 500 volts. With further increase in primary velocity there is a gradual decrease."

(b) *For solid bodies*, especially platinum, the results were as follows for a primary velocity U "Rapid increase of the effect was shown above U = 100 volts up to about U = 200 volts, this being unnoticeable in the neighborhood of U = 0; the increase up to about U = 400 volts was slow and above that nearly constant up to U = 1000 volts, while above this there was a slow decrease. If it is taken into consideration that from U = 400 to U = 1000 volts, the primary amount coming [996] through the diaphragm increases from 60 to 80 per cent, it follows that the primary velocity of maximum effect is for Pt = 400 volts.

In gases as well as in solid bodies, the secondary radiation was greatly diffused and of very small velocity (platinum = 10.8, copper = 7 volts).

A reflection of the primary rays was not noticeable in Lenard's experiments.

Recently, experiments made by O. v. Baeyer[2] with slow cathode rays, which were liberated from a glowing oxide cathode, have now yielded a reflection of the primary rays for velocities of 10 to 15 volts and under.[3]

A reflection could therefore also be assumed for small radiation velocities of photoelectrically emitted cathode rays. The following experiments serve to prove the existence of this and give an improved electrometric investigation of the secondary radiation.

2. *Experimental Arrangement.* The experimental arrangement used which was constructed essentially according to that of Mr. v. Baeyer, is represented in Fig. 1. The light of a quartz-mercury high-pressure

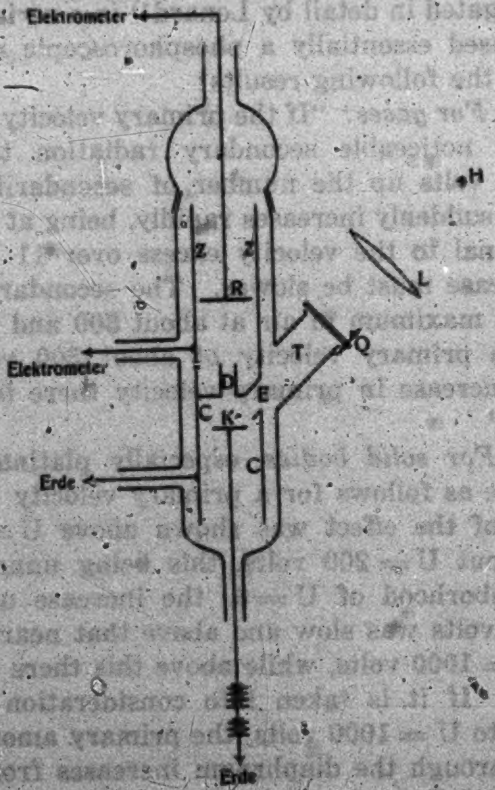


Fig. 1. Versuchsanordnung zum Nachweise der reflektierten bzw. Sekundärstrahlung.

lamp H, furnished by the firm of W. C. Heraeus in Hanau, was concentrated through a quartz lens L of about 10 cm. focal length and fell at an angle of about 45° through a side tube T of an experimental tube 3 cm. wide on the highly polished copper cathode K, 1 cm. in diameter, there causing an electron emission. The side tube T was closed air-tight by a parallel quartz plate G, which was cemented to it and which was 3 mm. thick and cut perpendicular to the optical axis. The copper cathode K was surrounded by a brass cylinder C, open on one side and grounded, 2 cm. in width in which a [997] small brass tube D, having thin walls 1 cm. in length and 5 mm. wide serving as a diaphragm, was centrally inserted. A slanting cylindrical tube E made possible the entrance of light in the cylinder C.

The electrons liberated from the cathode K after passing the diaphragm tube D struck the "reflector," a metallic plate R having a diameter of 1.5 cm., which could be moved parallel to itself in a brass cylinder Z, 2 cm. in diameter and 5 cm. long, by help of a small electromagnet. A large ground joint which was made tight by means of rubber grease, served for changing the reflector R. The reflector R as well as cylinder Z surrounding it were insulated with amber. The cylinders C and Z and the diaphragm D were properly centered and were well covered with wax-candle black.

[998]

Mica diaphragms prevented any part of the metal in the tube with exception of cathode K from being struck by direct ultra-violet light. The mercury lamp was fed by storage battery current (140 volts) and burned generally with terminal voltage of 70 volts which was continually controlled. The electrons produced at the cathode K could be accelerated, which was done by help of a small storage battery whose negative pole was connected to K and whose positive pole was grounded.

The glass apparatus described was evacuated by means of a Gaede pump under steady heating of the coconut charcoal in a side tube up to about 400° C. The charcoal had been previously heated in air nearly up to red heat and then was freed of the tars and gases still clinging to it by energetically heating in the vacuum several phosphorous pentoxide receptacles being connected to it. A three to four hour evacuation was found to be sufficient for obtaining hard Roentgen vacuum. The tube was then disconnected from the Gaede pump and the charcoal cooled in liquid air. In order to obtain perfect constancy in the phenomena, it was cooled at least three hours before measurements were taken. In spite of the cement and ground joints used, a very good vacuum was obtained in this manner.[4)]

The stream of electrons flowing from the reflector R and the cylinder Z surrounding it, was now measured. The current was measured by means of a Dolezalek electrometer having a sensitivity of 2.10^{-4} volts/second, and a Bronson resistance. The resistance was constant for the whole range of voltage involved. A volt effect was always present but was not disturbing in any way when the measurements were made. In order to be free from a possible disturbing influence of temperature variations,[5)] the resistance was inserted in paraffin. All the leads to the electrometer, protected against static [999] disturbances, passed in tubes or cases of sheet zinc.

3. *Measurements and Results.* In order to measure the secondary or reflected radiation, the current was ascertained which flowed from the reflector R and the cylinder Z surrounding it, first (J_1) when the reflector was drawn back into the cylinder so that both formed a Faraday cylinder, and then (J_2) when the reflector shut off the cylinder in front. In the last case the reflected or secondary radiation is caught by the cylinder C. The quotient $\frac{J_1 - J_2}{(J_1)} . 100$ gives the reflected or secondary radiation in percentage of the incident radiation. In these measurements it is assumed that double reflection is never made noticeably disturbing, especially when the reflector stands at the lower end of Z. The peculiar form of the blackened cylinder C standing opposite, as well as the observation (compare Table 5 below) that soot gives an extraordinarily weak secondary cathode radiation, offers sufficient guarantee for this. It may also be remarked that drawing the reflector into the cylinder Z 3 cm. is sufficient to obtain complete reflection or secondary emission which argues for a greatly diffused character of secondary radiation.

The following Tables 1-5 are the result of such measurements; they give the reflected or secondary radiation for various reflectors in relation to the velocity of primary radiation. The primary velocity given in the first columns is everywhere expressed in terms of the potential between cathode X and anode C in which the potential of one accumulator was put equal to 2 volts. Strictly speaking, the primary velocity must everywhere be increased by the amount of the initial velocity of the liberated electrons, which, according to the available measurements on copper, might be estimated on an average at 1 volt. The graphical representation of the [1000] tables is given in Figures 2-6.

TABLE I

Aluminum (brightly polished)

Primary velocity in volts	J_1	J_2	$\frac{J_1 - J_2}{J_1} \cdot 100$
0	—	—	—
2	31.0	18.0	42.0
4	46.0	19.3	58.0
6	55.3	21.0	62.0
8	61.5	27.7	56.6
10	67.3	33.0	51.0
12	71.8	31.8	55.7
14	76.0	27.0	64.5
16	78.8	23.2	70.6
18	80.5	19.7	74.3
20	83.1	18.3	78.0
22	85.5	16.6	80.7
24	86.7	15.3	82.6
26	88.2	13.7	84.4
30	92.4	7.7	92.7
60	102.0	— 29.2	128.6
90	106.1	— 57.6	154.2
120	108.3	— 76.1	170.1
150	110.0	— 88.6	180.5
180	111.8	— 96.5	186.2
210	112.3	—100.2	189.1
240	113.7	—101.0	189.1
270	114.0	—102.0	189.3
300	—	—	—
330	115.7	— 96.0	183.0
360	—	—	—
390	117.8	— 90.3	176.6
420	—	—	—
450	120.5	— 82.2	168.2
480	121.0	— 78.0	164.4

TABLE II

Lead (well polished)

Primary velocity in volts	J_1	J_2	$\frac{J_1 - J_2}{J_1} \cdot 100$
0	5.2	2.8	46.2
2	31.2	13.0	58.4
4	45.7	15.4	66.3
6	56.6	22.0	61.1
8	66.2	27.0	59.2
10	72.8	28.1	61.4
12	78.7	27.0	65.6
14	85.0	23.9	71.6
16	89.6	20.0	77.7
18	94.4	16.9	82.0
20	98.5	15.0	84.8
22	102.25	12.9	87.3
24	104.6	10.8	89.6
26	106.3	9.0	91.5
30	113.1	3.2	97.1
60	133.3	— 39.1	127.0
90	141.0	— 64.7	145.7
120	146.7	— 85.3	158.0
150	149.5	— 93.5	162.5
180	152.3	—100.0	165.6
210	154.8	—102.8	166.2
240	156.8	—104.1	166.2
270	159.7	—102.3	164.0
300	—	—	—
330	163.0	— 97.7	160.5
360	—	—	—
390	166.7	— 91.5	154.9
420	—	—	—
450	170.1	— 86.75	151.0
480	171.6	— 83.3	148.5

TABLE III

[1001]

Cobalt (brilliantly polished)

Primary velocity in volts	J_1	J_2	$\frac{J_1 - J_2}{J_1} \cdot 100$
0	4.2	2.7	35.8
2	33.3	16.1	51.7
4	47.2	17.4	63.2
6	58.0	20.6	64.5
8	65.7	26.9	59.0
10	71.9	30.7	57.3
12	77.2	28.3	63.3
14	82.6	23.2	71.9
16	83.2	16.9	79.7

18	92.5	13.2	85.8
20	95.7	10.1	89.4
22	97.3	7.8	92.0
24	101.0	5.2	94.8
26	103.9	2.0	98.1
30	110.7	— 3.3	103.0
60	130.5	— 66.8	151.1
90	140.0	— 105.0	174.8
120	146.3	— 133.6	191.1
150	150.2	— 152.2	201.2
180	154.5	— 163.5	205.8
210	156.2	— 170.7	209.0
240	157.8	— 173.5	209.2
270	159.2	— 174.9	209.6
300	—	—	—
330	163.4	— 173.5	206.0
360	—	—	—
390	165.7	— 167.8	201.2
420	—	—	—
450	174.5	— 158.8	191.4
480	175.0	— 154.0	187.9

TABLE IV
Copper (brilliantly polished)

Primary velocity in volts	J_1	J_2	$\frac{J_1 - J_2}{J_1} \cdot 100$
0	2.3	2.2	—
2	27.0	12.0	55.6
4	41.[illegible]	12.8	69.3
6	51.7	15.0	71.0
8	59.4	19.2	67.7
10	67.0	24.2	63.8
12	72.2	22.1	69.4
14	79.0	16.0	79.8
16	82.8	11.7	85.9
18	88.1	7.0	92.1
20	91.3	4.7	94.8
22	94.7	2.8	97.0
24	97.0	0.2	99.8
26	100.2	— 3.0	103.0
30	108.8	— 16.4	114.3
60	128.0	— 73.0	156.9
90	136.5	— 112.0	182.0
120	138.3	— 135.1	197.3
150	140.9	— 150.1	206.4
180	143.7	— 157.5	209.4
210	146.4	— 161.2	210.0

240	149.0	—160.5	207.5
270	150.9	—159.3	205.5
300	—	—	—
330	153.3	—152.2	199.1
360	—	—	—
390	155.7	—143.6	192.2
420	—	—	—
450	158.3	—136.2	186.0
480	160.7	—131.5	181.7

TABLE V

Soot

[1002]

Primary velocity in volts	J_1	J_2	$\frac{J_1-J_2}{J_1}\cdot 100$
0	6.7	3.3	—
2	31.3	28.0	10.5
4	44.8	40.0	10.7
6	53.9	48.9	9.3
8	63.0	55.3	12.2
10	69.0	59.9	13.2
12	74.2	64.8	12.7
14	79.7	67.2	15.7
16	84.5	70.0	17.2
18	89.7	72.0	19.7
20	92.2	73.2	20.6
22	95.5	74.1	22.4
24	98.8	75.4	23.7
26	101.2	76.3	24.6
30	108.1	77.5	24.3
60	129.0	76.0	41.1
90	139.3	70.7	49.3
120	144.9	66.8	53.9
150	149.2	64.7	57.6
180	151.0	63.1	58.2
210	153.0	62.3	59.3
240	155.5	63.0	59.5
270	159.0	63.1	60.3
300	—	—	—
330	162.0	64.7	60.0
360	—	—	—
390	164.5	66.0	59.9
420	—	—	—
450	168.0	67.8	59.7
480	168.5	68.3	59.5

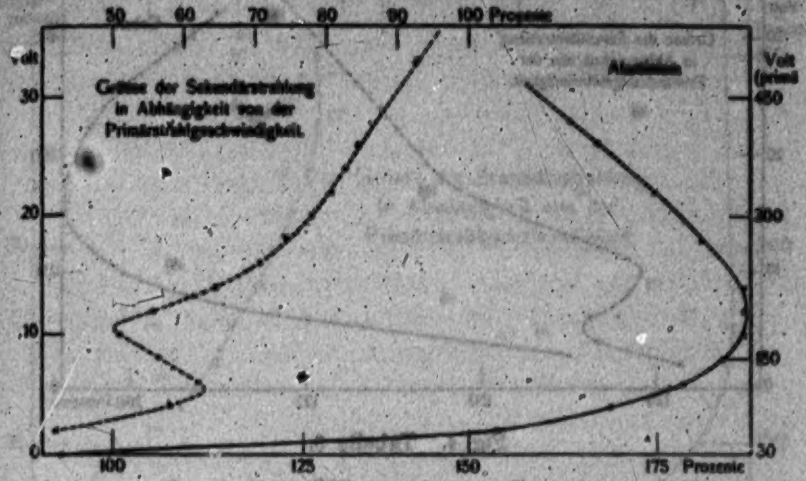


Fig. 2. Tabelle 1.

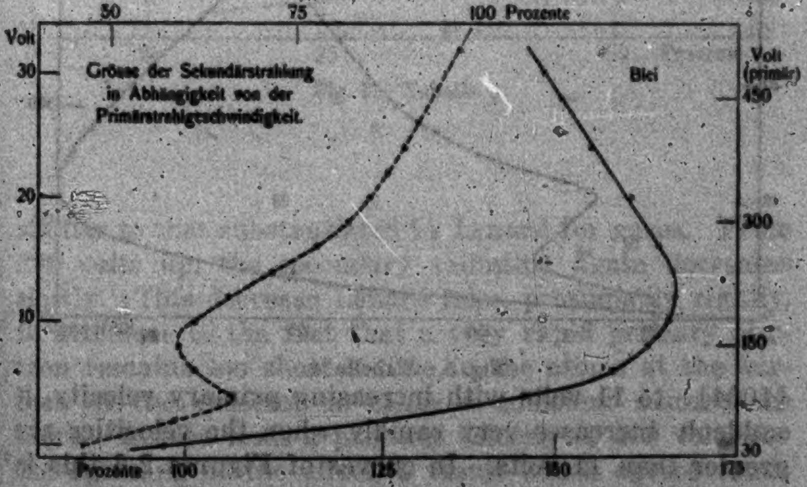


Fig. 3. Tabelle 2.

4. *Discussion of the Results.* As is to be seen from the tables given, when Table V with soot is disregarded, and even more distinctly from the accompanying curves of Figures 2-6, a sudden variation occurs in the relation of the quotient $\frac{J_1 - J_2}{J_1} \cdot 100$ when the primary velocity is 11 volts. While the quotient diminishes up

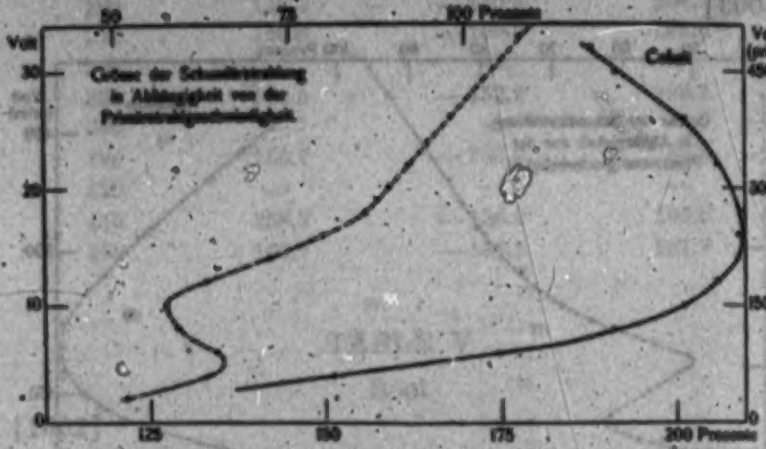


Fig. 4. Tabelle 3.

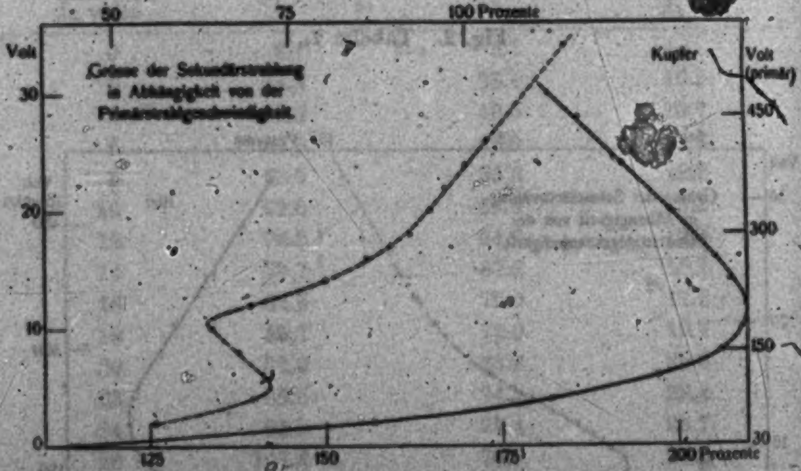


Fig. 5. Tabelle 4.

[1004] to 11 volts with increasing primary velocity, it suddenly increases very rapidly when the velocities are greater than 11 volts. In curves of Figures 2-6 this is expressed in the sharp bend at 11 volts. The phenomenon appearing so suddenly above 11 volts is to be interpreted as the secondary radiation discovered by Lenard. [1005] It increases rapidly with increasing primary velocity and attains the value of primary radiation at about 30 volts—this point varies slightly with the material and the surface condition of the reflector. It was traced up to a primary velocity of 500 volts. Up to 200 volts there was an increase in the secondary radiation, nearly proportional at first (from 20 volts on) to the surplus velocity over 20 volts, and later more slowly,

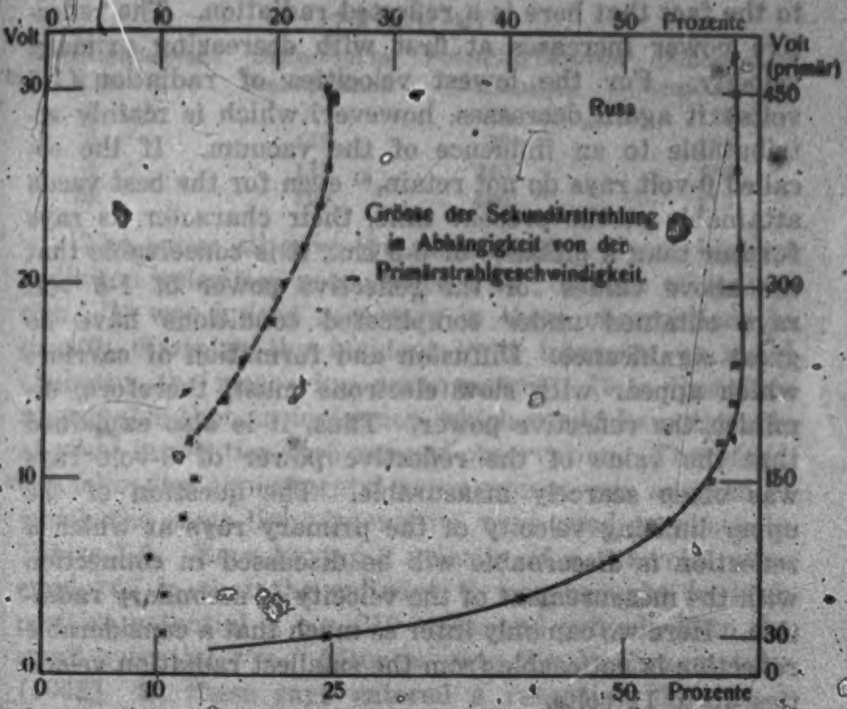


Fig. 6. Tabelle 5.

similar to that substantiated by Lenard for gases. From 220 volts up, the secondary radiation again decreases slowly. This decrease Lenard tries, presumably rightly, to attribute to the fact that a very rapid primary electron remains too short a time in the atoms at the surface of the reflector to cause a sufficient disturbance there. Lenard finds a primary velocity of 300 volts for the optimum of the effect, a result which agrees excellently with that of 220 volts given here considering his [1006] more qualitative phosphoroscopic method. The lower limit for the primary velocity at which a secondary emission is still to be noted is therefore 11 volts. The fact that for gases as well as for metals the same lower limit of 11 volts was ascertained for the velocity of primary radiation is a good support for the assertion of Lenard as to the identity of the secondary radiati[illegible] of solid and gaseous bodies.

Below 11 volts the quotient $(J_1 - J_2) / J_1 . 100$ decreases with increasing primary velocity. This points to the fact that here is a reflected radiation. The reflective power increases at first with decreasing primary velocity. For the lowest velocities of radiation (1-5 volts) it again decreases, however, which is mainly attributable to an influence of the vacuum. If the so-called 0-volt rays do not retain,[6] even for the best vacua attainable at the present time, their character as rays further than a distance of 5-6 cm., it is conceivable that the above values for the reflective power of 1-5 volt rays obtained under complicated conditions have no great significance. Diffusion and formation of carriers which appear with slow electrons must, therefore, diminish the reflective power. Thus, it is also explained that the value of the reflective power of 0-volt rays was often scarcely measurable. The question of the upper limiting velocity of the primary rays at which a reflection is discernable will be discussed in connection with the measurement of the velocity of secondary radiation. Here we can only infer so much that a considerable reflection is noticeable from the smallest radiation velocities up to 11 volts.

Soot behaves peculiarly in regard to the reflective power as well as the secondary radiation (Table V, Fig. 6). It indicates both phenomena only in a small [1007] degree. The turning point at 11 volts shown in the other curves here disappears.

A distinctly marked influence as to material is shown neither in the case of secondary radiation nor of reflection.

5. *Sources of Error.* In the observation recorded, only the secondary radiation in the vapor residuum (collision ionization) and the production of carriers for lower primary velocities were presumably the sources of error. The influence of both was ascertained in special experiments. First saturation current curves were made in connection with the series of observations given above, in that the current flowing away from the cylinder C, Z and the reflector R was ascertained in relation to the potential between K and C. As an example of an observation of this sort, the following series is given which was ascertained immediately after the conclusion of Table I.

TABLE VI

Potential between K and C.	Deflection in scale division	Potential between K and C.	Deflection in scale division
0 volt	74	26 volt	120
2 "	119	32 "	120
4 "	119	240 "	120
10 "	120	480 "	119

The series all gave the same result. Up to highest radiation velocities used, there was no trace of ionization. It was indeed necessary in these observations to greatly diminish the incident light intensity to avoid changing the measuring arrangement. It is therefore conceivable that an ionization which would be noticeable at great intensities here escaped observation. Therefore, the following experimental arrangement was adopted in which the same light intensities were used as above in Tables 1-5. Rays having a velocity of a ± x volts were employed in that the cylinder C was brought to high positive potential *a*, e.g, 210 volts, and cathode K to the small potential ± x. After passing the diaphragm tube [1008] D, these rays entered a retarding field of *a* volts between R and Z on the one side and C on the other. The current flowing from Z and R was measured. The result was as follows:

TABLE VII.

a	± x	Current flow from Z and R in scale divisions.
+ 210 volts	— 4 volts	125
+ 210 "	— 2 "	120
+ 210 "	0 "	64
+ 210 "	+ 2 "	0
+ 210 "	+ 4 "	0
+ 450 "	+ 2 "	0
+ 450 "	+ 4 "	0

In the latter case (a = + 450 volts, x = + 4 volts) all the positive ions produced by impact or otherwise had to be transported to K and Z. Thus the error caused by impact ionization is surely less than 1 per cent and may be disregarded in the above measurements.

In order to study the influence of the formation of carriers which can only be noticeable when the radiation velocities are small, the diffusion of the primary rays was investigated in a manner similar to the investigation of von Baeyer.⁷⁾ This was done by measuring the current flowing away from the reflector R when the plate R was at varying distances from the diaphragm D while the cylinder Z was grounded.⁸⁾ Table VIII gives an example of measurements of this kind which were made for velocities of primary rays of 1, 3, 5 and 11 volts.

TABLE VIII

Distance R-D in mm.	**Current from R at a primary velocity of**			
	1	**3**	**5**	**11 volts**
8	2.1	27.0	26.0	44.5
14	2.1	26.5	26.0	44.0
20	2.0	22.0	25.0	43.0
30	1.3	17.0	21.0	42.0
45	0.5	12.0	15.0	36.0

[1009]

As is to be seen from this, the cone of rays arising from the tangential components, always present when there is photoelectric liberation and arising as a result of the dispersion through the vapor residuum, strikes the cylinder sheath Z for 1 and 3 volt rays about 2 cm. distant from the diaphragm D, and 5 volt rays about 3 cm. distance and for 11 volt rays about 4.5 cm. distant from diaphragm D. From this it follows that the dispersion and carrier formation is of influence when the velocities of the rays are small, from 1-5 volts, but not, however, for 11 volt rays.

Reflected light nowhere fell on the plate R nor the cylinder Z. If the electrons liberated from the cathode K were held back by application of a sufficiently small positive potential, the electrometer never indicated a trace of a deflection.

II. *Velocity Measurement of the Secondary and Reflected Electron Radiation.*

6. The rather sudden start of the secondary radiation when the primary velocity amounts to 11 volts must manifest itself in a variation of the velocity distribution curve of the electrons leaving the reflector. The reflected radiation generally has to indicate the velocity of the primary radiation while, according to the observations of Lenard, a small natural velocity independent of the velocity of the primary rays is to be expected for the secondary radiation.

The velocity of the electrons emitted from the reflector was measured according to the method used by von Baeyer for the same purpose in the case of oxide cathodes. In the space between the diaphragm tube D and the cylinder C, there was introduced a soot-covered ring B insulated with amber and the space was closed by a fine meshed soot-covered wire net (Fig. 7). The reflector R closed off the cylinder Z in front. Otherwise, the arrangement is the same as above (section 2). The [1010] parts C, Z and R were charged to the same positive potential with respect to K so that in the space between R and the wire net the secondary radiation could be developed undisturbed. The current flowing from B was measured. By variation of the field between B and C, the velocity of the electrons bombarding B could be determined. In this manner the data given in Tables 9-12 were procured, which are partially represented in [1011] the curves 8-10.

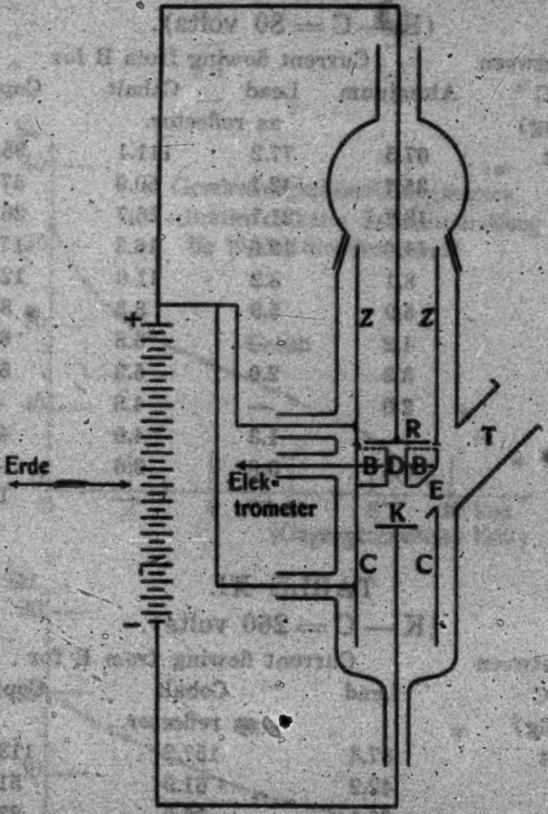


Fig. 7. **Versuchsanordnung zwecks Geschwindigkeitsmessung der reflektierten bzw. Sekundärstrahlung.**

TABLE IX.

Potential difference K — C = 10 volts.

Potential between B and C (retarding)	Current flowing from B for Copper	Lead as reflector.	Cobalt
0 volt	30.0	20.1	32.7
2 "	19.7	14.4	20.2
4 "	14.2	10.2	15.8
6 "	10.2	6.8	11.6
8 "	5.8	4.7	6.7
10 "	0.0	0.6	0.0

TABLE X.

(K — C = 80 volts).

Potential between B and C (retarding)	Current flowing from B for Aluminum	Lead as reflector.	Cobalt	Copper
0 volt	67.5	77.2	111.1	95.9
2 "	35.7	42.1	50.0	47.2
4 "	18.2	21.7	26.7	26.0
6 "	11.6	12.6	16.3	17.5
8 "	8.1	8.2	11.0	12.2
10 "	5.9	5.9	8.3	8.8
12 "	4.2	—	6.8	6.9
14 "	3.3	2.0	5.3	5.7
16 "	2.0	—	4.8	—
18 "	—	1.3	4.0	4.7
20 "	0.8	0.8	3.6	—
22 "	—	—	—	1.9

[1012]

TABLE XI.

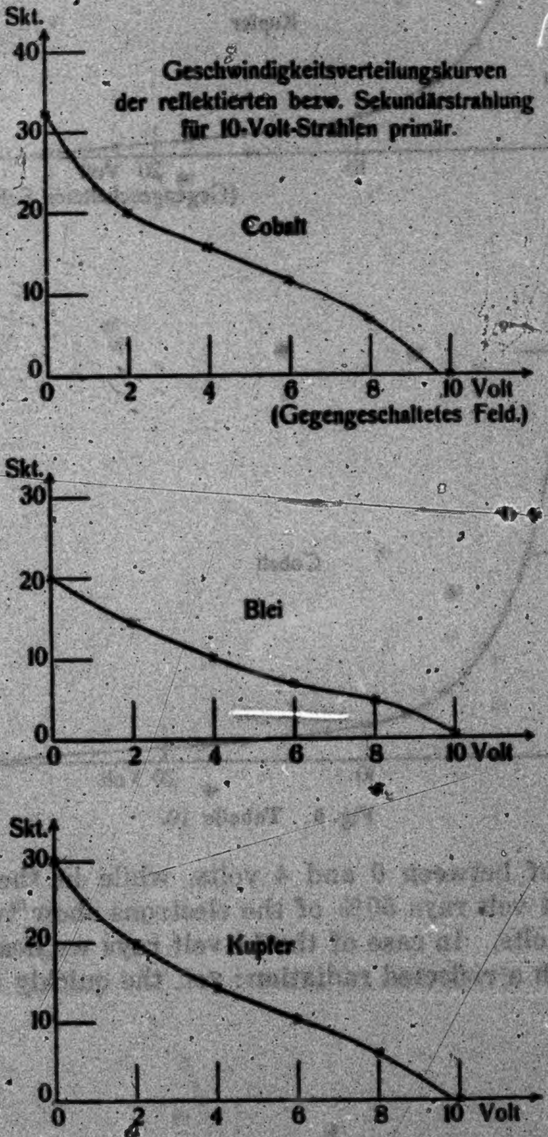
(K — C = 260 volts).

Potential between B and C (retarding)	Current flowing from B for Lead	Cobalt as reflector.	Copper
0 volt	87.3	157.2	113.0
2 "	42.2	61.9	51.9
4 "	20.1	30.0	27.0
6 "	11.9	17.1	16.2
8 "	7.4	11.0	11.0
10 "	5.3	7.2	8.1
12 "	3.7	5.9	5.9
14 "	2.4	—	4.2
16 "	2.3	4.1	—
18 "	1.6	—	1.8
20 "	1.2	2.7	—
22 "	—	—	0.6

TABLE XII.

(K — C = 500 volts).

Potential between B and C (retarding)	Current flowing from B for Lead	Cobalt as reflector.	Copper
0 volt	80.8	143.3	104.0
2 "	38.7	56.7	44.5
4 "	16.7	27.0	24.0
6 "	9.0	14.9	14.7
8 "	5.8	9.3	11.0
10 "	5.3	6.1	7.7
12 "	2.2	4.6	4.8
14 "	—	—	3.7
16 "	1.1	3.0	—
18 "	—	—	1.9
20 "	0.0	1.7	—
22 "	—	—	0.7



Geschwindigkeitsverteilungskurven der reflektierten bezw. Sekundärstrahlung für 10-Volt-Strahlen primär.

Fig. 8. Tabelle 9.

7. *Discussion of Results.* As is shown by the
[1013] curves in Fig. 8-10, there is, for example, a distinct difference between the curves for the 11 volt rays and those for the 80 volt rays. In the latter case a ma-
[1014] jority of the electrons (about 75%) have a velocity of between 0 and 4 volts, while in the curves for the 11 volt rays 50% of the electrons show velocities above 4 volts. In case of the 11 volt rays we deal essentially with a reflected radiation; yet, the quickly increas-

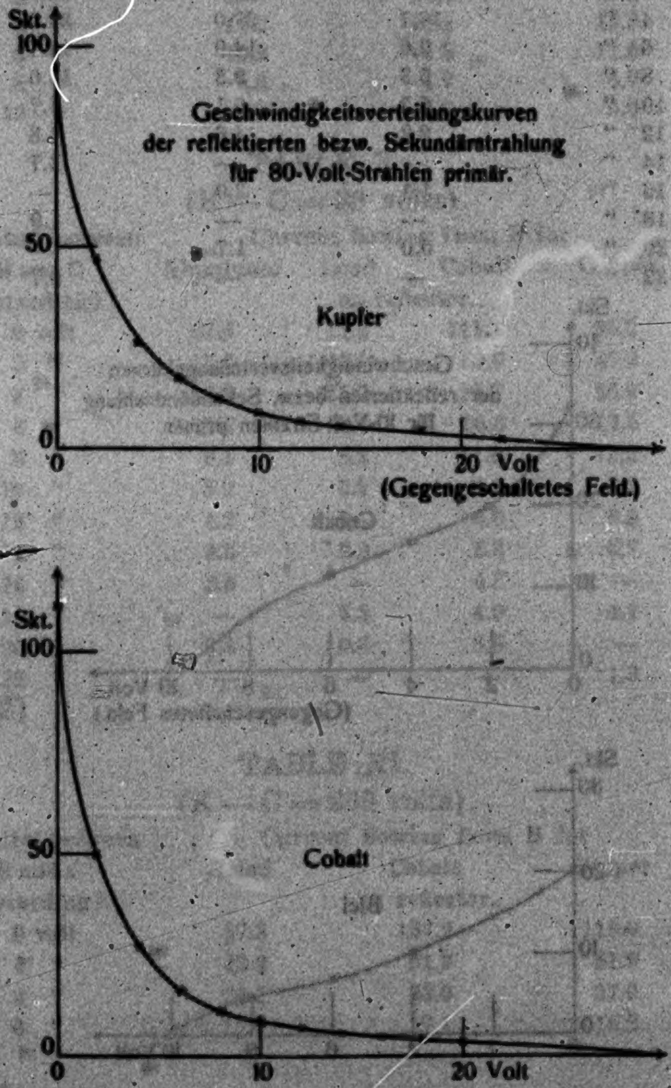


Fig. 9. Tabelle 10.

[1015] ing fall between 0 and 4 volts which was not inconsiderable and which took place with increasing primary velocity, indicated the existence of a secondary [1016] radiation even at 11 volts. A secondary radiation or reflected radiation with a velocity greater than 25 volts was no longer noticeable even for the most rapid primary rays (500 volts).

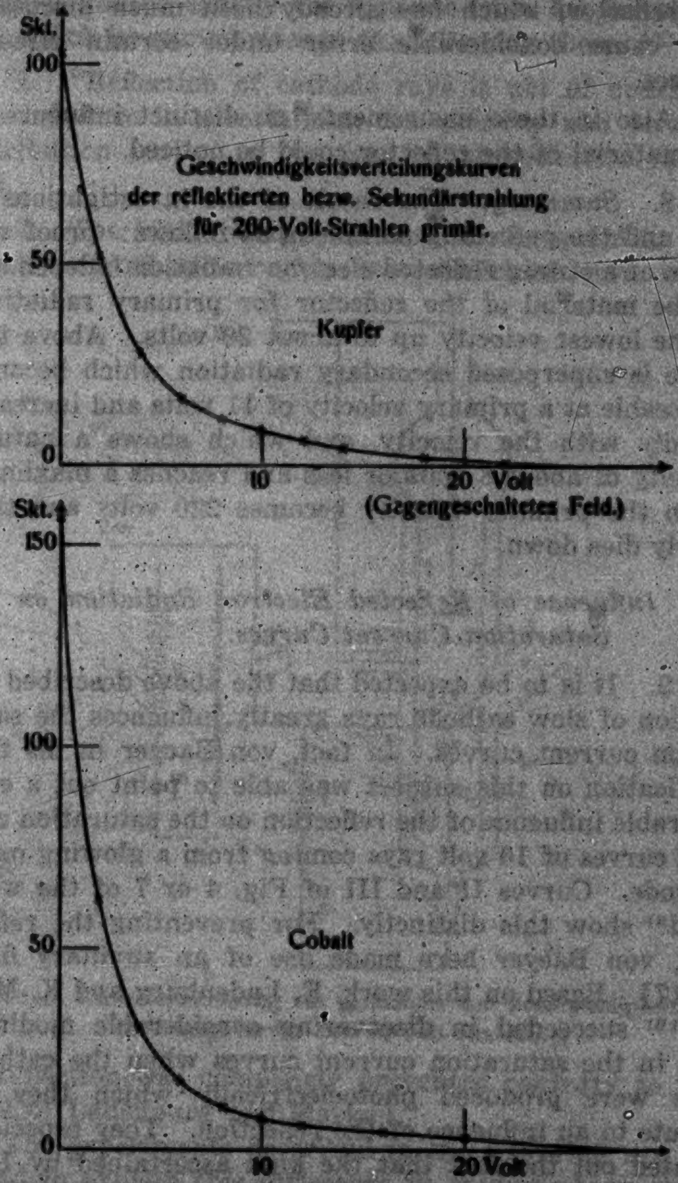


Fig. 10. Tabelle 11.

The measurements, however, may only properly be indicated as qualitative as von Baeyer has already explained. The diffused course of the rays coming from the reflector, which has already been much discussed, may cause considerable error under certain circumstances.

Also in these mearements, no distinct influence of the material of the reflector could be noticed.

8. *Summary.* The result of the investigations of this and the preceding section is as follows: proof was given of a strong reflected electron radiation independent of the material of the reflector for primary radiations of the lowest velocity up to about 20 volts. Above this there is superposed secondary radiation which becomes noticeable at a primary velocity of 11 volts and increases rapidly with the velocity, and which shows a natural velocity of about 8 volts or less and reaches a maximum when the primary velocity becomes 220 volts and then slowly dies down.

III. *Influence of Reflected Electron Radiation on the Saturation Current Curves.*

9. It is to be expected that the above described reflection of slow cathode rays greatly influences the saturation current curves. In fact, von Baeyer in his first publication on this subject was able to point out a considerable influence of the reflection on the saturation current curves of 10 volt rays coming from a glowing oxide cathode. Curves II and III of Fig. 4 or 7 of the work cited[9)] show this distinctly. For preventing the reflection, von Baeyer here made use of an auxiliary field. [1017] Based on this work, E. Ladenburg and K. Markau[10)] succeeded in discovering considerable modification in the saturation current curves when the cathode rays were produced photoelectrically which they attribute to an influence of the reflection. They especially pointed out the fact that the kink ascertained by Lenard[11)] in the quantity and velocity distribution curve vanishes when reflection is prevented; that it is therefore not due to any surface force. They also were able to show that a very definite narrowly limited range of velocity of the liberated electrons corresponds to each exciting wave length. They made use of an auxiliary field for avoiding reflected cathode radiation at one time

and at another time a Faraday cage and in both cases obtained the same result. Recently, however, Klages[12] obtained results exactly the opposite from his investigation which he summarizes in the following theses.[13]

1. "Reflection of cathode rays is not of considerable influence in ascertaining the quantity and velocity distribution curves in the case of photoelectric radiation.

2. The kink found by Lenard in the quantity and velocity distribution curves was confirmed even when

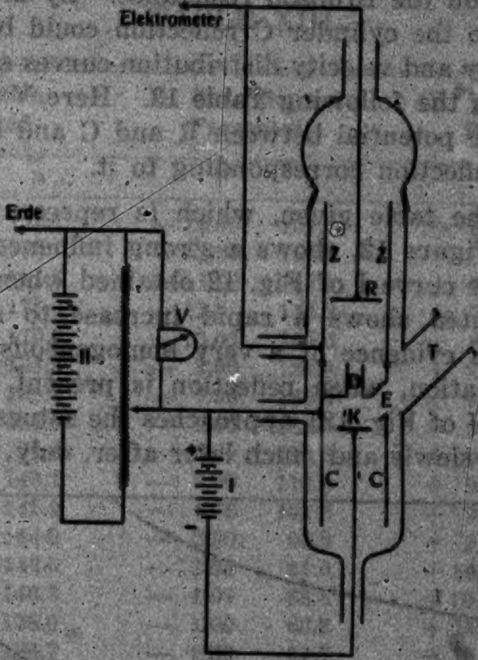


Fig. 11. Versuchsanordnung zur Aufnahme der Geschwindigkeitsverteilungskurven von 10-Volt-Strahlen.

the reflection was completely prevented contrary to the doubt of Ladenburg and Markau."

The experiments described in the following are intended to explain this difference in opinion; they show distinctly an influence of the reflection on the quality and velocity distribution curve, as well as a dependence of the kink on the presence of a reflected radiation.

10. In order to make perfectly clear the influence of the reflected electron radiation on the quantity and [1018] velocity distribution curve of the photoelectri-

cally liberated cathode rays, the experiments of von Baeyer with 10 volt rays were repeated when the cathode radiation was photoelectrically liberated. The experimental arrangement was now as follows (Fig. 11). The experimental tube described in paragraph 2 was used except that this time a constant potential of 10.4 volts was maintained between cylinder C and cathode K which was produced by battery I. Battery I, cylinder C and cathode K were then raised by the battery II whose one pole was grounded to a measurable (by the millivoltmeter V) positive or negative potentials with respect to R and Z which was on the Bronson resistance. By drawing the plate R into the cylinder C reflection could be avoided. The quantity and velocity distribution curves so obtained are given in the following Table 18. Here V stands for [1019] the potential between R and C and *a* the electrometer deflection corresponding to it.

11. The table given, which is represented in the curves of Figure 12, shows a strong influence of reflection. While curve I of Fig. 12 obtained when reflection was prevented shows a rapid increase to saturation, which gives evidence of a very homogeneous character of the radiation, when reflection is present, the curve [1020] (II of Fig. 12) approaches the saturation value much more slowly and much later after, only with accel-

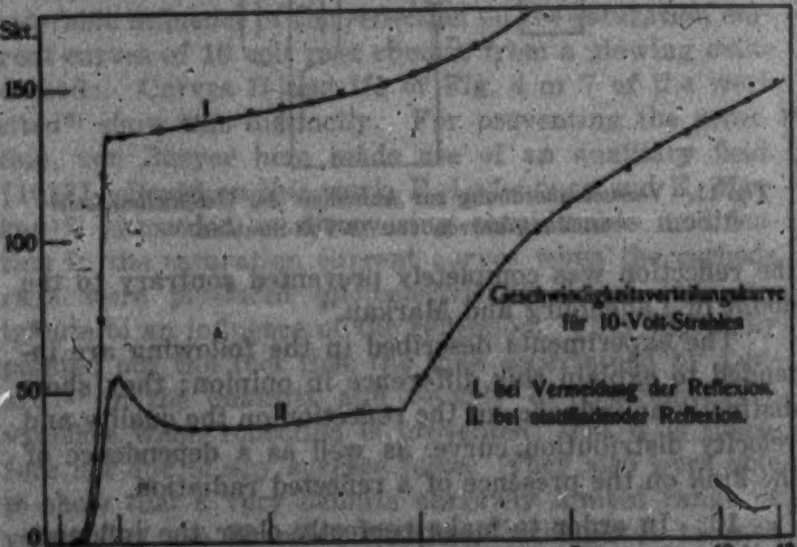


Fig. 12. Tabelle 18.

erating fields. That the saturation is not an ideal saturation in curve I, i.e., that a further slow increase can also be detected beyond 10 volts retarding, might be attributed to the fact that with increasing field between the cylinders C and Z there is a variation in the conditions of emanation of the rays leaving the diaphragm tube. The knob appearing in the curve entitled the "reflection not prevented" at 10 volts retarding is explained by the peculiar behavior of the slowest rays frequently mentioned above, which is based on the vacuum being insufficient for this.

TABLE XIII.

I. Reflection Prevented		II. Reflection not Prevented		III. Reflection not Prevented	
V	a	V	a	V	a
— 12.0	192.7	— 12.40	151.5	+ 6.00	37.9
— 10.0	185.7	— 12.01	150.0	+ 6.50	38.0
— 8.0	181.7	— 11.50	147.3	+ 7.00	38.0
— 6.0	176.0	— 11.0	144.2	+ 7.50	37.5
— 4.00	170.0	— 10.01	140.0	+ 8.01	38.0
— 1.99	163.2	— 9.00	134.0	+ 8.50	39.8
— 0.50	156.2	— 7.99	130.0	+ 9.01	42.7
+ 0.1	154.0	— 7.00	122.0	+ 9.30	45.7
+ 1.00	150.7	— 6.00	117.2	+ 9.51	48.7
+ 2.50	148.7	— 5.00	110.0	+ 9.63	49.9
+ 3.51	145.0	— 4.02	101.3	+ 9.80	52.0
+ 4.50	144.0	— 3.00	93.0	+ 9.89	54.2
+ 5.51	142.0	— 2.00	81.0	+ 10.00	54.7
+ 6.48	140.3	— 1.07	68.3	+ 10.11	53.7
+ 7.50	138.0	— 1.00	68.2	+ 10.20	52.9
+ 8.50	136.7	— 0.80	64.7	+ 10.31	49.8
+ 9.81	134.8	— 0.58	61.6	+ 10.41	43.9
+ 10.16	134.7	— 0.42	58.8	+ 10.50	37.2
+ 10.30	134.3	— 0.20	54.2	+ 10.61	29.0
+ 10.39	122.2	± 0.00	51.9	+ 10.70	22.1
+ 10.55	74.1	+ 0.93	48.2	+ 10.81	12.2
+ 10.70	41.1	+ 1.99	43.0	+ 11.00	6.3
+ 10.80	29.2	+ 2.98	41.3	+ 11.21	1.4
+ 11.03	12.1	+ 4.00	40.0	+ 11.40	0.2
+ 11.20	4.2	+ 4.98	38.0	+ 11.50	0.0
+ 11.37	1.0	+ 5.49	38.1		
+ 11.51	0.0				

12. After this preliminary experiment we proceed to point out the influence of the reflection on the saturation current curves for the unaccelerated photoelec-

trically liberated cathode rays. The following is the idea underlying the experiments. If the reflection has considerable influence on the curve form, and because the reflected radiation is greatly diffused, the curves [1021] must be freed more and more from the errors resulting from reflection when the distance between plate receiving radiation and intercepting plate is increased, for with increasing distance between the plates a smaller and smaller part of the reflected rays turns back to the illuminated plate and thus lessens the radiation, providing that the surrounding region does not reflect to any noticeable degree. It is especially to be expected that the kink mentioned, in case it is the result of the reflection, is made to disappear by enlargng the distance between the plates.

13. On account of these considerations the following experimental arrangement (Figure 13) was finally chosen after a large number of preliminary experiments. The light of the mercury high pressure lamp after being concentrated by a thin quarts lens falls through the 4 mm. diaphragm in the cap of the brass cylinder C open on one side, 3 cm. wide and 5.5 cm. long normally

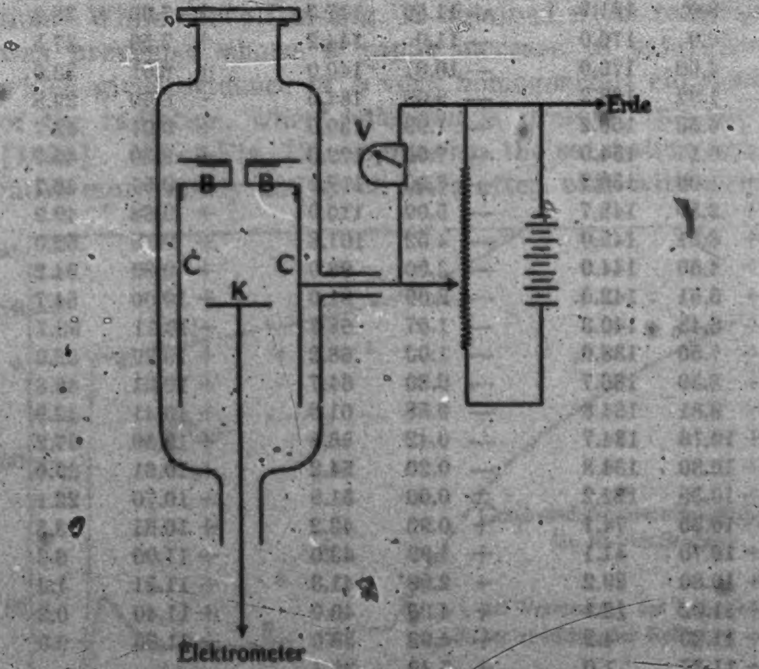


Fig. 13. Versuchsanordnung zur Ermittelung der Mengen- und Geschwindigkeitsverteilungskurven.

[1022] on the illuminated copper plate K having a diameter of 1.5 cm. The cylinder C is closed on one side by a brass cap B polished highly within and inserted in a small additional tube which carried a mica diaphragm protecting the cylinder from direct light. All the parts—with the exception of the highly polished cap—are well covered with wax-candle black. The radiating plate K is moved by an electromagnet in a direction parallel to itself. It was well insulated with amber and lay on the measuring device described above. The cylinder C was brought to the desired potential by branching from the circuit of some storage cells. In the following, the potentials are always calculated as positive when they retard the electrons emitted from K.

The following results which are recorded in Tables 14 and 15 were obtained with this arrangement. In these tables V stands for the potential maintained between K and C or B and a the corresponding electrometer deflection.

TABLE XIV.

V in volt	a for a distance K — B of			
	3 mm.	9 mm.	36 mm.	48 mm.
— 6.00	95.3	98.4	99.7	100.0
— 2.00	90.5	96.1	96.5	98.7
— 0.50	78.4	93.8	95.3	96.3
— 0.20	73.6	90.0	91.7	94.9
0.00	66.7	80.4	85.7	90.6
+ 0.20	53.3	63.5	73.9	79.3
+ 0.50	26.4	34.8	44.8	60.4
+ 1.00	5.5	10.4	17.0	31.4
+ 1.50	0.0	1.3	6.0	16.0
+ 2,00	0.0	0.0	2.5	7.7
+ 2.50	0.0	0.0	0.5	3.5
+ 3.00			0.0	1.7

[1023]

TABLE XV.

V in volt	a for a distance K — B of		V in volt	a for a distance K — B of	
	3 mm.	[illegible]8 mm.		3 mm.	48 mm.
— 6.00	99.0	100	+ 0.1	—	82.0
— 2.00	91.5	99.3	+ 0.2	51.6	70.6
— 1.50	89.8	[illegible]	+ 0.3	41.4	60.2
— 1.00	86.8	98.5	+ 0.4	32.8	50.1

— 0.9	85.5	—	+ 0.5	22.8	41.6
— 0.8	84.0	98.2	+ 0.6	16.6	34.8
— 0.7	82.7	98.2	+ 0.7	13.2	29.6
— 0.6	82.7	98.0	+ 0.8	9.9	24.5
— 0.5	82.1	97.7	+ 1.0	5.3	16.9
— 0.4	80.2	—	+ 1.2	2.0	12.0
— 0.3	78.0	—	+ 1.5	0.0	6.3
— 0.2	75.4	96.4	+ 2.0	0.0	2.4
— 0.05	70.7	—	+ 2.5	—	0.9
∓ 0.0	67.8	88.9	+ 3.0	—	0.0
+ 0.05	64.7	—			

14. An influence of the distance between the plates is recognizable from the data submitted and even more distinctly from the curves of Figures 14 and 15. While the kink is distinctly present when the distance K — B = 3 mm., it is not recognizable when the distance K — B = 9 mm., and when K — B = 36 mm.; at 48 mm. it

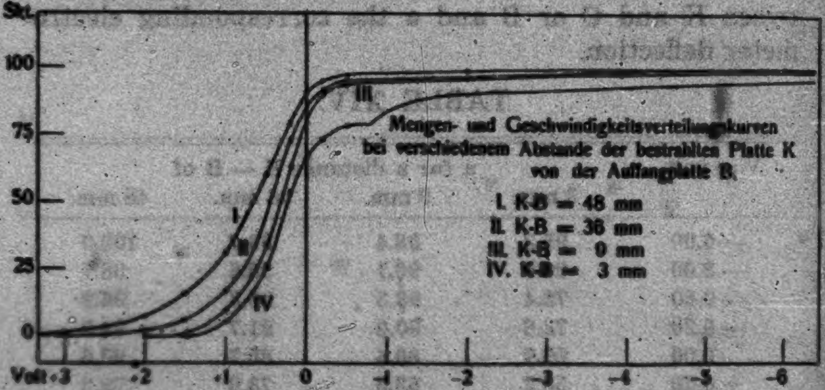


Fig. 14. Tabelle 14.

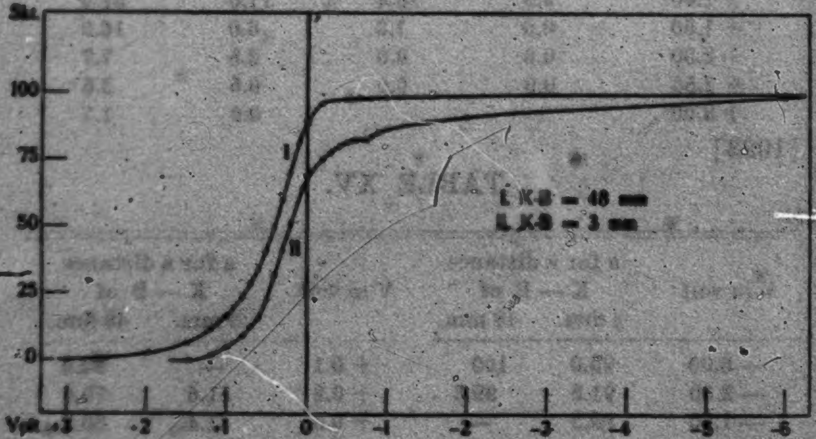


Fig. 15. Tabelle 15.

[1024] entirely disappears. At the same time the rise in radiation behind the zero point (on the negative branch of the curve corresponding to accelerating potentials) considerably decreases while the rise in the positive branch is steeper. This leads to the conclusion that the kink ascertained at first by Lenard is essentially a result of the reflected radiation in opposition to the doubts of Klages. Under no circumstances the appearance of the kink is to be attributed to a process taking place on the illuminated plate, e.g., to formation of double layers on it. For in that case, it is not understood why a mere increase or decrease in the distance between the plates can cause the kink to disappear or to appear. Also a surface force had to have exactly the same effect when the distance was great as when small. That in the experiments of Lenard,[14] Lienhop[15] and Klages,[16] the kink appears with great distinctness, seems accordingly for the most part the result of the small distance between the plates. Lenard and Lienhop used a distance of 5 mm. in the experiments considered here and [1025] Klages only one of 3 mm.

The fact that the kink is essentially the result of the reflection is also confirmed by the following test. If a cap is used which is not a highly polished one, but is covered with soot, the kink must disappear—even when the distance is only 3 mm.—as soot reflects an exceedingly small amount. This is shown in fact by the curves of Figure 16, these being a graphical representation of the results of Table 16.

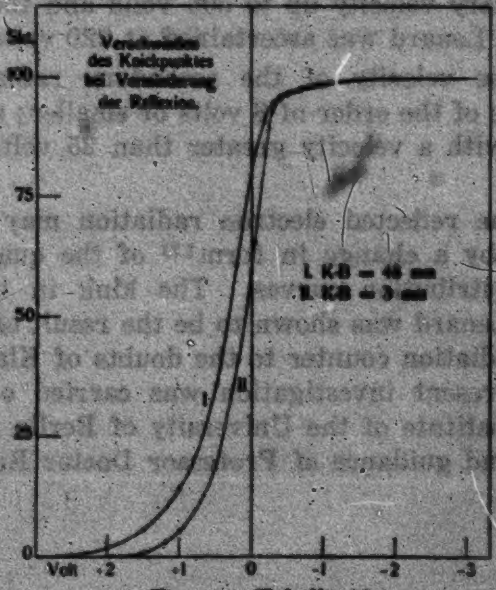


Fig. 16. Tabelle 16.

Tabelle 16.

TABLE XVI.

V in volt	a for a distance K — B from 3 mm.	48 mm.
— 6.00	100	100
— 2.00	100	100
— 1.00	98.5	—
— 0.9	—	98.7
— 0.7	97.8	98.2
— 0.5	96.7	97.1
— 0.4	96.0	96.2
— 0.3	93.4	95.0
— 0.2	84.2	90.9
— 0.05	65.9	84.4
∓ 0.0	59.6	79.5
+ 0.2	41.0	61.1
+ 0.5	18.8	35.7
+ 1.0	5.3	14.6
+ 1.2	3.1	10.4
+ 1.5	0.9	5.5
+ 2.0	0.0	2.0
+ 2.5	0.0	0.0
+ 3.0	0.0	0.0

[1026]

IV. *Results.*

1. A reflected radiation was indicated for low velocities of the rays when the cathode rays were photoelectrically liberated, on which there is superposed a secondary radiation arising rather suddenly when the primary velocity is 11 volts. The latter was continued for a primary velocity up to 500 volts and the point of reversal of Lenard was ascertained at 220 volts.

2. The velocity of the secondary radiation was found to be of the order of 8 volts or smaller; a reflected radiation with a velocity greater than 25 volts was not noticeable.

3. The reflected electron radiation may be made noticeable by a change in form[17] of the quantity and velocity distribution curves. The kink in them first found by Lenard was shown to be the result of reflected electron radiation counter to the doubts of Klages.

The present investigation was carried out at the Physical Institute of the University of Berlin at the instigation and guidance of Professor Doctor Rubens and

Professor Doctor von Baeyer. I am also permitted to present my cordial thanks to my highly honored teacher, Geheimrat Rubens, for the lively interest in my work and the constant assistance in the same. I also owe sincere thanks to the Privatdozents Doctor von Baeyer and Doctor Ladenburg for their manifold advices.

Physikalische Institut der Universität
Berlin.

GI

NOTES.

1. P. Lenard, Ann. d. Phys. 8, p. 149, 1902; 12, p. 449, 1903; 15, p. 485, 1904; furthermore, Ueber Kathodenstrahlen (Nobelvorlesung) Leipzig, 1906.
2. O. v. Baeyer, Physik. Zeitschr. 10, p. 168, 1909; Verh. d. Deutsch. Physik. Ges. 10, p. 96, u. 953, 1908.
3. The phenomena of reflection and secondary radiation with rapid cathode rays have been presented by: H. Starke, Wied. Ann. 66, p. 49, 1898; Ann. d. Phys. 3, p. 75, 1900, and L. Austin and H. Starke, Ann. d. Phys. 9, p. 271, 1902.
4. K. Scheel u. W. Heuse, Zeitschr. f. Instrumentenk. 29, p. 46, 1909; H. Dember, Ann. d. Phys. 30, p. 137, 1909; E. Hupka, Ann. d. Phys. 31, p. 169, 1910; Diss. Berlin 1909.
5. H. Ebert, Physik. Zeitschr. 8, p. 775, 1907.
6. E. Ladenburg and K. Markau, Verh. d. Deutsch. Phys. Ges. 10, p. 578, 1908.
7. O. v. Baeyer, Phys. Zeitschr. l. c. p. 178.
8. The influence of the temperature reflection is discussed in section 3.
9. O. v. Baeyer, Physik. Zeitschr. 10, p. 171-175.
10. E. Ladenburg and K. Markau, Physik. Zeitschr. 9, p. 821, 1908; Verh. d. Deutsch. Physik. Ges. 10, p. 562, 1908. Referring to the process given by Klages, the latter publication will always be cited.
11. P. Lenard, Ann. d. Phys. 6, p. 177, 1902.
12. A. Klages, Ann d. Phys. 31, p. 343, 1910; Diss. Heidelberg 1909.
13. A. Klages, l. c. p. 363.
14. P. Lenard, l. c. p. 178-182.
15. A. Klages, l. c. Tab. 3, Fig. 3, p. 357.
16. A. Lienhop, Ann. d. Phys. 21, p. 281, 1906.
17. The data contained in the dissertation on the position of the distribution curves regarding amount and velocity are omitted here because an investigation by O. von Baeyer and A. Tool (Verh. d. Deutsch. Physik. Ges. 13, p. 569) has disclosed the fact that polarization phenomena of the volta effect are also involved.

DEFENDANT'S EXHIBIT No. 22.

J. T. MARSHALL, DEC'D.
E. T. MARSHALL, EXECUTRIX.
PROCESS OF EXHAUSTING LAMPS.
APPLICATION FILED OCT. 23, 1911.

1,205,002. **Patented Nov. 14, 1916.**

Fig. 1.

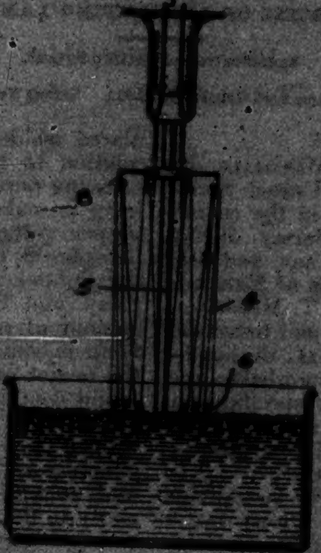


Fig. 2.

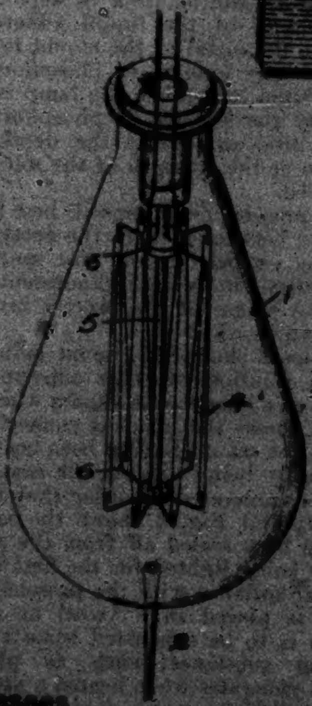
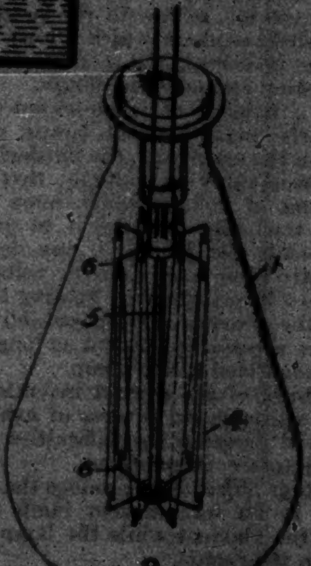


Fig. 3.



Witnesses:
Allen Oxford
Benjamin B. Hull

Inventor:
John T. Marshall, deceased.
Eliza T. Marshall, executrix
by Albert
Attorney.

UNITED STATES PATENT OFFICE.

JOHN T. MARSHALL, DECEASED, LATE OF METUCHEN, NEW JERSEY, BY ELIZA T. MARSHALL, EXECUTRIX, OF METUCHEN, NEW JERSEY, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

PROCESS OF EXHAUSTING LAMPS.

1,205,002. Specification of Letters Patent. Patented Nov 14, 1916.

Application filed October [illegible], 1911. Serial No. [illegible].

To all whom it may concern:

Be it known that JOHN T. MARSHALL, deceased, late a citizen of the United States and a resident of Metuchen, in the county of Middlesex, State of New Jersey, during his lifetime invented certain new and useful Improvements in Processes of Exhausting Lamps, and that I, ELIZA T. MARSHALL, executrix under the last will and testament of the said JOHN T. MARSHALL, do hereby declare, to the best of my knowledge and belief, that the following specification, taken in connection with the accompanying drawing, is a clear, true, and complete description of said improvements.

This invention relates to the production of evacuated vessels in which a high degree of vacuum is desired, and more particularly to exhausting incandescent lamps.

When a number of incandescent lamps, particularly metal filament lamps, are exhausted in the usual way, the finished lamps differ considerably in voltage; that is, in the amount of voltage which must be applied to the lamp to cause it to give the candle power for which it was designed. Apparently these variations in voltage are caused to a large extent by heating the filament in the presence of the gases and vapors which are necessarily present as long as the lamp is connected to the pump.

One object of the present invention is to produce an improved process of exhausting which will decrease the difficulties of this kind heretofore encountered.

A further object is to produce the desired vacuum in an incandescent lamp without heating the filament while the lamp is connected to the pump.

A still further object is to regulate more exactly than heretofore the amount of phosphorus vapor evolved in the lamp or vessel which is being exhausted; and in general to improve the production of incandescent lamps and similar evacuated vessels.

To accomplish these objects phosphorus or similar vapor is evolved directly in the lamp or vessel after the lamp has been sealed and is entirely finished so far as [illegible] is concerned. The vapor may be evolved in a vessel or lamp in various ways, but preferably the phosphorus, or some substance which is capable of evolving the desired vapors when heated, is placed inside the vessel or lamp in such a relation to the filament or other current carrying portion of the lamp that when the lamp is sealed off and then lighted at the proper voltage to produce the blue glow, phosphorus vapor is evolved by the heat of the lighted filament, the blue glow disappears, and the vacuum is perfected. The amount of phosphorus introduced into the lamp is controlled very exactly by dipping the mount of each lamp into a solution, or liquid containing suitable material, such as phosphorus. Preferably each mount is dipped to the same extent, while the strength of the solution is kept uniform, and enough of the liquid adheres, especially to the metal of the mount to produce the necessary amount of phosphorus vapor in the lamp bulb when the lamp is lighted. To vary the amount of phosphorus introduced into each lamp the depth of immersion or the strength of the solution may be varied.

The present invention will best be understood in connection with the accompanying drawing, which merely for purposes of illustration shows an incandescent lamp at different stages of the process invented by him, and in which—

Figure 1 shows the mount being dipped into a solution of some substance which will evolve phosphorus vapors when heated; Fig. 2 shows the lamp as connected to the pump, the mount having been coated at the bottom by being dipped, the coating being much exaggerated in order that it may be visible; and Fig. 3 shows the lamp after having been sealed off from the pump and before being lighted for the first time.

In accordance with the present invention there is placed in a vessel or a lamp 1 which is to be exhausted some vapor generating substance, such as phosphorus, which generates when heated a vapor which reacts with the residual atmosphere of the lamp and is capable of improving the lamp and perfecting a "partial" vacuum. The vessel or lamp is then connected to the pump by a tubulature 2 in the usual way and while being pumped out is heated by some external source of heat to such a temperature that occluded gases and vapors are driven out, but the vapor generating substance is not heated enough to cause generation of vapor, as the filament is not heated while the lamp is on the pump. When the vacuum is as high as is usually obtained by pumping when exhausting in the usual way, the lamp or vessel is sealed off at 3 close to the bulb. This operation removes the tubulature and is the last glass-working operation performed on the lamp, which is now finished so far as glassworking is concerned. No portion of the tubulature or any other projection which contained phosphorus must afterward be cut off, as in the customary method of exhausting where phosphorus paint is placed in the tubulature and none of the glass of the lamp need afterward be heated high enough to drive out of it occluded gases or water vapor.

The vacuum produced by pumping is not high enough and is perfected by generating in the lamp or vessel from the vapor generating substance, such as phosphorus some vapor which will react with the residual atmosphere in the presence of the highly incandescent filament and perfect the vacuum, or in some way improve the lamp. This substance, usually some form of phosphorus, may be heated by the filament to generate vapor. In the preferred construction the vessel to be evacuated contains a high resistance, conductor, and the vapor generating substance is placed on or in thermal relation to the conductor so that when sufficient current is passed through the conductor the substance will be heated sufficiently to evolve the vapor.

In exhausting incandescent lamps, the phosphorus vapor is preferably introduced by placing the vapor generating substance on the mount, which is inside the lamp when the lamp is finished and which comprises the metal filament 4, preferably of tungsten, and its supports, such as the glass post 5 and metal anchor or supports 6. This substance is placed on some metal part of the mount in thermal relation to the filament 4 so that lighting the lamp at a voltage which produces a blue glow in the bulb will heat the substance and cause the phosphorus vapor to be generated. This vapor acts as in the usual method of exhausting, and in its presence the blue glow disappears and the vacuum is perfected.

The vapor generating substance may be placed upon the mount in various ways, but, preferably the mount is dipped into a liquid containing the substance, then withdrawn, and the adhering liquid permitted to dry. Practically the whole mount may be immersed in the liquid, wetting the filament and supports, or it may be dipped until only the lower end of the post 5 and the lower metal anchors or supports 6 are immersed, as shown in Fig. 1. The same amount of phosphorus is introduced into each lamp by dipping each mount to a uniform depth into a bath or solution of phosphorus of which the strength is kept uniform. A bath of phosphorus of such a strength that it produces a barely discernible deposit upon the glass of the mount after the adhering liquid has dried is sufficient to perfect the vacuum. The amount of phosphorus introduced into the lamp may be controlled very exactly by varying the strength of the bath or solution or by varying the depth of immersion. This method of introducing phosphorus or similar material into a lamp or vessel may be used to advantage in any method of exhausting which requires the introduction of such material.

Although the mount is preferably dipped into a bath or solution of phosphorus, such as finely divided phosphorus mixed with or dissolved in alcohol, the phosphorus or similar material may be placed upon the mount in other ways, and may be placed anywhere on the filament or on the metal supports for the filament in such a relation to the filament that when, after being sealed off and finished, as shown in Fig. 3, the lamp is lighted for the first time and at a voltage sufficient to produce the blue glow, the hot filament causes sufficient phosphorus to vaporize from the metal to remove the blue glow and perfect the vacuum in the presence of the intensively incandescent filament, without heating the glass of the lamp enough to drive out of it any occluded gases or water vapor.

This invention may be embodied in many other forms than that shown and described and is not limited to the precise arrangement disclosed herein, since various modifications thereof will suggest themselves to those skilled in the art without departing from the spirit of the invention, the scope of which is set forth in the annexed claims.

What is claimed as new and desired to be secured by Letters Patent of the United States, is:—

1. In the manufacture of an incandescent lamp having metal parts comprising a tungsten filament and metal anchors for the filament, the process which consists in applying to metal parts of the mount in position to be vaporized by the heat of the incandescent filament a substance solid at room temperature but reacting with the residual atmosphere to improve the lamp when vaporized in the presence of the incandescent filament, exhausting the lamp without heating the filament, sealing off the lamp, and then for the first time passing current through said filament to vaporize said substance and produce an atmosphere containing the vapor of said substance conjunctively with intensive incandescence of said filament while all glass of the lamp is below the temperature at which occluded gases are driven out of it.

2. In the manufacture of an incandescent lamp having metal parts comprising a tungsten filament and metal supports for the filament, the process which consists in applying phosphorus to metal parts of the mount in position to be vaporized by the heat of the incandescent filament, exhausting the lamp to a predetermined degree without heating the filament, sealing off said lamp, and subsequently raising said filament to intensive incandescence to vaporize the phosphorus while all the glass of the lamp is below the temperature at which occluded gases are driven out of it.

3. In the manufacture of an incandescent lamp having a mount comprising a metal filament and metal anchors, the process which consists in wetting the metal of the mount to a predetermined extent with a liquid having uniformly distributed through it a definite percentage of a substance solid at room temperature and vaporizable by incandescence of the filament, drying the metal to leave on it a coating of the solid substance, exhausting the lamp containing the coated metal without heating said filament, sealing off the lamp and then for the first time passing current through said filament to vaporize said substance and raise said filament to intensive incandescence conjunctively with the generation of said vapor while the glass of the lamp is below the temperature at which occluded gases are evolved.

4. In exhausting incandescent lamps, having mounts comprising metal filaments and metal anchors, the steps of introducing the same amount of phosphorus into each lamp by dipping the corresponding metal parts of all the mounts to the same extent into a liquid having phosphorus uniformly distributed through it, drying the metal parts to leave a coating of phosphorus on them, pumping out the lamp without heating the filament, sealing off the lamp, and then for the first time passing current through the filament and raising it to intensive incandescence.

5. The steps in the manufacture of a tungsten filament incandescent lamp which consist in coating at least a part of the tungsten filament with a substance solid at room temperature and reacting with the atmosphere in the lamp when vaporized in the presence of the incandescent filament to improve the lamp, exhausting and sealing off the lamp without vaporizing said solid substance, and then for the first time passing current through the filament to vaporize said substance and render said filament intensively incandescent in the vapor of said substance while the glass of the lamp is below the temperature at which occluded gases and water vapor are driven out of it.

In witness whereof, I have hereunto set my hand this seventeenth day of October, 1911.

ELIZA T. MARSHALL,

Executrix of the estate of John T. Marshall deceased.

Witnesses:
JOHN W. HOWELL,
JENNIE STEED.

DEFENDANT'S EXHIBIT No. 29.
Physical Review, Vol. 32 (1911).

DISCHARGE FROM HOT CAO.

By C. D. Child.

It was suggested a few years ago by Sir J. J. Thomson[1] that certain phenomena of electrical discharge could be explained by what we may call ionization by *repeated* impact. He had found that luminous discharge could be produced from a cathode of hot CaO with potential differences much smaller than those which are needed when a cold cathode is used, and that at a certain critical point it needed but a very small increase in the voltage to produce a large increase in the current and to change from the non-luminous to a luminous form of discharge. He believed that the ionization in the luminous form of discharge was not due to the breaking up of an atom by a single impact with an electron, but rather to an explosion of the atom because of its having absorbed so much internal energy from repeated impacts with electrons that its equilibrium had become unstable.

If this idea is correct, it is important not only because it explains this particular phenomenon, but also because it offers an explanation of the ionization of the arc and gives us some information concerning the character of the atom. I have, therefore, given some study to the subject, but find that there are several reasons for rejecting this explanation.

Improbability of Repeated Impacts.—The first of these objections is that there are far too few electrons present in the tube at any time before the discharge becomes luminous to occasion repeated impacts. For example, in one experiment performed by myself the largest current that could be passed through the tube without having a luminous discharge was 5×10^{-8} ampere, which is 150 electrostatic units. The charge carried by each ion[2] is 3.4×10^{-10}. The cross section of the tube used was approximately 5 sq. cm. So that the number of electrons passing through each square centimeter per second was 8.85×10^{10}. The pressure of the gas was .014 mm. and the mean free path of the electron at this pressure is approximately 3.76 cm.[1] So that in each cubic centimeter only 2.34×10^{10} electrons would hit molecules per sec.

---

[1] Nature, 73, 496, 1906.

[2] Thomson's Conduction of Electricity through Gases, 2d ed., p. 158.

According to Myers[2] there will be 11.2×10^{14} molecules per c.c. under these condition of pressure and temperature. From this we find that each molecule will on the average be hit once in 48,000 sec., or once in thirteen hours, and it only requires a fraction of a second to produce the luminous discharge when the conditions are right for it.

This is, of course, not an argument against ionization by repeated impact after the luminous discharge has commenced, for then the number of electrons will be very much greater, but the idea of such impact was used by Thomson as an explanation of the beginning of the luminous discharge, and it is an argument against such an explanation. There will, however, be other data given later which indicate that not at any time is there ionization by repeated impact.

Critical Condition Does not Depend on the Amount of Current, but on the Condition of the Cathode.—In the second place experiments indicate that the voltage required to change from the non-luminous to the luminous discharge depends but slightly, if at all, on the amount of current flowing, but does depend very greatly on the kind and condition of the cathode. That is, the number of electrons passing through the tube and hitting upon the molecules does not determine the point where the change occurs, while other conditions do.

The form of apparatus used for showing this is given in Fig. 1. *T* is a tube 2.8 cm. in diameter. *P* is the connection to the vacuum pump, McLeod gauge, and drying tube. *C* is the cathode consisting of platinum foil, approximately 2 mm. in width, 12 mm. long, and .02 mm. thick, the bottom being covered with CaO. This was welded to aluminum wires which led out of the tube and was heated by an alternating current connected at *c* and *c'*.

A is an iron anode, fastened to an iron wire which is brought down through the tube *a* into a mercury cup, so that the anode could be raised or lowered. A shunt of 50 ohms resistance was placed across *cc'*. The middle of this, lettered *b*, had the same potential as the middle of the foil *C*. A potential difference was maintained between *b* and *A* by connecting them to *d* and *d'*, two points on a variable resistance through which a current was passed from a dynamo. By this means any potential difference from 0 to 130 could be used. *V* is a Weston voltmeter measuring this potential difference. *G* is a galvanometer measuring the current through the tube.

---

[1] Idem, p. 476.

[2] Myers' Kinetic Theory of Gases, p. 333.

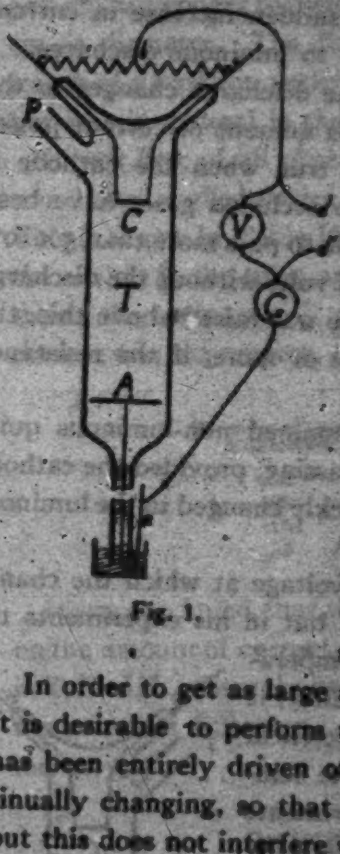


Fig. 1.

The first experiment was a comparison of the discharge from clean hot platinum with that from hot platinum covered with CaO. With clean platinum it is possible to get a large current without changing the character of the discharge, while with CaO it requires but a very small current to produce this change, the potential difference between the electrodes being the same in the two cases.

In order to get as large a current from the platinum as possible it is desirable to perform the experiment before the occluded gas has been entirely driven off. If this is done, the current is continually changing, so that no two sets of readings are the same, but this does not interfere with our present purpose.

The readings as taken are given in Table I., the first column giving the potential difference between the electrodes and the second the current. The platinum foil was a little more than red hot and the pressure of the gas was approximately .04 mm.

TABLE I.

Potential Difference in Volts.	Current in Amperes Times 10^{-7}.
71	.1
80	.5
84	2.1
90	6.5
125	48.2

There was here no abrupt change in the amount of current and the discharge was not at any time luminous. There is in some cases a slight luminosity with the discharge from clean platinum, but even then there appears to be no sudden increase in current nor sudden change from non-luminous to luminous discharge.

On the other hand with hot CaO the discharge changes to the luminous form before anything like this amount of current passes through the tube. This is especially true when the cathode is quite hot and has been used until the occluded gases have been driven off. In one case it was impossible to pass more than 5×10^{-6} ampere with a potential difference of 95 volts without the discharge becoming luminous. When the voltage was raised above this, the current became as large as an ampere or more, if the resistance in series with the tube was small.

Thus we see that the discharge remained non-luminous quite irrespective of the amount of current passing, provided the cathode was clean platinum and that it very quickly changed to the luminous form, if the cathode was very hot CaO.

Thomson states that he found the voltage at which the change took place to depend on the current, but in his experiments the current was changed by raising the temperature of the cathode. When that is done, it is not possible to decide whether the critical point depends on the current or on the temperature of the CaO. In the experiments described above it is made clear that it is the condition and temperature of the cathode that determines this point and not the amount of current.

The Potential Difference between the Beginning and End of a Striation.—The potential difference between the beginning and end of a striation was examined, hoping that it would throw some light on this question.

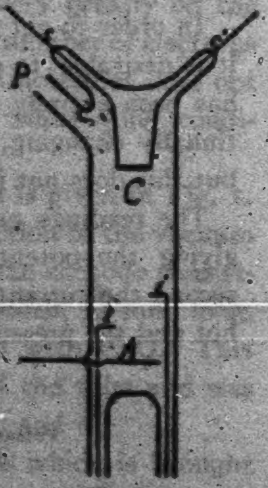


Fig. 2.

The tube was exchanged to the form shown in Fig. 2. Both *A* and *C* are here fixed; *e* and *e'* are two movable exploring electrodes which are connected to an electrometer. The vertical parts of these were covered with small glass tubes for a few centimeters near the top, so that only the horizontal ends would receive charges. These ends were platinum wires .5 mm. in diameter. They were placed as near as possible to the sides of the tube and did not appear to distort the striations. The main tube was 4.2 cm. in diameter. The distance between *A* and *C* was 8 cm. The length of a striation varied as the pressure of the gas was varied, but was in general in the neighborhood of 2.5 cm.

It was first of all observed that the potential difference which was being studied varied as the pressure of the gas was changed. This is shown in Table II. The first column gives the pressure of the air left in the tube, and the second the potential difference between the beginning of one striation and that of the next. The current was .02 ampere.

TABLE II.

Pressure of Gas in Millimeters.	Potential Difference in Volts.
.06	11
.08	12.9
.164	16
.38	21.5

It was also found that the striation potential difference depended on the amount of current flowing through the tube. This is shown in Table III., where the first column gives the current and the second the potential difference. The pressure in the gas was .06 mm. of mercury.

TABLE III.

Current in Amperes.	Potential Difference in Volts.
.00032	14
.00064	13.2
.01	12
.2	10

Since these experiments were performed an article has been published by Wehner,[1] giving the results of a full investigation of the striation potential difference when there was discharge from a cold cathode. His experiments on the change produced in this quantity when the pressure of the gas was changed were performed in hydrogen and the potential differences which he gives are lower than the ones given above, but they show the same kind of a change.

---

[1] Ann. d. Phys., 32, 49. 1910.

In general he also found the same kind of a change when the current was changed. The changes, however, were through a much smaller range than that given here and were accordingly less noticeable. The lowest value which he found for the potential difference was 8.56 volts.

At first sight Table III. appears to give some reason for believing that ionization may take place more easily where there is a chance for repeated impact. Certainly it is true that where there is the greatest number of electrons passing through a gas, there is the smallest striation potential difference, and it is probable that this quantity is closely related to the potential difference needed to produce ionization by impact, as is suggested by Wehner.

But a second thought will hardly encourage such a view. The current was six hundred times greater in the last case given in the table than in the first. Each molecule would be hit six hundred times in one case where it would be hit but once in the other, and yet the potential difference decreased but a few per cent. It is certainly highly improbable that such a small change would occur, if repeated impact causes the molecules to be more easily ionized.

Certainly it is possible to suggest some more probable explanation. For example, when the larger current is flowing, the temperature of the gas must be much above that of the room. A small percentage of the electrical energy dissipated in the tube would be sufficient to raise the temperature of the gas several hundred degrees in a few seconds and it is altogether probable that at high temperatures the gas is more easily ionized than at low ones.

However, we will not be ready to give any explanation of these facts until we know more about what the facts are. For example, the lowest voltage here recorded was 10 volts, but Thomson states[1] that he found the potential difference between one striation and the next to be as low as 2.7 volts under certain conditions. He does not state what these conditions are, and I have not been able to get such a value. But until the phenomena have been more thoroughly examined, it is not possible to state what the cause of the relation between the voltage and the current is, and certainly we cannot say that these phenomena uphold in any way the idea that ionization occurs more easily when there is repeated impact.

---

[1] Phil. Mag., 6, 18, 449, 1909.

Increase in Current not due Alone to Ionization in the Gas.—We have given reasons for believing that the change from the nonluminous to the luminous form of discharge is not due to ionization by repeated impact. We may go a step further and say that the change does not appear to be due alone to ionization of any kind in the gas. There is no question but that ionization by impact occurs, but there are reasons for believing that it is not the only cause producing the change.

There are two ways in which ionization in the gas can increase the current. It can increase the number of positive ions moving toward the cathode, or it can change the field near the cathode, so that all the electrons shall be drawn from it, instead of being driven back by the electrostatic repulsion of those which had previously been emitted.

That the great increase in the current cannot be accounted for by a movement of positive ions toward the cathode is shown by two lines of reasoning. The first is that the electrostatic effect on the positive ions would check any large increase in the current due to them alone.

The Electrostatic Effect Produced by Ions.—An electrostatic effect occurs whenever there are more ions of one kind than of the other in a given volume. This effect may become so large as to reverse the previous direction of the field and to limit very greatly the amount of current flowing. This is especially apt to occur when there are positive ions present, for their mass is much greater than that of the negative ions and their motion correspondingly slower.

The ratio of the mass of positive ions to their charge is approximately 20,000 times as great as the corresponding ratio for the negative ions.[1] As a result one positive ion going through a given space per second would neutralize the effect of 20,000 electrons. If there were more positive ions than this they would raise the potential of the region and tend to check their own movement. It is not possible to compute just how many positive ions it would take to raise the potential so as to check the current when the cathode is an irregular piece of foil, but we may get some idea of what is to be expected by considering the current density between parallel plates of infinite extent, when there are only positive ions present. The less the ions are stopped by collisions with molecules, the greater will be their velocity and the less the electrostatic effect produced by the movement through the field of a given number. In order to find the maximum current, we may assume that there are no collisions. I have not been able to find any computation applying to this case, and hence have given it in the following paragraphs.

---

[1] Thomson's Conduction of Electricity through Gases, 2d ed., p. 149.

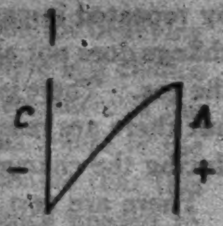


Fig. 3.

Let us assume that the plates A and C are of infinite extent, separated by a distance x_1. Let the potential of C be zero and that of A be V_1, and assume that there are at A an indefinitely large number of positive ions. The electric force will cause these to move toward C, producing a current.

Let I = the current flowing through a unit cross section,
n = the number of ions in a unit volume,
e = the charge in electrostatic units carried by each ion,
m = the mass of each ion,
V = the potential in electrostatic units at any point at a distance x from C,
v = the velocity of the ions at a distance x from C,
ρ = the density of the electricity at a distance x from C.

$I = nev$ = a constant, and the acceleration of the ions equals the charge times the electric force divided by the mass, or

$$\frac{dv}{dt} = -\frac{e}{m}\frac{dV}{dx}$$

If we multiply this equation by the equation, $vdt = dx$, and integrate, remembering that the velocity is zero when V is V_1, we have

$$\frac{1}{2}v^2 = \frac{e}{m}(V_1 - V) \qquad \text{or} \qquad v = \left\{\frac{2e}{m}(V_1 - V)\right\}^{\frac{1}{2}}.$$

But

$$\rho = ne = \frac{I}{v} = \frac{I}{\left\{\frac{2e}{m}(V_1 - V)\right\}^{\frac{1}{2}}},$$

and if we assume that there is no variation in potential in directions parallel to the plate we have

$$\frac{d^2V}{dx^2} = -4\pi\rho = -\frac{4\pi I}{\left\{\frac{2e}{m}(V_1 - V)\right\}^{\frac{1}{2}}} = -\frac{k}{(V_1 - V)^{\frac{1}{2}}}$$

where k is a constant equal to $4\pi I/\sqrt{2e/m}$.

Multiplying this by the equation

$$\frac{dV}{dx}dx = dV$$

and integrating, we have

$$\frac{1}{2}\left(\frac{dV}{dx}\right)^2 = 2k(V_1 - V)^{\frac{1}{2}} + C.$$

The constant, C, equals the value of $\frac{1}{2}(dV/dx)^2$ at A. As the space between A and C becomes more and more filled with positive ions, the value of dV/dx approaches zero, and for the largest current which it is possible to have it would equal zero. For such a current we have

$$\frac{dV}{dx} = 2\sqrt{k}(V_1 - V)^{\frac{1}{4}}.$$

Further integration gives us

$$V = V_1 - (V_1^{\frac{3}{4}} - \tfrac{3}{2}\sqrt{k}\,x)^{\frac{4}{3}},$$

since $V = 0$ when $x = 0$. The curve in Fig. 3 between A and C represents such a distribution of potential as this.

Since V_1 is the value of V when $x = x_1$, we have

$$\tfrac{3}{2}\sqrt{k}\,x_1 = V_1^{\frac{3}{4}}$$

$$I = \frac{1}{9\pi}\sqrt{\frac{2e}{m}}\,\frac{V_1^{\frac{3}{2}}}{x_1^2}.$$

In other words, this is the largest current which it is possible to have carried by positive ions with the given distance and the given potential difference between the plates.

The value of e/m for positive ions in electrostatic units is approximately 12×10^{11}.[1] If for example we take one third of an electrostatic unit (100 volts) for the potential difference between *A* and *C* and the distance 4 cm., the current would be 2.08×10^3 electrostatic units, or 7×10^{-7} ampere. This is the amount of current which could be carried if there were only positive ions, or the amount carried by the excess of positive ions. A certain amount might be carried by negative ions, a second small amount by the positive ions which would be needed to neutralize the electrostatic effect of these negative ions and the amount given above would be the greatest possible additional amount which the excess of positive ions could carry.

---

[1] Thomson's Conduction of Electricity through Gases, p. 149.

The potential difference and distance assumed are similar to those existing in the experiments which have been described. The shapes of the electrodes in the experiment were indeed quite different from those considered in the mathematical treatment. But when we remember that it was possible to have an increase of nearly an ampere per sq.cm. a few centimeters away from the cathode and of many times this density of current near the cathode, we can see how improbable it is that any such increase in the current was carried by positive ions coming from the gas.

But an even more convincing reason for believing that the increase in current is not produced by a movement of the positive ions toward the cathode is given by the appearance of the luminous discharge. With non-luminous discharge there were, of course, no streams of cathode rays which could be detected. With the luminous discharge there were very noticeable cathode rays, appearing as brilliant streamers extending from the cathode to the sides of the tube or down into the gas. That these were cathode rays was shown by the effect which a magnet had upon them and by the phosphorescence which they produced. One could hardly see these streamers without realizing that something had happened to increase enormously the number of electrons leaving the cathode.

Increase in Current not due to Change in Field.—While the increase in current cannot be due to the movement of positive ions, it is conceivable that it is due to a change in field produced by them. When there is no ionization of the gas, the electrons coming from the cathode may be so numerous as to reverse the direction of the field in part of the space and hold back other electrons which might be leaving the CaO. That this actually could occur is shown by the data given in Table IV. When there are also positive ions in the field, they may so neutralize the effect of the electrons, that all the electrons which escape from within the CaO will pass to the anode. In order to consider this possibility the potential between the electrodes was examined both with non-luminous and with luminous discharge.

Potential between the Electrodes.—The apparatus shown in Fig. 2 was used to measure the potential between the electrodes, and since only one exploring wire was needed, e' was removed.

There are given in Table IV. a series of readings of the potential between *A* and *C* taken when the cathode was a dull red and a non-luminous current of 1×10^{-8} ampere was passing through the tube. In Table V. there is given a similar set taken with a luminous current of .03 ampere. In both cases the pressure of the gas was .02 mm. This was so low that there were no striations nor anode glow between the electrodes. The potential difference between *A* and *C* was 90 volts, and the distance 8 cm. Column one gives the distance from *C* and column two the potential difference between *C* and the exploring electrode as measured by an electrometer.

TABLE IV.

Distance from Cathode in cm.	Pd between *C* and *e* in Volts.
.3	−1.
2.	0.
4.	3.2
6.	7.7
7.	14.3

TABLE V.

Distance from Cathode in cm.	Pd between *C* and *e* in Volts.
.3	71
2.	71
4.	69
6.	69
7.	66

The first value in Table IV. indicates that the potential of the gas near the cathode was slightly lower than that of the cathode itself. This is due to the tendency of the CaO to give out electrons faster than the field draws them away, in fact to emit them against a small electric field, as has been pointed out by Richardson.[1]

---

[1] Phil. Mag., 6, 16, 354, 1908.

In the second case the same kind of an effect occurs except that here the electric force is reversed not near the cathode but a few centimeters from it. This fact has been observed by Thomson.[1] The momentum of the ions is such that it carries them for some distance against the opposing field.

The potentials here given are much lower than those given by Westphal.[2] He was undoubtedly working with much higher temperatures than those existing in these experiments.

These results are plotted in Fig. 4, the first curve showing the potential when the discharge was non-luminous and the second when it was luminous. With the first one there is an excess of negative ions between the electrodes, with the second an excess of positive. In the first case there is little or no ionization in the gas, while in the second there is a large amount. This might at first lead one to think that the difference between these two forms of discharge was entirely due to the presence of the positive ions near the cathode and the resulting drop in potential at that point. For this would cause all of the electrons which might escape from within the CaO to pass through the tube, but further light is thrown on the matter by examining the potential between the electrodes when discharge is passing from clean platinum.

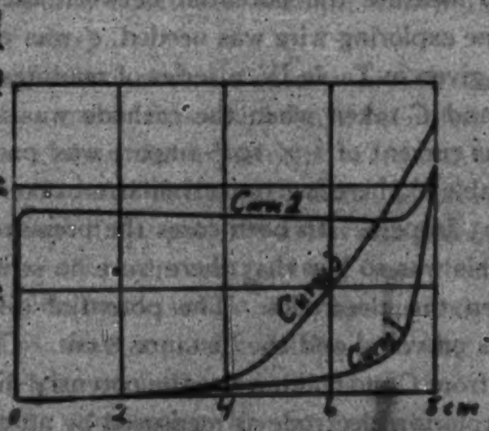


Fig. 4.

For this purpose clean platinum was substituted for that covered with CaO and observations were taken with the platinum heated to a bright red. The potential difference between the electrodes was 90 volts and the current through the tube was 5×10^{-7} ampere. The potential at different points was found to be approximately the same as those given in Table IV., when there was non-luminous discharge from CaO.

---

[1] Phil. Mag., 6, 18, 442, 1909.

[2] Deutsch. Phys. Gesell. Verh., 10, 11, 481, 1908, and Science Abs., 11, p. 510.

TABLE VI.

Distance from Cathode in cm.	Pd between C and a in Volts.
.3	−1.
2	− .4
4	4.5
6	42.
7	70.

These data are plotted in curve three, Fig. 4. There is here little change between this curve and that found with small currents as far as the space near the cathode is concerned, but a large change near the anode. There is apparently ionization of the gas near the anode, but not enough positive ions are produced to change the potential of all the space.

By raising the temperature of the platinum still higher a current of 4.8×10^{-4} ampere was passed through the tube. The potential in the neighborhood of the cathode was unchanged, while that in the neighborhood of the anode was still further raised. For example, the potential 6 cm. from the cathode became 68 instead of 42 volts.

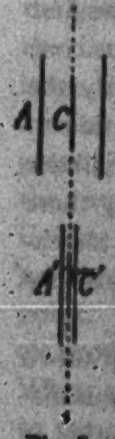


Fig. 5.

It is apparent that this form of discharge is not the same as either the non-luminous or the luminous form of discharge from CaO, since we have some ionization of the gas and yet there is no great change near the cathode. Apparently something besides ionization in the gas is needed in order to produce this change.

Some Ionization of the Gas Necessary.—While something besides ionization of the gas appears to be necessary in order to change from the non-luminous to the luminous discharge, it is also necessary that there should be this ionization, as is shown by the following experiment.

Two pieces of platinum wire, C and C' in Fig. 5, are surrounded by brass cylinders of different diameters and placed in a vacuum

450

tube. Both wires were .5 mm. in diameter, had the same length and were heated by the same current. They were coated with CaO and were made the cathode with the cylinders as anodes. The smaller cylinder was 4.85 mm. and the larger 23 mm. in diameter. Both were 4.5 cm. in length. The potential difference between the wires and the cylinders was in all cases 90 volts. There are given in the following table the currents to the cylinders with two different pressures of the gas.

TABLE VII.

Pressure of Gas in mm.	Current to Small Cylinder in Amperes.	Current to Small Cylinder in Amperes.
.35	.01	8×10^{-3}
.014	5.8×10^{-6}	1.6×10^{-3}

This shows that the current to the small cylinder decreased very much when the pressure of the gas was diminished below a certain amount, and that at the same time the current to the large cylinder increased. The number of electrons coming from within the CaO was no doubt the same for both wires, and the electric force was, of course, in both cases larger for the small cylinder. In the first case the discharge to the small cylinder was the larger, as one would expect, since the electric force was larger. Apparently the small discharge to the small cylinder in the second case is due to the fact that there were then so few molecules within the cylinder that there was less opportunity for impact and consequently there was little ionization. It would, therefore, appear that while ionization of the gas is not the only requirement, it is at least a necessary requirement.

The Correct Explanation.—It has already been stated that much smaller potential differences are adequate to produce luminous discharge from hot CaO than from any cold cathode, but this is practically the only difference between the two cases. In both the luminous discharge commences with great suddenness and in both there are streams of electrons shooting out from the cathode. It would, therefore, seem as if some modification of the explanation which Thomson has given for the ordinary discharge in a vacuum would come nearer the truth than that which was suggested.

His explanation for such discharge is briefly as follows: The current through the tube is carried by ions. The production of these is a two-fold action. Negative ions which have been driven off from the cathode hit the molecules of the gas and ionize them by their impact. The positive ions thus formed are drawn up to the cathode and ionize the molecules at the surface of the cathode by their impact on them. The negative ions thus formed repeat the process by ionizing more molecules of the gas. The electric force in the tube must be sufficient to produce ionization at both of these places, but since it requires a much higher potential difference to ionize by the impact of the positive ions, it comes about that the critical potential difference is reached when such ionization begins.

It is altogether probable that the same thing occurs in the case of discharge from hot CaO, the only difference being that the molecules on the surface of the hot CaO are more easily ionized than those on the cold cathode, and there are reasons for believing that this is true, as will be given shortly.

If we make this assumption the phenomena may be explained as follows: As soon as the electric force is great enough to ionize the gas, we have a slight increase in current, such as is shown with the discharge from clean platinum. This increase does not become large, unless the positive ions thus formed are able in turn to produce ions by impact on the surface of the CaO. When this occurs, the greater the number of positive ions formed in the gas, the greater the number bombarding the cathode with the corresponding further increase in the number of electrons sent off. There is thus produced the sudden change in current which occurs at the critical point. This change is limited by the rise in potential between the electrodes which is caused by the presence of the positive ions. When this increase becomes so large that the ions are not carried to the electrode as fast as formed, the current remains stationary.

This sudden increase is probably helped by the fact that the rise in potential in the tube causes the principal drop in potential to be near the cathode, instead of near the anode. The electrons coming from the cathode have a certain velocity when first emitted. A drop in potential in its immediate neighborhood increases this and produces a greater final velocity than if applied to electrons which might be starting from rest at some point in the gas.

There are the following reasons for believing that the molecules on the surface of the cathode are more easily ionized by impact of positive ions when the cathode is hot than when cold. Due to their high temperature they are already in unstable equilibrium, as is shown by their sending out electrons even when not being bombarded. One would in fact be surprised, if it did not require a smaller momentum in this case to produce ionization than when the molecules are at a low temperature.

Secondly it has been shown by Hittorf[1] and Cunningham[2] that heating the cathode causes the cathode drop to become smaller.

Furthermore I have found that the higher the temperature of the CaO the less the cathode drop in its neighborhood. The drop given in Table V. was 71 volts, but when the temperature of the CaO was raised, this decreased rapidly. When heated as much as practical without melting the platinum foil, the cathode drop was only 8 volts.

Increasing the current through the tube also decreased the cathode drop but only to a slight extent. Thus in one case the current was varied from .02 to .4 ampere by changing the voltage at the terminals of the tube, the heating current through the foil remaining constant, and the cathode drop varied from 30 to 21 volts. The same change could be made by a very slight increase in the current heating the foil, and it is altogether probable that this change was due to the increase in the temperature at the surface of the cathode caused by the increased bombardment of the cathode and not by repeated impact on the molecules of the CaO.

Production of Electrons by Bombardment of CaO with "Canal-strahlen."—In addition to this it was shown that electrons may very easily be produced when CaO is bombarded with positive ions in the form of "canal-strahlen." It has already been shown by Austin[3] that when such rays strike a metal plate electrons are produced, but it seemed well to investigate the phenomena which exist when they strike hot CaO under conditions somewhat similar to those which held in the preceding experiments.

---

[1] Wied. Ann., 21, 133, 1884.

[2] Phil. Mag., 6, 4, 684, 1902.

[3] Phys. Rev., 22, 312, 1906.

For this purpose the tube given in Fig. 6 was used. An opening was made in the side of the tube shown in Fig. 1, and a second tube, T', was sealed into this. This had a cathode, C', and an anode, A', the distance between them being 9 cm. The anode, A', was a metal disk filling the inside of the small tube and having an opening of 2 mm. in diameter in the center. A discharge could be sent through this tube by means of a Wimhurst machine or an induction coil at I and with proper pressure of the gas "canal-strahlen" would hit on the cathode, C. The anode A' was kept at the same potential as C by connecting it to the point b shown in Fig. 1.

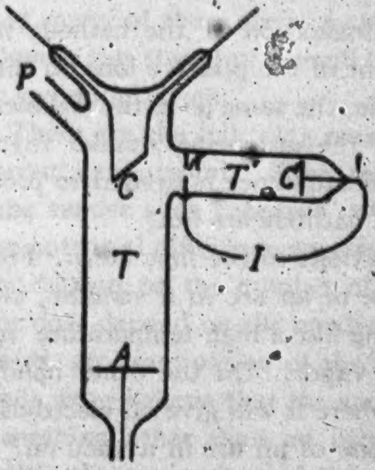


Fig. 6.

With this arrangement C was heated by passing a current through it as in the preceding experiments and a potential difference was established between A and C somewhat below that needed to cause the luminous discharge. If then a discharge was caused to pass from A' to C' so that the "canal-strahlen" hit upon C, luminous discharge would start up in T. With potential differences of about 70 volts this discharge would pass as long as C was being hit by these rays and would stop as soon as the rays would stop.

With larger voltages a continuous arc was often formed. With lower voltages the discharge between A and C was non-luminous but still considerably larger than what it was when there were no "canalstrahlen."

It was found that it was not even necessary to heat C. When C was at the room temperature, and the voltage was approximately 100 volts, the positive rays striking on C caused a luminous discharge between A and C to flash out for an instant. This luminous discharge showed striations the same as those usually produced by hot lime, and if the resistance in series with A was sufficiently small, the discharge became an arc.

Relation between this Work and the Theory of the Electric Arc.—

The work which has been described has an important bearing on the theory of the electric arc. There is no question but that the ionization at the cathode is the essential phenomenon of the arc, but there are two views concerning the cause of this ionization. According to Stark[1] and Thomson[2] the electrons are driven out of the cathode because of its high temperature in the same way as discharge is produced from hot platinum wire. The bombardment of the cathode by the positive ions heats it, but does not directly cause the ionization.

According to the other view the ionization at the cathode is produced directly by the bombardment of the positive ions on the molecules on the surface of the cathode, the same as in the Geissler tube discharge, the cathode drop in the arc being smaller than elsewhere, because a smaller potential difference is needed to produce ionization when the molecules of cathode are hot.

There are some rather serious objections to the first view. For example, mercury can be the cathode of an arc in a vacuum, although it cannot be raised to anything like a high temperature in a vacuum without changing it to a vapor. On the other hand, iron can easily be heated to a point where it will give off electrons, and yet it cannot be made the cathode of an arc in a vacuum.[3]

In addition to these arguments the work which is here described furnishes a further argument in favor of the second view. The arc is apparently the same form of discharge as that which we have been studying, for it has been shown[4] that it is possible to pass by gradual changes from the luminous discharge produced by hot CaO to that of the electric arc. The only essential difference between the two is that in the arc the current through the gas heats the cathode sufficiently to maintain the temperature of the cathode, while in the other form the temperature must be maintained by some outside source, and this difference has nothing to do with the manner in which the ions are produced.

We are, therefore, safe in saying that the weight of evidence is in favor of the view that the ionization at the cathode of the arc is not caused by the high temperature of the cathode, but by the impact of positive ions on the hot surface.

---

[1] Ann. d. Phys., 12, 673, 1903.

[2] Conduction of Electricity through Gases, 2d ed., p. 612.

[3] Phys. Rev., 20, 369, 1905.

[4] Phys. Rev., 29, 361, 1909.

Summary.—When the potential difference between the electrodes is increased the discharge in a vacuum from hot CaO passes through a critical condition, the current being very much greater after the critical point is passed and the discharge becoming luminous. It has been suggested by Sir. J. J. Thomson that this sudden change is caused by the molecules having been hit so often by the electrons that many of them are in a state of unstable equilibrium, and that when in this state but a small increase in the electric force is needed to cause ionization.

There are the following reasons for thinking that this is not the correct explanation. First, the scarcity of electrons present in the tube render such repeated collisions very improbable. Secondly, the potential difference necessary to cause this sudden change does not depend on the number of electrons passing through the tube but does depend on the condition and temperature of the cathode. Third, an examination of the potential gradient through the tube leads us to believe that the sudden increase in current is caused by something other than an increase in the ionization in the gas. Lastly the appearance of the discharge indicates very plainly that the number of electrons streaming from the cathode increases enormously when the discharge becomes luminous, becoming in fact very noticeable streams of cathode rays. On the other hand, some ionization of the gas appears to be necessary as is shown by the fact that, when the pressure of the gas is very low, the discharge from a wire coated with CaO to a small surrounding cylinder is much smaller than that to a large cylinder.

The phenomena may be explained by asssuming that ionizaton is produced at the cathode by the bombardment of its surface by positive ions and that such ionization occurs very much more easily with a very hot cathode than with one which is cold.

The potential difference between the beginning and end of a striation was found to increase as the pressure of the gas increased and to decrease slightly when the current was increased. It was in certain cases as low as 10 volts.

Because of the similarity between this form of discharge and the electric arc, it is reasonable to assume that the electrons at the cathode of the arc are also produced by bombardment of the cathode by the positive ions which come from the gas, and that they are not to any great extent emitted from within the cathode because of its high temperature. Such an explanation accounts for certain difficulties which may be raised against any other explanation.

Colgate University,
January, 1911.

DEFENDANT'S EXHIBIT No. 30

[TRANSLATION]

Atti Della Reale Accademia Dei Lincei—1912

Seric Quinta Rendiconti, Roma.

Clasje di scienze fisiche, matematiche e naturale. Vol. XXI. Pages 235 to 239

Note by Quirino Majorona

Presented by P. Blasarna.

Received by the Academy August 15, 1912

Received in library October 24, 1912.

ON ELECTROMAGNETIC WAVE INDICATORS BASED ON THE PRINCIPLE OF ELECTRONIC EMISSIONS FROM INCANDESCENT WIRES

[235]

A certain category of indicators of electromagnetic waves utilizes apparatus over which perturbations or electric waves produce passage of electricity dissymetrically with respect to the direction of the instantaneously generated electric charge. Thus, under the action of the waves, we finally obtain direct current for which it is much easier to construct very sensitive indicators. In this category, besides others well known, we have the indicators which untilize the passage of uni-directional electricity produced by incandescent filaments, for example, the Fleming valve and the audion of DeForest.

The scope of this note is particularly to study these last two indicators in order to be able, in the succeeding note, to consider a new type which, while also founded on the utilization of the same phenomenon, is characterized by the fact that the effect is independent of the nature of electric impulse (generated by the perturbation or by electric waves) and of the sign of the impulse itself. This new indicator has, in certain cases, sensitivity of action notably superior to that of the indicators heretofore known. It will briefly consider the history of the phenomena which have led to the realization of these types of indicators.

That the air becomes a conductor of electricity in the neighborhood of hot bodies was already known, and we owe to Becquerel to have demonstrated that, even at red heat, it dissipates the charges due even to a small fraction of a volt. Later on Guthrie was the first to begin to show that the phenomenon depended also on the direction of the current. We owe also to Elster and to Geitel (1882-1889) a systematic study which has thrown considerable light on the phenomenon in question. From this study, it results that a hot platinum wire throws off electric charges which, at ordinary pressures, are positive, and at lower pressures, negative. There is, therefore, a certain *pressure of inversion* which depends besides on the nature and the temperature of the wire, on the nature of the surrounding gas, and on the state of occlusion of the gas on the part of the wire itself. We can also speak of *temperature of inversion* since, with pressure constant and temperature increasing, the filament emits charges which pass gradually from the positive to the negative side.

The so-called *Edison phenomenon* is nothing but a particular case, even though sufficiently complex, of the [236] general phenomena which I am considering. It consists, as noted, in the passage of a continuous current through the rarified gas contained in an incandescent bulb, comprising besides the filament, a cold metallic plate. The latter is connected externally with the positive end of the filaments, and the current passes in the rarified gas from the plate to the filament. In consequence of the indicated disposition of the apparatus, the negative end of the filament presents, with respect to the plate, a negative charge which, disposing itself in part as a cause of the electronic emission, gives rise to the above mentioned current. J. J. Thomson, in his book on The Conduction of Electricity Through Gases, discusses many views of experimental and theoretical character on this subject, and from these views, there results, in the case of the dissipation of negative charges from the heated filament in the rarified gas, that it is actually a phenomenon of emission of particles, similar in all respects to that constituting cathode rays; in fact, the ratio between the charge and the mass of these particles or electrons is the same as that which we find in the above mentioned cathode rays.

The passage of electricity through a rarified gas, determined by the presence of a heated filament, is not characterized solely by the uni-directional quality of the phenomenon (emission of negative particles); it departs from the simple linear law. An e. m. f., gradually increased, gives rise to the passage of negative electricity from a filament to a plate enclosed in the same globe of rarified gas, in a manner more rapidly increasing than the law of Ohm would allow. The current thus generated becomes almost stationary for higher values of the e. m. f., if, as J. J. Thomson notes, the value of this e. m. f. be not capable by itself of producing ionization in the gas. There is, therefore, a certain *intensity of saturation* beyond which it is not possible, however, the acting e. m. f. be increased, to augment the current of negative electrons leaving the hot filament.

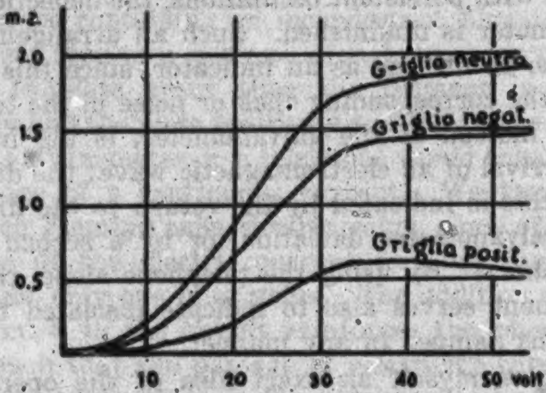
From this rapid review, we recognize how complex is the phenomenon of the electronic emission on the part of hot filaments. Many elements contribute to the variety of its manifestations, so much so that it is often difficult to foresee, even qualitatively, the results. In any case, the limitation of the study of the question to the case of rarified gases (or better still, extremely rarified) facilitates a great deal this study. For such reasons, and because in the case of the electronic emission in vacuum, the phenomena are more conspicuous, and having to draw from these practical applications, as those made in certain types of radio-telegraphic indicators, it is convenient to consider only those dispositions of apparatus elements which utilize the emission of electrons in a rarified gas.

The first researches made in this direction are those [237] of J. A. Fleming. Inserting in a circuit, forced to oscillate electrically with a frequency which may be high, a globe containing an incandescent filament and a plate, there results a passage of negative current from filament to plate every time the filament is charged negatively and the plate positively and not in the opposite case. A galvanometer or a telephone would thus indicate the passage of a continuous current. We thus obtain that which Fleming calls electric valve, since of the two directions of the electric current forming the electric oscillations, only one is of value. The addition of a constant e. m. f. in the circuit reinforces the phenomenon if it be such that the passage of electricity through the rarified gas takes place in the neighborhood of a sharp change in curvature in its characteristic curve.

DeForest, after Fleming, has tried to utilize the same phenomenon of the emission of negative electrons on the part of hot wires, obtaining apparatus (called *audions*) which are sometimes similar, at least in theory, to that of Fleming, but the form and the functioning of the last *audion* constructed by DeForest are very different from those of the *valve* of Fleming. (Rendiconti R. Accademia Dei Lincei, January 3, 1909). I had occasion, in a previous note, to express some ideas on the theory of the DeForest arrangement, even though DeForest himself has no explanation. I wish now to consider briefly such experiments which confirm my former mode of viewing the phenomenon.

The *audion*, in its latest design, is composed of a glass bulb with rarified air, containing three conducting bodies F, G, L; F is a metallic filament which becomes incandescent by means of a continuous current at low voltage (3 or 4 volts); G is a grid or metallic screen with rather large mesh; L is a metallic plate. Connecting F with L externally, and through an e. m. f. of about 30 volts, in such a manner that F be negative, electrons leave F and fall on L, after having traversed the grid G. This takes place regularly (and we can observe this fact by means of a galvanometer) since F and G have the same potential; if, on the other hand, F and G are connected to a circuit with persistent oscillations, the deflection of the galvanometer is diminished. Such an arrangement can, therefore, be utilized as an indicator, since this diminution, or the corresponding click or noise in the telephone, inserted instead of the galvanometer, is the indication of the arrival of an electromagnetic wave; the disappearance of this is indicated by the return to the first value of the galvanometer deviation, or by a second click in the telephone. By using the telephone alone, the above arrangement serves also to indicate insolated trains of oscillations damped in any manner.

To give myself an exact idea of the operation of the audion, I have constructed, as I will mention, different characteristic curves of the passage through such an apparatus of electricity transported by the electrons. [238] The audion made by me for such experiments has a tantalum filament 18 millimeters long, bent horseshoe shape, and traversed by a current of .5 ampere at a voltage 3.8 volts; thus the filament is brought to an almost white heat. The grid consists of parallel platinum wires of diameter .3 mm., distant 2 mm. from each other; the plate is square, 2 centimeters by 2 centimeters. The planes of the filament and the grid and of the plate are parallel, and the first distant from the second, and the second from the third about 4 mm. The grid G is in connection with one of the extremities of the filament; for example with the positive. Thus, its potential is not identical with that of all the points of the filament itself, since, as mentioned, the potential of the latter varies from zero to 3.8 volts. The results which I will now indicate refer to the connection made with the positive extremity; quantitatively, they would be as much different if they were made with the connection to the negative pole; but that would not have changed the general conclusion which I want to arrive at. The plate L is connected through a sensitive galvanometer to a regulable e. m. f. from zero to 50 volts with the same positive terminal of the filament F. The e. m. f. electrifies negatively the filament, and positively the plate, and



gives rise, therefore, to the passage of a current indicated by the galvanometer in consequence of the emission of negative electrons on the part of F. Varying the e. m. f. above mentioned, I began to construct the curve in the figure when the grid was in a neutral state. The curve is referred to two axes, one indicating the value of e. m. f. used and the other the deviation of the galvanometer. From such a curve, we see that the current of saturation is about two milli-aperes, with an e. m. f. minimum of about 30 volts. I construct two other curves obtained with the grid having a negative potential with respect to the positive terminal of the filament, and with a positive potential, respectively. The value of this potential is in each case 10 volts.

It is seen that the *negative* curve is depressed more than the neutral curve, and that the positive is still more depressed. Such depressions are a consequence of the electro-dynamic reaction between the grid and the elec-
[239] trons from the filament. If the grid is electrified positively, the electrons are in part directed by it, and reach in lesser number the plate; if negatively, they are still more impeded in trying to reach the plate, because they are repelled in part by the grid. In any case, the intensity of the current circulating in the galvanometer is diminished.

For these two curves also, the intensity of saturation, even though smaller, corresponds to an e. m. f.

minimum of about 30 volts, a value which is a little greater than that found by Fleming for his *valve*. This can be explained, in addition to considerations of other experiments, in the presence of the grid between the filament and the plate, which grid is entirely absent in the *valve*.

Examining the curve in the figure, we see that, for example, if we maintain a difference of potential constant to 30 volts between F and L (F negative), we obtain an intensity of 1.7 milli-amperes for the case of neutral grid, an intensity of 1.3 milli-amperes for the grid negative, and an intensity of 0.6 milli-amperes for the grid positive plate. Connecting between F and G and the alternating E. M. F., a maximum value of 10 volts, I found an intensity of 1.2 milli-amperes. Such a value represents a sort of mean value, depending either on the instantaneous values of the sinsusoidal e. m. f. or on the dissymetrical action of the charges positive and negative.

The electrification of the grid with respect to the filament produces, therefore, in any case, a diminution of the intensity of the current between the filament and plate; and this is true, even when such electrification comes from an alternating electromagnetic action of high frequency, as in the case of radio-telegraphy.

The above considerations, and the experimental results noted, give data for the explanation of the operation of the audion as a receiver in radio-telegraphy. It does not seem to me that we can speak of a true selection of waves, the negative from the positive, as Fleming would have it, and as in the *valve* of Fleming really takes place. In the audion, both charges, positive and negative, generated by the waves, act to depress the characteristic curve of the current of electrons falling on the positive plate, whereas in the valve, only the half-waves, which produce negative electrification of the filament, have effect.

Such explanation of the functioning of the *audion* leads us to the conclusion that the energy necessary to the formation of signals in a galvanometer or telephone is not, at least exclusively, a transformation of the energy in the radio-telegraphy wave. Rather we should consider that these signals are formed, in great part, at the expense of the energy furnished by the local battery. This fact is particularly interesting inasmuch as in certain cases, the energy taken from the battery can be superior to that received by the receiving antenna. It is very useful, therefore, following this general lead, to push recent researches enabling us in this manner to arrive at the construction of indicators of superior sensitivity to those heretofore known.

PLT-GX

DEFENDANT'S EXHIBIT No. 30-A.

[TRANSLATION]

Atti Della Reale Accademia Dei Lincei—1912
Serie Quinta Rendiconti, Roma.
Clasje di scienze fisiche, watamatiche e naturale,
Vol. XXI. Pages 274-277.

Note by Quirino Majorona.

Presented by P. Blasarna.

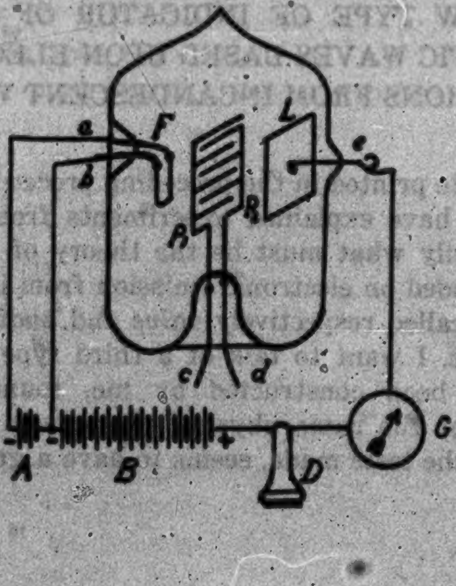
Received by the Academy August 15, 1912.
Received in library October 24, 1912.

ON A NEW TYPE OF INDICATOR OF ELECTROMAGNETIC WAVES BASED UPON ELECTRONIC EMISSIONS FROM INCANDESCENT WIRES.

[274]

In a note printed in the preceding proceedings of this academy, I have explained experiments from which we deduce readily what must be the theory of the two detectors founded on electronic emission from incandescent wires, and called respectively *valve* and *audion*. In this [275] note, I want to talk of a third type of detector which has been constructed by me, founded on the utilization of the same physical phenomena. This new type, from the tests made, seems to have a greater sensitivity than that of the audion, which heretofore was considered the most sensitive radio-telegraphic indicator. It can be called "Electronic Deviator", and is based on the concept of producing displacements of deflection of the electronic currents coming from an incandescent filament, and falling on a cold plate by means of electrifications, either positive or negative, produced by the arrival of the electromagnetic wave. To such displacements correspond diminutions in the local current, which give rise to the formation of signals, for example, in a telephone. In order that the arrangement, which I will describe, be of exquisite sensitivity, the displacements produced by this arrangement are *normal to the direction of the electronic emission.* It consists of the following:

The glass bulb of about 3 centimeters in diameter (see figure), and *in which the vacuum has been made*



as high as possible, contains four conducting elements; F is a filament, preferably metallic, which can be heated by means of a current from battery A, through the wires *a* and *b;* and *p1* and *p2* are two metallic combs contained in the same plane in which the wires alternate without touching. The combs communicate respectively with the wires *c* and *d;* L is a metallic plate, communicating with the wires *e*. The planes of the filament, of the combs, and of the plate are parallel, and distant, one from the other, a few millimeters. A battery B of about 30 volts electrifies negatively the filament and positively the plate L. In this circuit are comprised a galvanometer G and a telephone D. Under these conditions, if the filament is brought to an almost white heat, there circulates a continuous current which can be, depending on the form and dimensions of the apparatus, about half a milli-ampere. The negative electrons which from the [276] filament go to the plate, and to which is due such current, traverse the space between the combs *p1* and *p2* and in part are retained by the latter. The form, the distance from the filament to the plate, and the dimensions of the combs have been studied in such a manner that diminution of the electronic current, registered by the galvanometer, by the presence of the combs themselves, is about 10%. That such takes place, the potentials of the combs must be identical, and that they do not differ very much from the mean potential of the incandescent filament F. If, however, we create a difference of potential, even small, between *p1* and *p2*, the intensity of the current which is observed in the galvanometer diminishes immediately. This comes from the fact that a part of the negative electrons, being repelled by the negative comb and attracted by the positive comb, fall on the latter rather than on the plate L. The arrangement is so sensitive that about 10 volts is necessary to bring almost completely the current register in condition of repose by the galvanometer, to induce variations in the current corresponding to the noises in the telephone.

If now, instead of the static charges on the combs, we have alternating charges, the arrival of negative electrons on the plate varies the alternations of the charges themselves. The galvanometer, because of the inertia of its movements, finally registers a mean deviation inferior to that of maximum at repose; and the telephone, within the limits of its functionability, gives a tone if the frequency of the alternation is of acoustic character, and is silent if we have rapid electrical oscillations, persistent and constant; or registers with noise or sound the variations or the modulations of the oscillations themselves. Thus, the described arrangement can very usefully be used in radio-telegraphy or radio-telephony. For this purpose, it is merely necessary to connect the terminals *c* and *d* with two points in the receiving circuit between which there exists a difference of oscillating potential; for example, with the extremities of a condenser forming part of such a circuit.

The *deviator*, being sensitive to the differences of potential and not to the oscillating currents, must be applied in a place where such differences are greatest. It is, therefore, advantageous to construct an oscillating circuit resonating with the antenna, which latter is in resonance with the arriving waves, having great self-induction, and very little capacity. This circuit is connected directly with the *deviator*. Practically the capacity can also be suppressed, the capacity of the combs and that of the oscillating bobbin being sufficient to obtain a resonance, the oscillating bobbin in the case, possessing relatively very high self-induction.

As far as concerns the reliability of this apparatus, I can state that the *deviator* has given very good results. The only thing we must avoid is the excessive incandescence of the wire: for, if on the one hand it gives rise to a notable increase in the sensitivity of the apparatus, on the other hand, besides reducing the life of the apparatus itself, renders necessary continuous variations in the local battery e. m. f. in order to obtain the [277] maximum effective reception. Such variations result from two causes, on the one hand from the changing of the state of rarification of the bulb, depending upon the emission, or at times, the absorption of gas on the part of the incandescent filament; on the other hand that which is more grave, on the deposit of metallic oxides, coming from the volitization of the filament. This deposit forms gradually on the plate L and in time makes the surface nonconductive. This, I have been able to determine from plates taken from *deviators* that were of no further use. These deviators, whereas at first they used to work well with 20 to 25 volts, had to be used with more than 100 volts in order to give rise to sufficient passage of negative electricity from the filament to the plate. In this respect, it is preferred to adopt a carbon filament rather than tantalum metals which usually are used. Carbon gives rise to deposits which are always conductors, but has the inconvenience of requiring greater energy in comparison with metallic filaments for radiating the same quantity of negative electricity. From what I have explained, and keeping in mind what I said in the previous note, there results that, whereas the *valve* acts only onto the action of the negative waves, the *audion* is sensitive to both half-waves, but with preference to the negative; and the *deviator* is sensitive equally to the half-waves of both sides.

As to the practical results obtained, I can briefly give the following: A *deviator* records the signals received from an antenna 24 meters high of the Institute Superiore dei Delegrafi in Roma. It is capable of registering with great intensity those of the station of the R. Marina Italiano, which is nearer, and very well those of almost all the others, and from the ships in the surrounding waters of our peninsular. The Victoria Station in Sicily (distant 580 kilometers), when working in good conditions, gives signals to the *deviator* which can be heard even if the telephone is detached 5 centimeters from the ear. As mentioned at the beginning, the *deviator* can act with alternating charges of any frequency. It, therefore, besides being capable of use as *radio-telegraphic receiver*, can evidently act as a *telephone repeater*. It is only necessary for this purpose to use an induction coil, the secondary of which has a large number of turns, and to unite the extremities of such a secondary with the two combs of the *deviator*. The differences of oscillating potential with the acoustic frequency, and induced in the primary of the coil, create charges which give rise to pulsations of current traversing the circuit of the battery B, sufficient to reproduce very clearly the sounds or the voice transmitted in the telephone D. In order to be able to call the electronic *deviator* also by the term *telephonic relay*, we must have the energy received by the telephone D greater than the one admitted into the telephonic induction coil. This, in truth, does not seem to take place in the case of apparatus constructed by me with form and dimensions proper for the needs of radio-telegraphy; but I reserve, therefore, for a future date, the explanation of other experiments and instructions on this subject.

DEFENDANT'S EXHIBIT No. 31

[TRANSLATION]

From the Physical Institut (Director Prof. Dr. O. Wiener) and the surgical polyclinic Institut (Director Prof. Dr. H. Heineke) of the University of Leipzic.

An X-Ray Tube of an Optional and Instantaneously Attainable Degree of Hardness Independent of Vacuum

By Dr. J. E. Lilienfeld and Dr. W. J. Rosenthal.

(Addendum Table XVII.)

Part I.

DESCRIPTION OF THE X-RAY TUBE AND ITS PHYSICAL PROPERTIES.

By J. E. Lilienfeld.

1. *Fundamental Facts and Description.*

The illustrated tube differs from the usual X-ray tubes by the feature in the first place, that it is as far evacuated, the metal in it is as completely denuded of the occluded gases in it, as possible. It offers therefore a resistance to the passage of the current between the ordinary aluminum cathode and the anode which cannot be overcome by the voltage of an ordinary induction coil or rectifier. In the known tubes the conductivity required for the passage of the current is given by the greater or lesser gas density in the tube. In the new construction before us, however, this conductivity is independent of the density of the gases contained as residues in the tube and produced in any quantity through a particular process. This procedure is technically feasible through the fact, that between a sufficiently highly heated cathode of heavy fusible and hard-sublimating metal on the one hand, and an anode of the usual kind there can be produced a discharge in the vacuum with low tension. The incandescent cathode may be coated thereby with earthly potassium oxides according to Wehnelt.

I found that the required voltage for the production of a certain current strength from an incandescent cathode, which at first, diminishes, when the tube is evacuated, then again begins to increase, as the gas attenuation is carried, beyond a certain limit. This tension does not then increase with diminishing pressure, but remains stationary at a certain limit, i. e., if it reached this limit, and the tube is further freed of gas, the tension no longer changed with diminishing pressure. In the X-ray tube to be described, this tension is of a magnitude which is just exceeded by the usual tension of a city system. It may be seen from the actual connection given that accordingly a discharge between an incandescent cathode and an anode with a relatively low tension current a discharge may be produced even in the highest vacuum. At all events the tension drop in the path of discharge is so great because of the highly developed vacuum that the tube, for instance, cannot be used as a valve for the current source so that by sacrificing a small part of the energy of the desired phase, the balance of this energy is used up outside of the tube, with simultaneous cutting out of the opposite phase.

The incandescent cathode is marked 3 in the figure. Wires 3′ and 3″ conduct the current necessary for its heating. The energy consumption of this heating circuit corresponds to that of an incandescent lamp of medium intensity. 4 is the cylindrical anode. The discharge taking place between 3 and 4, supplied by the city network or another suitable current source, will hereinafter be called the primary discharge.

Now, I found—and this is the fundamental fact for the construction—that this primary discharge develops a conductivity in the interior of the tube in the highest vacuum, hence in a vacuum which no slides and cementations are used in order to insure stuffing up, and which is forced as far as possible by all available means. As we shall show further down, this is something that we may denote from the general standpoint as surprising considering the strict bipolar character of this phenomenon. All the more surprising when the bipolar character is maintained even then, when the conditions of the experiment are so chosen that the lighting up of the spectrum of the last gas residues are as good as entirely absent (cf. par. 8, a).

This is the conductivity which, as already indicated, takes the place in the new construction of the conductivity created by the gas filling in the usual tubes. It has a feature specially predestining it for this purpose: it arises and vanishes, increases and wanes instantaneously with the primary current. If therefore the negative pole of the magneto is applied to a cathode of the usual form 1, while the positive one is connected with 4, there will occur a high-tension discharge based on the conductivity produced by the primary current. The energy of the cathode rays of this discharge is caught up with anticathode 4 connected with 3, and partly transformed into X-rays on its mirror. The greater the primary current, the greater the conductivity, the smaller therefore, the tension required for the production of the current, the slower the cathode ray to be applied here, the softer the X-ray thus produced, and vice-versa. But as the conductivity instantaneously changes with the primary current, thus accordingly the resulting X-ray radiation becomes instantaneously softer with the increasing primary current, harder with diminishing current, between limits taken entirely at will. We are therefore practically in a position to give to the discharge instantaneously any degree of hardness we choose by simply displacing a contact on the resistance regulating the primary current.

Numerical data, as well as the description of the extreme by simple manipulation of the tube are contained in the second part of the work before us. We should emphasize more especially that these data are applicable for the case where the primary discharge is produced by a direct current. If an alternating current is used for this purpose, very divergent conditions arise, the details of which will be given below.

2. *Duration, Intensity, Distinctness.*

In this first part of the work, let us indicate at first the following from the technical standpoint.

(a) Pulverizations do not at all occur in the tube, and other injurious effects of the current at closing are also eliminated. As the density of the gas is also of no importance, thus the duration of the tube is mainly determined by the duration of the incandescent electrode 3. And this is a very long one; it may be figured in hundreds of hours of service and will be comparable in duration with the duration of an incandescent lamp according to its size.

(b) There are as yet no available data regarding the intensity of the radiation under equal charges in tubes of the ordinary make. Judging from all appearances, however, the anticathode heats up conspicuously little under considerable intensities of the X-rays. If we consider that, as a result of the extreme evacuation of the tube the calorification of the anticathode is restricted by the impinging negative ions, it may be expected that the saving in the rays is a very favorable one. For such negative ions, arising especially under great gas densities, hence in soft tubes, bombarded by the cathode to the anticathode, calorify and destroy only the mirror of the latter (similarly to the pulverization through impinging canal rays) without such energy contributing in the slightest possible degree to the increase of the X-rays. A proof of this may be had in the fact that, as is generally known, the mirror in extremely soft tubes becomes incandescent even under a relatively small charge and corrodes while these conditions are very much more favorable in the case of very highly exhausted tubes. In fact the differences are so marked, that they are from every indication of another order of magnitude than those which might be expected on the basis of a procentual output of X-ray energy in the case of speedy cathode rays.

(c) As the development of disturbing wall charges is prevented in the entire space through the good conductivity conditioned by the primary discharge, it is to be expected that the cathode rays are not electrostatically deflected from their normal course. But the constancy of their focus hangs together with the unruffled path of the cathode rays, hence also the distinctness of the image. In fact it will be recognized from the images discussed in the second part that the tube satisfies wide expectations in this connection.

3. General Considerations.

It is to be mentioned from the general physical standpoint:

(a) The construction here described owes its being to the considerable studies I have carried on in connection with discharges in extreme vacua. The latest report in this connection was published in vol. 43 of the Berichte der math.-physik. Klasse of the Kgl. Gesellschaft der Wissenschaften, Leipsic (1911, pp. 534-539). This publication brings a new construction for the fact that, in case the current density of the discharge in extreme vacua exceeds a perhaps very small minimum value, there is an equivalent number of positive charges to offset the negative electrons which serve for the current transportation. In fact the laws applicable to the conduction of electricity are independent of the magnitude of the vacuum, provided that a certain limiting value of gas density is not exceeded.

This is a result, which contracts the generally expected behavior of things according to popular ideas, as we have already passingly mentioned in par. 1, in connection with the absence of the spectral illumination of the last gas residues. For the positive charge is bound to the atom and the molecule in the shape of an ion. Now, if the matter is considerably removed from space by exclusing slides, cementations and mercury vapors and using the best available means for the production of the vacuum, it is to be expected that the number of positive charge carriers, hence also the spacial density of these charges is constantly becoming smaller. And it is to be foreseen that there will finally be obtained a vacuum in which the transportation of electricity is mediated solely by the negative electrons emanating from the incandescent cathode. In reality the opposite is the case, as a result of the above determination.

It was of value for the continuation of my experiments, to obtain a technical possibility for the production of cathode rays of optional speeds in high vacuum. I made an apparatus for this purpose which could be so easily handled that I could not refuse myself the use of these cathode rays for the production of X-rays. Thus arose the technically very thoroughly developed type of X-ray tube we have described.

(b) The considerations which led up to my construction, are based on the knowledge of the laws indicated in (a.). The high vacuum crossed by positive and negative charges in the current path is manifestly an electric conductor. And in fact a conductor, the excellence of which below a certain limiting value of gas density is given independently of the gas density, solely through the density of the electric current. It was therefore to be supposed that, in case a discharge is produced between two electrodes in the high vacuum created by this current, the tension required to drive a certain current strength through between these electrodes, this will be given by the density of the current conditioning the conductivity, which we have called the primary current. The experiment confirmed not this supposition alone; it could be observed beyond it, that between the secondary electrodes, as it appears, an independent discharge is used. Especially did the secondary cathode send out cathode rays which appeared to have emanated from its surface through the bombardment of the carriers of positive charges in an extreme high vacuum. This construction of the processes, which is at first given only according to the general appearance of the discharge, requires at this time a substantiating proof to be obtained from exhaustive experiments. But it is supported by the fact that experience showed the tube construction here illustrated as by far the most favorable, where the primary discharge takes place at the first possible distance from the secondary cathode; hence outside of the dark space surrounding this cathode, if I may transfer the current appelation for the ordinary independent gas discharges to the present deviating conditions.

(c) There may be wanting in the above discussion perhaps a comprehensive listing of the fundamental physical measurements required for the use of X-ray tubes. From the just indicated development, however, it will be deduced that the construction was originally designed, solely as a means of investigating a field of phenomena; that, furthermore, so far as we can forsee, there will be obtained from this coming investigation a more fundamental result for the understanding of the processes in the tube, than from an empirical combination of various experiments on an apparatus, in which relatively complicated processes take place which have not yet been sufficiently investigated according to the principle underlying them. And it will therefore be found justified if I bring before the public a technically useful tube with the hope to leave the systematic measurements, partly to engineering, partly, however, to my further investigations to be made in the near future.

The principle of the tube was laid before the Biological and Medical Society at Leipsic, on December

18, 1911, by X-ray photographs of the hand and the chest. The present publication is the first in print.

Leipzic, Physikalisches Institut der Universitaet.
January 1912.

Part II

Practical Application of the X-Ray Tube

By DR. W. J. ROSENTHAL.

Assistant on the Surgical-Polyclinic Institute of the Leipzic University.

The chief shortcoming of all hitherto constructed X-ray tubes is that its degree of hardness depend on its gas contents. The result of this is, in the first place, that a new tube quickly becomes soft under the influence of the heating. For its glass walls and its electrodes will give off some gas, which they contain in the "latent" state.

As the tube is longer in service, the gas contents of the tube are more and more used up. Careful manipulation and some kind of regeneration devices might perhaps retard this shortcoming. At length, however, every tube becomes so hard after new exhaustion, that it is no longer to be used. There is as yet no X-ray tube, the degree of hardness of which may be varied as long as desired or which can be kept constant at will.

A further disadvantage of the prior-art tube is for one the metal pulverization in its interior, whereby the hardening of the tube is accelerated, on the other hand, however, the calorification of the anticathode, occasioned by long exposure and stronger charging, which endangers the tube.

Now, as shown by his previous exposition, Dr. Lilienfeld has constructed an X-ray tube, which has the advantage, that it possesses a degree of hardness that may be varied as quickly as desired. This variable degree of hardness of the tube is independent of its vacuum.

He has rather succeeded to regulate the discharge tension between the cathode and the anode in the tube by means of an independent primary discharge circuit, and thus to change at will the degree of hardness.

As proof that the very greatly exhausted tube without the conductivity current is not permeable for the high tension currents was the experiment of producing discharges in the tube with fully switched Grissen-transformer. The tube did not function here at all, while the discharge, e. g. indicated the presence of tension quite distinctly in a Guodelach-valve tube or in the parallel spark gap.

I will give a short report of the practical experiments which were performed with the new tube.

The application of the tube is very simple. Before every X-ray picture or photograph the heating current of the incandescent cathode and at the same time the primary discharge current, which makes possible the discharge between the cathode and anticathode, regulating same, is switched on by means of a cock. (The description of the small additional electrotechnic appliance, which is required for operating the tube with a set of instruments that may chance to be available, will be given, and also the most convenient method of operation established on the basis of a considerable amount of practical experience). Both currents may be left in service as long as desired, without any injury to the tube. The photographic plate in the usual individual service is not in any way attacked by the light of this source which emits only ordinary light rays.

The heat current remains constant. It corresponds to the one in a medium-strong incandescent lamp, according to the number of watts used up.

The primary current sent through the tube, which varies the hardness of the tube as desired during the photography, is changed by 50 to 180 milliamperes. If the current in the primary discharge circuit is raised above 180 milliamperes, the tube sends out such soft rays that they are of no use for photography. With soft arrangement, that is about 150 milliamperes, the outlines of the dark phalanges may at once be recognized on the X-rayed hand.

If we reduce the conductivity current to 100-80 milliamperes the tube becomes harder. The bones in the outstretched hand appear more distinct, and take on the typical light grey color by further diminution of the primary current to 50 milliamperes, as given by hard tubes on the barium-platinum cyanide screen. In X-raying the thorax, the various ray hardnesses can be recognized characteristically on the more or less clear appearance of the mediastinal organ against the bony chest. The degree of hardness of the tube used in the X-ray photographs varies between 5-12 wehnelt, measured with the Wehnelt cryptometer.

The heat developed in the anticathode is a comparatively small one even after a longer exposure (30 minutes without interruption with the fully switched Grisson transformer). A strong copper rod, conductively connected with the cathode may then be touched with the hand without any danger. The calorification of the glass as compared with the anticathode is naturally smaller than with the usual tube for every possibility is eliminated that the current at closing should produce an injurious and metal destroying effect.

Of the X-ray photographs, which were taken after previous regulation of the tube to a certain degree of hardness, I will reproduce two sets of three photographs each. (Compare the pictures.) I may mention that all photographs were taken without strengthening screen (folium). Besides the three degrees of hardness reproduced there exist naturally transmissions, as well as extremely hard, super-illuminated plates.

Group 1.

Three hand photographs, which were taken in immediate succession, after previous regulation of the hardness of the rays (extremely soft to hard) under the same exposure period. Pictures 1-3.

Object	Illumination Period	Distance of Tubes	Degree of Hardness Wehnelt Scale	Strength of Conductivity Current
Normal left hand of an 18 year old				
Right hand of the same man - - - -				
Fract. metacarp. III and V - - - - -				
The same object as 2				

ad. 1. The dark phalanges may just be distinguished from the soft parts, while the middle hand bones do not at all rise into view from their surroundings. There is no bone detail sketch.

ad. 2. On the end phalanges the structure of the bone becomes already somewhat prominent. At any rate, the bones are clearly distinguished from the soft parts, but all details are missing.

ad. 3. Distinct demarkation of the bony structure. About the phalanges the soft parts in lighter tones. The prominent fracture lines are noticeable. (Fract. metacarpi III and V.)

Series 2.

Three hand drawings, which were also taken in immediate succession after previous regulation of the radiation hardness (hard to extremely soft): Photographs 4-6.

Object	Illumination Period	Distance of Tubes	Degree of Hardness Wehnelt Scale	Strength of Conductivity Current
Normal left hand of a 30 year old man				
Ditto				
Ditto				

ad. 4. Very prominent bony structure of a normal hand. Great variation in the tones and ample details.

ad. 5. The same hand. Details are yet hardly noticeable on the dark colored bones. The soft parts also in dark color tones.

ad. 6. The same hand. The phalanges shown as deep black shadows. In the middle hand almost no differentiation of the bones from the soft parts.

As shown from the picture, it is possible to make X-ray pictures of full distinctness with the tube in any rapid succession by simply changing the conductivity current, and also such in which the bone just appears differentiated from the soft parts. And in fact the tube passes through the degree of hardness from extreme softness to extreme hardness with the same speed, as vice-versa. But it may also be kept at a given degree of hardness for any length of time unchanged. The main condition therefore at the hardness of the rays is solely the strength of the conductivity current, which may be changed or kept constant at will, and not by the minimal gas quantity which is still present in it.

In order to prove that photographs of heavier objects may also be made with the tube, I desire to reproduce also a shoulder and thorax photographs (Photograph 7 and 8), which are made with another tube specimen.

Object	Illumination Period	Distance of Tubes	Degree of Hardness Wehnelt Scale	Strength of Conductivity Current
Normal left shoulder of a 15 year old boy - - - -				
Normal thorax of the same individual - - -				

No. 7 gives a very prominent picture of the normal shoulder, while 8 reproduces the thorax full of contrasts. The fact that the thorax plate shows easily vanishing outlines of the ribs is explicable by the comparative duration of the illumination (40). But this does not depend on the tube, which certainly supports charges of short duration, but on our instruments. Photographs and readings were taken at first with a combined improvised apparatus in the Leipzic Physical Institut. The Grissonator, which delivered the tension did not permit itself to be switched on suddenly with a full charge, as it is necessary for short readings of thicker objects, for the fuses burnt out. We had therefore to leave the half of the series resistance in the primary current, circuit, and to illuminate for a correspondingly longer time. At this time the accessory instruments (cf. footnote p. 260), which may be obtained at a small cost, is connected in the proper manner with the X-ray apparatus of the Chir. Universitaets-Poliklinik, that we shall soon be in a position to report about readings with short illumination with the new tube.

One more thing may be mentioned about X-ray readings at longer periods. As we are able to pass through the entire gamut of hardness during the reading, even when it last a short time, it may be imagined that we obtain with them pictures rich in contrasts, by superposition, as it were, of a hard and soft reading from the same focus.

On the other hand, again, there may be precisely arranged before the reading on the fluorescense screen the degree of ray-hardness required for the exact object, hence as it were the Roentgenographic optimum. One may be sure that the respective readings occur by means of rays of the required hardness.

As to the application of the tube for therapeutical purposes, I believe I can assume that it is very greatly useful for this purpose.

Firstly because of the great duration, which in practice is limited only by the destruction of the metal of its incandescent cathode. Secondly, because it may be kept constant at every desired degree of hardness, as already stated.

The same tube will therefore allow the production with rapidity of the hardness required for irradiations, which tube is also to be used for readings, thus obtaining the desired depth effect. Likewise, when specially soft, biochemically strongly effective rays are used, for the treatment of irradiation of superficial, malignant tumors, the tube can be held at the same softness for the period of all irradiations.

The advantages, which the new X-ray tube has in comparison with those hitherto used, are therefore to be summarized as follows:

1. The tube receives a degree of hardness independent of its vacuum.

2. This degree of hardness may be changed at will and as rapidly as possible with the aid of a primary current circuit.

3. In this way, the tube may be regulated for any desired degree of ray hardness before every X-ray read-

ing. Likewise the most various degrees of hardness may be applied in the same radioscopy.

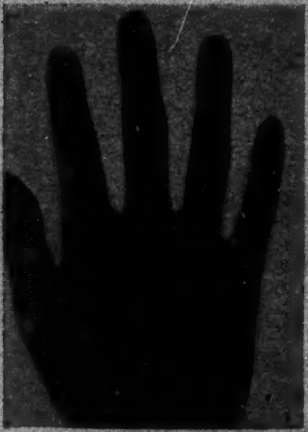
4. The durability of the tube seems to be especially good, even under longer exposure and higher load. Its duration will be as far as we can forsee, the same as that of a metal filament lamp.

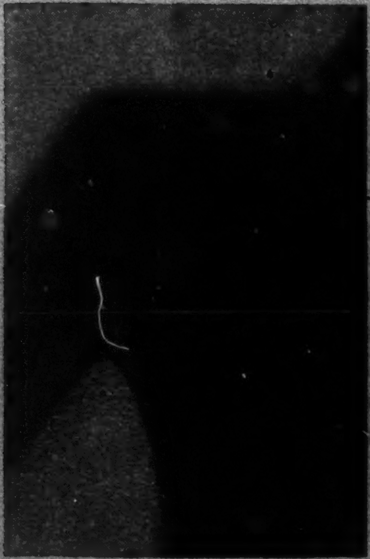
5. The heating of the anticathode as well as that of the glass-wall is a comparatively slight one.

6. The metal pulverizations do not seem to take place in the interior of the tube.

We will report further on the practical application of the new tube.

Defendant's Exhibit No. 31





DEFENDANT'S EXHIBIT No. 32

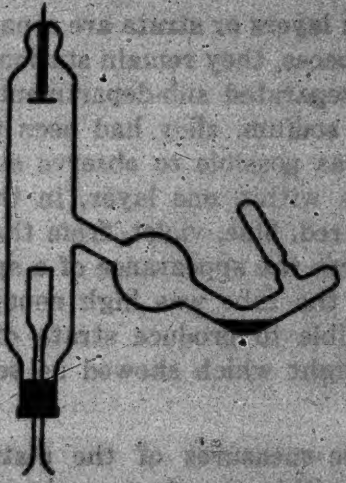
[TRANSLATION]
Physikalische Zeitschrift,
Vol. XIII, 1912, pp. 594-595.

ABOUT THE DISTRIBUTION OF LIGHT DURING THE STRATIFIED DISCHARGE IN VAPORS OF ALKALI METALS

By JACOB KUNZ and JAKOB G. KEMP.

While studying the photoelectric properties of the alkali metals, it has been observed that a plainly noticeable separation of the colors of the light during the stratified discharge occurred in the electric discharge produced by the vapors of these metals. It could be noted that towards the cathode a blue light was produced and that towards the anode, however, a reddish and violet light of potassium vapors was noted. According to the radiation theory of Planck, one should have expected that nearer the cathode that light would occur in which the light quantities have the least value, thus red and yellow light. In fact, the energy quantity, which is produced by a radiating resonator, increases in proportion with the frequency and, on the other hand, the kinetic energy of the electrons leaving the cathode ought to increase depending upon the distance from the cathode. If now the energy of the ionizing and light producing electrons increases, it should be expected that the values of the emitted light quantities increase according to the various distances from the cathode. This, however, is not always necessarily the case, as, according to investigations made by J. J. Thomson, the field direction in the stratified discharge may be reversed. It is therefore, only possible to decide by way of quantitative measurements whether there is a contradiction as to the radiation theory of Planck. Some quantitative experiments have been made which were supposed to determine the conditions of the separation of the light rays in the radiating strata.

The tube to be employed had the shape as per accompanied figure. A Wehnelt calcium oxide electrode has been used as cathode, while a small aluminum disk constituted the anode. The distance between the two electrodes was about 12 cm., the diameter of the tube amounted to 2,3 cm. Potassium and sodium was placed and vaporized in the lateral extending portion of the tube. A complete vacuum was produced so that Roentgen rays were created, without heating the Wehnelt cathode. As soon, however, as the calcium oxide electrode had been sufficiently heated, then there appeared the blue rays of electrons which spread from the cathode to the anode, however, without producing any other light.



It seemed to be difficult, even impossible, to produce a stratified discharge when using potassium exclusively. However, as soon as a small quantity of hydrocarbon gas had been introduced, and the tube was slightly heated, the separation of the various kinds of lights could be plainly noticed. The lower part of the strata appeared well blue, and separated from the next violet layer by mathematically determined margins. The hydrocarbon gas was plainly obsorbed by the alkali metals.

The direct current potential difference between the electrodes amounted to 450 volt maximum, the current increased sometimes to 0.02 amp. It is mostly necessary to start the discharge by means of an induction apparatus.

The various layers or strata are separated from each other by dark spaces, they remain stationary, and consist of thoroughly separated sub-departments. In case the fluid potassium sodium, alloy had been used, instead of potassium, it was possible to observe even four plainly separated strips within one layer, in the following sequence; yellow, red, blue, violet, from the cathode to the anode; it produces the appearance of a spectrum. If the temperature of the tube was high enough, then it was sometimes possible to produce strata of almost purely yellow sodium light which showed no separation of the colors.

Quantitative measures of the distribution of the electric energy within the strata or layers, accompanied by a spectroscopic test, and of the influence of helium and hydrogen gas will render new lights about the ample and beautiful phenomena.

DEFENDANT'S EXHIBIT No. 33.

A paper presented at the 29th Annual Convention of the American Institute of Electrical Engineers, Boston, Mass., June 25, 1912.

Copyright, 1912, By A. I. E. E.

VACUA

BY W. R. WHITNEY

The purpose of this article is to publish a few observations made in the research laboratory on some phenomena in vacua, as they may possibly be of interest to others who are working in the field of evacuated apparatus.

The subject has a double interest because at first glance it seems difficult to see how there can be much ground for study, or material and phenomena for useful investigation, in such an apparently confined volume of nothingness as the vacuum of an incandescent lamp. The many actual developments from this lack of material are interesting, and there is the added interest due to the fact that there are to be found in these lamps examples of many of the phenomena of gaseous ions which are receiving so much study in our day.

It has long been known that the life of an incandescent lamp is greatly influenced by the quality of its vacuum. In general, one may say that the better the vacuum, at least up to a certain point and until recently, the longer the life of the lamp. In the early days of lamp making, many schemes were devised to improve the vacua. This was then all the more necessary, as the mechanical methods of lamp-exhausting were very much inferior to present ones. The harmful effects of oxygen and water vapor, both of which reacted upon the filaments, were well known and many ways were devised for removing them.

What seems to be an especially interesting method of supplementing the vacuum pumps was the method of Malignani. This process, in its most perfect form, consisted in distilling into the bulb a small amount of some such substance as arsenic, sulphur, iodine, or phosphorus. At the instant when one of these vapors was introduced, he passed a high current through the filament, the lamp being closed from the pump. This has long been the common commercial process for lamps which are to operate on voltages above 50, and many millions of lamps have been exhausted by its aid.

In case of incandescent lamps where the voltage is above 50 for a fair brilliancy of filament, a blue discharge passes through the bulb and this blue quickly disappears when such vapors are introduced. The blue discharge seemed to be necessary for any considerable improvement of the vacuum, due to such vapors as phosphorus, and this led to the assumption that the gases still left in the lamp by the pump were removed quickly during the blue glow and probably by the vapors which were at the same time being deposited on the glass. Although the facts were pretty well known, we performed experiments to study the phenomena. It was found that when the vacuum was measured by a McLeod gage, the sudden marked improvement of vacuum was easily proven. For example, in experiments carried on by Mr. Willey, of the laboratory, when the pump had produced a vacuum of 0.030 mm. mercury and the cock leading to it was closed, a trace of phosphorus was distilled into the bulb while the filament was very hot and a blue glow had appeared; then about as quickly as the gage could be read the pressure had fallen to 0.002 or 0.001 mm.

That this improvement of vacuum is quite commonly produced when vapors of any kind are caused to condense in the space is not new. It even takes place markedly when the filament is first heated to very high temperature without added vapor, and a *blue glow* also passes through the lamp at the time. In improving the vacuum this latter way, however, it is known that the filament is injured and apparently a part of its material has been vaporized. This process soon causes blackening of the bulb by carbon.

This vaporization of phosphorus into the lamp at the moment when the pump has done its work, has long been the commercial method of finishing the exhaustion of incandescent lamps. The fact that even the carbon alone tended to the same end, though at the expense of the filament, being recognized, it became of interest to get a clearer view of this phenomenon.

In other words, if an incandescent lamp was burned while connected to a McLeod gage and the vacuum became poorer, the changes of vacuum might be measured by the gage from timto time. If, on the other hand, the vacuum improved so that the pressure tended to become less than the vapor pressure of mercury at the temperature of the gage, then the gage would not only not measure it, but the mercury vapor might even have affected the life of the lamp. When experiments were made to determine the effect of the vapor of mercury at the low pressures corresponding to a micron, which is the vapor pressure of mercury at 15 deg. cent., very peculiar results were obtained and the lamps showed very early blackening. It looked as though even the presence of this constant mercury pressure was fatal to the lamp. Therefore the discovery of a more practical vacuum gage was desirable.

Without committing ourselves to a theory, we can describe one or two interesting experiments with mercury vapor. It was first discovered that an incandescent lamp grew black very quickly when attached to a mercury column which served as a gage to indicate evolution of gas. No such combination could be made to last over a few hours. The lamp blackened just as though it was in an imperfect vacuum. It is hard to see how the mercury can have any chemical effect upon the filament as oxygen or water have, and the effect is common to carbon and tungsten lamps. Many lamps were then made which were exhausted as perfect lamps are exhausted, except that a small quantity of mercury was left in the bulb. It was assumed that this would not interfere with the removal of air and moisture and might even assist by the washing effect of the mercury vapor, mechanically removing air. Lamps were also made in which a large quantity of mercury was placed, the lamp put into an oven above the boiling point of mercury and the air washed out by the distilling mercury, no pump being used. When the mercury was nearly all removed the bulb was sealed. This method, if no visible mercury is left in the bulb, is capable of giving good lamps, but where a visible drop of mercury was present the lamp would show a persistent blue glow and rapidly blacken, even below its normal voltage. In some cases it would arc between the leads, exactly as in the case of poorly exhausted lamps.

Lamps were also made to which were attached tubes which carried small globules of mercury. When these side tubes were short and straight, such as one or two inches, and the lamp was exhausted as well as possible on the pump, the blackening of the bulb started at once when the entire glass was at ordinary temperature. If the side tube with its mercury was then submerged in different cooling mixtures, the length of time for a given blackening was increased. For example, at room temperature the lamp would be blackened so as to correspond to 80 per cent of its original candlepower, in a few minutes. When the side tube containing the mercury was at 0 deg. cent. this time became two or three hours; and when cooled in a freezing mixture at 20 deg. cent. the life to 80 per cent was over 75 hours. Such differences were also noted when the pressure of mercury vapor was controlled by using different cadmium amalgams, the amalgams higher in mercury corresponding to the shorter lamp life.

It was interesting to note also that by lengthening the side tube containing the mercury, the rate of this deposition of filament material in the bulb was decreased.

In a set of experiments at ordinary temperatures the length of the side tube was increased and it was wound as a spiral. This reduced the rate at which the mercury could reach the bulb proper. In this case, instead of there being a continuous faint blue glow, as there is when the mercury is in a short side tube, the blue glow appeared and disappeared continuously and regularly. It looked as though there was a certain pressure of the vapor necessary before the blue discharge could occur and that when this was reached, the sudden discharge produced the blue and cleared the vacuum to a much lower pressure. Then mercury vapor distilled anew from the long side tube until again the necessary pressure was reached, when the process of clean-up repeated itself.

If the lamp bulb was kept very hot, the blackening was reduced and even done away with altogether, as though the deposition of the mercury vapor upon the glass by the discharge signalized by the blue glow, could not take place. If, however, water vapor was present, even in very small amount, the blackening would take place very rapidly, even in the absence of mercury. In other words, most ordinarily exhausted lamps will blacken relatively quickly if allowed to burn in a heated oven. In general, the hotter the oven the more rapid the blackening, but this process is largely, if not entirely, due to imperfect exhaustion. All glass contains water which can be removed but slowly, even at relatively high temperatures. It has even been found that indefinite heating of a lamp connected to the vacuum pump is not capable of removal of all of this water. If exhaustion be carried on for a very long time at room temperature, then merely raising the temperature will cause liberation of more gas, and after heating and exhausting to an equilibrium condition at say 200 deg. cent. more water will be produced on heating to 300 deg. cent. and still more at 400 deg. For this reason it is customary to exhaust at as high a temperature as possible. At 400 deg. cent. the ordinary glass has reached its limit, owing to the proximity of the softening point. For this reason we have had to exhaust the oven in which the lamps were being exhausted, and thus remove the atmospheric pressure, in order to study the water evolution at higher temperatures.

For a long time it was impossible to follow the change of vacuum in a lamp, because the pressure could very evidently not be reduced below the vapor pressure of the mercury of the McLeod gage attached to the lamp. It has long been known, also, that the current passed through the space of the bulb to a considerable extent, and that this varied with the degree of vacuum, etc. A very complete discussion and description of experiments on this so-called Edison effect are given by Professor Fleming, in Vol. 42 of the *Philosophical Magazine*. In general, the conclusions are that in the vacuum of an incandescent lamp a current can flow across the space from the negative and of the filament to any conductor in the bulb, if this be so located that particles passing in straight line from the negative leg may come into contact with this conductor. This latter was usually a small platinum plate, and to it, as anode, a continuous current flowed from the negative half, or end of the filament, except when it was intermittently shielded from direct emanations. The current, often of several milliamperes, was measured by a galvanometer connected between the metal plate and the positive terminal of the lamp. It is known that the materials of the filaments distill in straight lines and cast well-defined shadows, because the mean free path at this pressure is greater than the diameter of the bulb, and it was natural to assume that this vaporizing carbon carried electric charges of negative sign. This assumption might seem to require the more rapid wasting away of the negative half of the filament than the positive, but no data are present to prove this. When condenser charges were superposed on this apparatus it was found that with the negative end connected with the negative side of the condenser, the condenser was at once discharged. When connected oppositely, it was not discharged. Current could pass as negative from the hot conductor or filament, but not from the cold plate, nor could positive current pass from either the hot or cold terminal.

In connection with this work of Fleming's, we have studied the effect of the condition of vacuum on the current, and also found that the presence of gas is necessary for this negative discharge. In general, the higher the pressure of the gas, when this does not exceed a few thousandths of a millimeter of mercury, the greater is the current. This makes it seem improbable that the current is solely dependent on the passage of carbon or tungsten from the filament to the positive electrode, though it leaves the possibility open that the current may be carried by gaseous ions produced by negatively charged material coming from the negatively charged filament.

By using alternating current and a metal electrode in a carbon lamp, Fleming obtained direct current on the circuit connecting the metal plate to either terminal of the lamp and the current was in the direction expected, the plate being negative to the terminal.

This outfit is thus obviously a rectifier, and it has been so used by Fleming for low currents.

The effect of a magnetic field on this gaseous conduction, just as in the case of metallic bismuth, is to increase the resistance.

It was finally found that the Crookes radiometer was a very sensitive gage for the changes of pressure in lamps, and by its use the changes could be followed in a qualitative manner, even throughout the life of the lamp, by having the radiometer sealed directly to the lamp. Dewar has shown the sensitiveness of this apparatus in the *Proc. Roy. Soc.*, 1907, 531.

The radiometer consists of a glass bulb containing a perpendicular needle with a glass cap on which are four aluminum arms with a mica vane at the end of each.[1] One face of each mica vane is coated with lamp-black. When the radiometer is evacuated to a high degree, the effect of radiant energy or light is to cause rotation, which is believed to be due to the fact that the molecules of gas take up energy from the blackened surface of the vanes more than from the plain surfaces, the black absorbing more of the incident energy and thus locally heating the gas molecules. These in the rarefied atmosphere largely give off this energy to the walls of the apparatus by direct impact, rather than to other molecules in the neighborhood of the vane. This results in a motion of the vane opposite to the motion of the gas molecules, because the unblackened face of the vane receives impact mostly from these cooler molecules.

The vacuum of the lamp as sealed from the pump approximates a few microns and is poor enough so that the radiometer rotates rapidly when exposed to light. By using a fairly constant light intensity and noting its effect upon a radiometer attached to a lamp which was lighted for intervals, it was seen that the radiometer gradually rotated more and more slowly, and finally after a period of normal lamp brilliancy of from 12 to 36 hours on tungsten lamps, it would stop rotating altogether. At this point it was found that a more sensitive measure of still higher vacua could be gained by starting in the dark, by mechanical motion a rotation of the vanes of a definite speed, and noting the rate of speed decay on standing. This was done by proper spinning of the whole apparatus in the hand and then getting the rate of decrease in this rotation of the vanes by counting definite revolutions after definite time intervals. Here the friction of the residual gases was merely overcoming the momentum imparted mechanically to the vanes at start. In this way, even by comparing the minutes required for the radiometer to come to a stop, quite interesting information was obtained.

This method was not developed into a quantitative one though it might have been. The radiometer method shows us, however, some interesting facts which are worth describing. Using the common type of radiometer often seen in jewelers' windows and sealing this directly to a lamp made for 110-volt circuit, the radiometer would rotate when in daylight. This showed the presence of some gas in the lamp, and the McLeod gage used at the time of sealing the lamp from the pump showed approximately 2 microns. If, now, the radiometer and the lamp were removed to a dark room and a rotating motion imparted to the vanes, they would proceed to rotate for about a minute, this time depending somewhat on the particular radiometer used, as well as on the condition of the vacuum.

Since at the moment when the filament was at bright heat and the vacuum very poor (so poor, in fact, that if the pressure were maintained constant the lamp would blacken in a few minutes), the vacuum greatly improved, due to some action occurring together with spattering of the filament, it seemed important to know more about the phenomena. We assume that the gas at first present goes to the walls of the lamp and is held there, possibly absorbed by the small quantity of deposited filament material. It is always possible to drive the greater part of it back into the vacuum space by warming the glass. It seemed perfectly possible that the process might be a cyclic one; that is, the gas carrying to the walls of the bulb some of the filament material and not of necessity remaining there, but possibly returning for a fresh supply. This continued process might account for the limited life of an incandescent lamp. It did not seem necessary to assume that there was any measurable rate of simple distillation from a carbon filament at the temperature of operation, though such a phenomenon could account for limited life of filament. It even seemed possible that the cyclic process, instead of being physical, might well be expressed as a chemical one, such as we know could exist, and might continue between the oxides of carbon and carbon itself. At the high temperature of the filament, carbon monoxid would be expected, but this, at a lower temperature, would form CO_2 and free carbon, the latter being deposited upon the glass. The free CO_2 coming into contact with the hot carbon filament would again form carbon monoxid, and thus the process be repeated continuously until the filament was burned through or the lamp became too black to be of use. It was therefore desirable to get a closer insight into the phenomena in the lamp at a pressure of a few microns.

Similar considerations can apply equally well to the case of tungsten filament lamps. In the case of osmium lamps this reasoning, extended, explains the fact that the presence of a little oxygen in the lamp was necessary to prevent blackening of the bulb by the deposited metal. A little oxygen in a carbon lamp might similarly remove deposited carbon from the glass and deposit it upon the filament, if the temperature at the two points were suitable, but with this element it seems impracticable because the oxid formed is not easily reduced below the CO state, thus differing from osmium.

While the lamp to which a radiometer was attached was not lighted, practically no change in vacuum could be detected by the radiometer. Therefore there is no leak of air from without. If, however, the lamp was lighted, the reverse was true. On allowing the lamp to be lighted for a few seconds only, and then cooling and testing in the dark room as before, the duration of rotation would usually be shorter, thus indicating a liberation of gas into the bulb space by this short time of burning. If, however, the lamp were allowed to burn at a normal brilliancy for a longer time and the same vacuum test was made from time to time on the unlighted lamp in the dark room, it was found that the duration of the impressed rotation rapidly increased. In many cases a rotation lasting 15 minutes would be produced by allowing the lamp to burn 24 hours. This phenomenon of automatic vacuum improvement received the name of the "clean-up." While the clean-up, as measured in this rough way, did not seem to take place in all lamps to the same degree, it was always present under ordinary conditions.

Other types of vacuum lamps improved their vacua on running. In fact, no lamp, unless we except the mercury arc, fails to do so. The well-known Moore tubular system of lighting, which is a development of the Crookes tube, consumes the gas, and for that reason an automatic valve was invented which supplies air to the tube when the vacuum improves to a certain point. It is also an old story, in the case of the cathode and X-ray tubes. X-ray tubes are usually made with a salt, such as potassium chlorate or potassium hydrate, mica, asbestos, etc., in an attached side tube. This may be heated when the tube in use attains too high degree of evacuation, and in this way gas is liberated into the bulb. This is in turn removed from the vacuous space by the operation of the tube. A natural question is raised at once: what becomes of these disappearing gases? In some cases they are probably forced or shot into the glass itself, for some of these old glasses bubble on being heated to the softening point. Possibly the greater part of the gas is absorbed by the exceedingly finely divided metal, which slowly deposits on the glass as it vaporizes from the electrode.

If an incandescent lamp, the vacuum of which had been thus cleaned up, was allowed to stand unlighted at ordinary temperature, the vacuum, as indicated by the test, would gradually grow poorer, though it would seldom fall to the starting value. If the bulb were heated in an oven at 100 deg. cent. for a few moments, it would also show a poor vacuum again on cooling. If such a spoiled vacuum lamp was again lighted, it would at once commence to recover its previous high vacuum. There was no indication of a fatigue evinced in lamps thus treated.

This explains the fact noticed in the case of most factory-made incandescent lamps, that their life at constant voltage varies with the external temperature. It is as though the gas, which is at first present in the space of the sealed bulb and is then thrown upon the walls by the clean-up, is also continually driven off from the walls at a rate dependent upon the wall temperature, and the deposition is bound up with some loss of filament material.

The experiments with the radiometers naturally led to attempts to develop more nearly quantitative apparatus which would still measure the low pressures of gas under consideration in incandescent lamps. Among the promising methods was that described by Pirani (*Ber. Deut. Phys. Ges.* 1906, 686). This was further developed by Dr. Hale of this laboratory, as described in the *Transactions* of the American Electrochemical Society, 1911.

This gage depends on the principal that energy loss from a heated wire in the vacuum to be measured depends on the pressure of the gas present. When the temperature of this wire is low (100 deg. cent., for example) the losses by radiation are relatively small, so that the rate of total loss at a constant temperature of wire would serve to determine the gas pressure. Conversely the temperature of this wire, if supplied with constant energy, from the battery, for example, would be higher, the lower the gas pressure. This latter scheme was adopted by Dr. Hale, and the gage consisted of a glass bulb sealed directly to the lamp to be measured and contained about two feet of fine platinum wire. This was heated by a current of constant watts and the temperature of the wire was given by knowing its temperature resistance coefficient and measuring the actual resistance for the case in test.

The measurement involved extrapolation towards perfect vacua from comparative measurements made with the new gage and the McLeod gage at pressures high enough so that the latter is reliable. Hale concluded that he could measure differences of pressure of one hundred-thousandth of a millimeter of mercury, or a hundredth part of the vapor pressure of mercury at zero centigrade. Here was a gage which, unlike the McLeod, exerted no appreciable vapor pressure of its own and therefore could serve to indicate the existing pressure at any period of the life of the lamp. It could disclose the fact if gases were produced within the burning lamp, if the seals or glass leaked at all, and how the clean-up actually changed the vacuum as indicated by the radiometer experiments. In using this gage new and interesting phenomena were disclosed, which must be further studied. In certain cases vacua a little more than perfect are indicated by this gage, and this suggests possible dissociation of the very attenuated gas. Barring this fact, it seems as though the clean-up effect proceeds to as nearly perfect vacuum as we can measure even qualitatively.

DISCUSSION ON "VACUA" (WHITNEY), BOSTON, MASS., JUNE 25, 1912.

A Member: Dr. Whitney refers to the gases which disappear from the incandescent lamp, and refers to the same phenomena in connection with the X-ray tube, and he calls attention to the fact that some of these old glasses from the old bulbs, either from the incandescent lamp or from the X-ray tube, bubble on being heated to the softening point. I hope that Dr. Whitney will clear up the claims of certain English physicists, and of German physicists, as to this matter. Dr. Robert Poole of the University of Berlin repeated some experiments made by an English physicist and he declares absolutely that the Englishman is mistaken; that an old glass does not give off this gas when it is under pressure in a vacuum so that the gas would be given off. Dr. Whitney refers to the fact that the glass when heated to a softening point will bubble, referring to the old glass, and I know a new glass does this as well, the conditions being that the old glass or new glass must be in a vacuum of something less than one millimeter actual pressure. I hope that Dr. Whitney will clear up this point, because the question of where the gas goes to is really a question that is important.

W. R. Whitney: I don't want to try to clear that up yet, because we don't know enough. There are various theories about it, but I cannot decide it.

Alfred H. Cowles: In a letter from A. H. Bucherer, of Bonn University, it is stated that in Europe they have a new method of creating a much higher vacuum than anything heretofore secured. I do not know whether that method is known in this country.

W. R. Whitney: As a further contribution to the question of gases within the glass of old X-ray tubes, lamps, etc., I will add that such gas also appears in the glass of old mercury rectifiers. Mr. Van Brunt, of the research laboratory, heated in a blast lamp the glass side-arms of old mercury rectifiers. The portions of the glass near the anodes turned white. On microscopic examination it was noted that this part of the glass was filled with minute bubbles which were not there prior to the heat treatment. They were within the glass itself, though much nearer the inner surface of the tube than the outer. This was shown by grinding and polishing in a plane which made a very acute angle with the surface of the glass. We did not consider the appearance of these gases in such glass an open question, but believe the question now is as to the source of the gas. Are these bubbles produced from gas which was dissolved or driven into the glass during the operation of the lamp or tube, or was the gas produced by a reaction between some injected material such as the electrode material and the material of the glass, or was it produced by the action of leakage current, static, etc., which caused a sort of electrolysis of the glass, the gaseous products remaining dissolved until the glass was subsequently heated?

DEFENDANT'S EXHIBIT No. 34.

E. L. CLARK.

METHOD OF COATING PROJECTOR LAMPS WITH REFLECTING SURFACES.

APPLICATION FILED JAN. 11, 1913.

1,121,802. Patented Dec. 22, 1914.

FIG.1

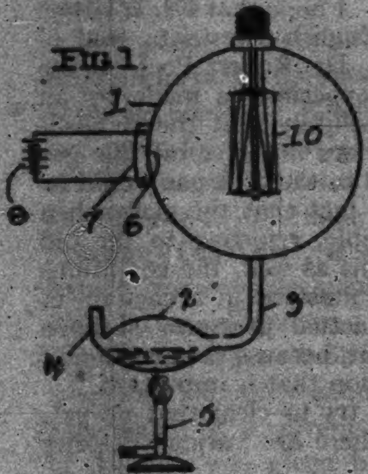

1
10
8
7
6
2
3
4
5

FIG.2

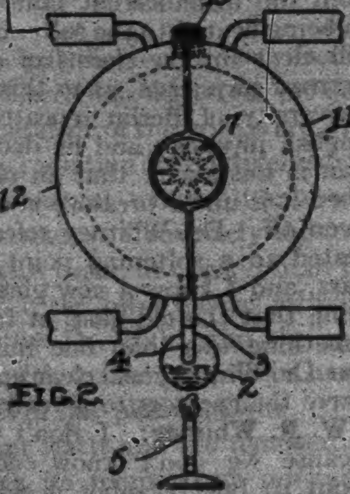

13
11
7
12
4
3
2
5

FIG.3

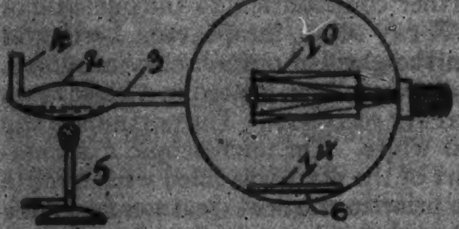
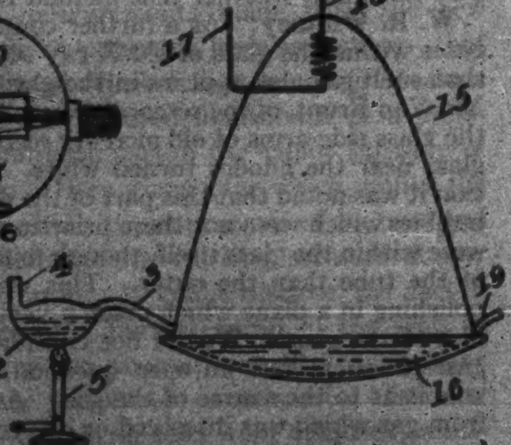


FIG.4


18
17
15
4
3
19
2
5
16

WITNESSES
G. Brewer
H. G. Grove

INVENTOR
EMERSON L. CLARK
BY Ira J. Adams
ATTORNEY

UNITED STATES PATENT OFFICE.

EMMERSON L. CLARK, OF LAKEWOOD, OHIO, ASSIGNOR TO NATIONAL CARBON COMPANY, OF CLEVELAND, OHIO, A CORPORATION OF NEW JERSEY.

METHOD OF COATING PROJECTOR-LAMPS WITH REFLECTING-SURFACES.

1,121,802. Specification of Letters Patent. **Patented Dec. 22, 1914.**

Application filed January 11, 1913. Serial No. 741,[illegible].

To all whom it may concern:

Be it known that I, Emmerson L. Clark, a citizen of the United States, residing at Lakewood, in the county of Cuyahoga and State of Ohio, have invented a certain new and useful Improvement in Methods of Coating Projector-Lamps with Reflecting-Surfaces, of which the following is a full, clear, and exact description.

My invention relates to a method for internally coating an incandescent lamp with a highly reflecting surface.

In my application filed October 17th, 1912, Serial No. 726204, for incandescent light for projection apparatus, I have disclosed an improved form of projector lamp of the incandescent type.

This invention relates to a method of applying the reflecting coating on the interior of the incandescent lamp there disclosed.

Figure 1 is a more or less diagrammatic representation of means for coating an incandescent lamp with reflecting material. Fig. 2 is an end view of the arrangement shown in Fig. 1 with means for cooling certain parts of the lamp. Fig. 3 shows a modified form of the arrangement for coating the lamp. Fig. 4 illustrates a further modification.

If a source of light be partly surrounded by a diffused reflecting surface and the remaining area of the surface be composed of a medium pervious to light, all of the light emitted from the source must eventually proceed through such area provided the efficiency of the reflecting surface is 100%. That is, if all the light is reflected back and forth from the reflecting surface and none of it is absorbed, it must be all emitted through the light pervious area. However, a diffused reflecting surface of 100% efficiency is not at present obtainable, so that with the lamp constructed as described, the entire light emitted from the source would not pass out through the window or light-pervious area, but a certain amount would be absorbed. The concentrating effect produced by such arrangement can be approximately computed as follows: Let I be the mean spherical intensity of the extended source within the reflecting inclosure; let R be the reflecting co-efficient of the reflecting inclosure; let P be the per cent. area which is uncoated with reflecting material; let r be the radius of the inclosure (assumed spherical) then the intensity of the illumination produced at the light-pervious area or window is:

$$\frac{I}{r^2}\times\frac{100}{100-(R-P)}$$

If, instead of a diffused reflecting surface, a polished surface is used so that specular reflection is had and the interior surface of the bulb is perfectly smooth and exactly spherical, not all of the light from the source would be emitted through the window. Since the reflecting surface would be everywhere symmetrical in regard to the source of light, a ray of light once reflected would continue to be reflected in the same plane. The planes of reflection would include the great circles of the spherical bulb. This means that only that part of the light would finally reach the window that was reflected in the plane of the great circles that intersect it. But even with specular reflection, the intensity of light would be greatly increased at the window. However, in practice, it would be impossible to obtain a bulb with such an exact interior surface that the light rays would continue to be reflected in the plane in which they started. As a matter of fact, the interior surface would consist of minute surfaces facing in diverse directions. This would be sufficient to cause all light to be eventually reflected through the window so that the light emitted through it would follow somewhat approximately the law of diffused reflection. The interior of the bulb may be made with an irregular surface to cause the light to more closely follow this law. From the law of diffused reflection, it will thus be seen that a slight increase in the reflecting co-efficient makes a large increase in the light emitted through the window. In my application above referred to, the invention is directed broadly to any form of reflecting medium. I have since found that metallic sodium and potassium have very high reflecting co-efficients, being in the neighborhood of 99.7. Their reflecting property is thus almost perfect. Substituting this value in the equation for diffused reflection, we get an intensification of approximately 77 at the window, assuming a window of 1% area. As explained above, the metallic surfaces would not follow exactly the law for diffused reflection, but would have a value somewhat less than that obtained by it. As stated above, the bulb could be coated with a roughening material or be made with rough and irregular protuberances so as to more closely follow this law. Since sodium or potassium oxidize very readily when in the presence of oxygen, it will be necessary to apply the coating with no trace of oxygen. I accomplish this result as follows:

Referring to Fig. 1, the incandescent bulb 1 which may be glass or metal as in my prior application, is connected to a container 2 by means of a tube 3. The container is connected to means for producing a vacuum through pipe 4. The vacuum pump or other means is not shown on the drawing. The container 2 contains the sodium, potassium, or other metal. This container may be a glass tube having restricted ends 3 and 4 connected to the bulb and pump respectively. After the incandescent filament is placed in the lamp, the air is exhausted through the tube 4 and the latter sealed. The sodium or other metal in the container 2 is then heated by any means, a gas jet 5 being shown for the purpose of illustration. The sodium or other metal is vaporized and passes up into the lamp bulb where it is condensed on the interior surface. In order to prevent the metal from condensing on the window 6, heat should be applied thereto. The window may be heated in any manner but I have shown a heating coil 7 closely adjacent thereto and connected to a source of E. M. F. 8. It is also best to send current through the filament 10 in order to prevent the metal from condensing there. After the metal has condensed on the interior of the bulb, the glass tube 3 is sealed off in the usual manner. The bulb is thus provided with a highly reflecting coating of sodium or other metal with the exclusion of oxygen, and it retains its brilliant surface indefinitely. The lamp, when thus coated with sodium or potassium, furnishes a much more concentrated light than with all other known reflecting coatings. In order to more efficiently coat the interior of the bulb, it will be advisable to cool the parts of the lamp to which the coat is to be applied. In Fig. 2, I have shown such an arrangement. Water or other cooling medium is circulated through jackets 11, 12, which may be hemispherical. The water jackets are shaped to leave openings for heating coil 7, the connecting plug 13 and the tube 3. With the cooling means shown, the deposit of metal will be more regular and the window will have a sharper contour. If desired, the lamp bulb may be coated while placed in a draft of cool air to cause the deposit of metal.

In Fig. 3, I have shown a further method of preventing the metal from depositing on the window 6. A disk 14 is placed in the bulb before it is sealed up. This disk is of the same size as the window desired, and is coated on one side with some material such as soft varnish or felt to prevent its scratching the reflecting surface after the lamp is complete. Before the sodium or other metal is vaporized, the lamp is turned until the disk 14 slides into the proper position, and then the air is exhausted and the metal vaporized. The metal will condense on the interior of the bulb and on the upper surface of the disk 14 but it will not condense on the window 6 because it is covered by the disk. After the coating process is complete, the lamp is turned so that the disk 14 slides off the window. In this way the interior of the bulb is coated with sodium or other metal, leaving a sharply defined window entirely free from the coating. The reflecting efficiency of the bulb is not impaired by the disk inasmuch as the upper surface of it is coated with reflecting material. Of course, care should be used in handling and in shipping to prevent the disk from turning over with the reflecting surface downward. In this arrangement, current may be sent through the filaments to prevent the metal from condensing thereon and the bulb may be cooled as in Fig. 2.

In Fig. 4, I have shown a still further modification. The lamp here shown is intended for a headlight on automobiles or other carriages. It consists of a body portion 15 having a substantially parabolic shape and a transparent portion or window 16. The window 16 may be sealed on to the body portion 15 in any well known way. The light emitting filament used in this type of lamp consists of a helix of thin tungsten strip or foil coiled flatwise with leads 17 and 18 as shown. By using the thin strip or foil, I am able to concentrate the light source at the focus. The interior of the body portion 15 is to be coated with sodium or other metal and the window 16 is to be uncoated. As a variation of the method above described, I may use mercury, oil or other liquid to prevent the metal from depositing on the window 16. The liquid may be introduced into the lamp through tube 19. After the air is exhausted from tube 3, the sodium or other metal in the container 2 is heated and is condensed on the interior of the body portion 15. This body portion may be cooled as previously described. The sodium may be allowed to condense on the mercury if such is used, forming an amalgam therewith. After the coating is applied, the mercury or other liquid is withdrawn through tube 19 and it, as well as tube 3, is sealed. In this way, the sodium is prevented from depositing on the window 16. This form of light may be used very efficiently with dry cells for instance. In this modification, the mercury or other liquid may be withdrawn through tube 3 after the sodium has vaporized and the tube 19 dispensed with.

I do not claim to be the discoverer of the fact that sodium and potassium have very high reflecting co-efficients, but I believe I am the first to disclose the method described for applying coatings of such material to the interior of incandescent lamps.

Having described my invention, what I claim is:

1. The process of coating a bulb with a reflecting surface which consists in freeing the interior of oxidizing gas, heating a supply of the coating material and causing the vapor thereof to condense on the interior surface of the bulb.

2. The process of coating a bulb with a reflecting surface which consists in freeing the interior of oxidizing gas, heating an external supply of the coating material and causing the vapor thereof to condense on the interior surface of the bulb.

3. The process of coating a bulb with a reflecting surface, which consists in freeing the interior of oxidizing gas, leading a supply of vapor into the interior and causing it to condense on the greater part of the interior surface while preventing it from depositing on the remaining surface.

4. The process of coating a bulb with a reflecting surface which consists in freeing the interior of oxidizing gas, heating a portion of the bulb, heating a supply of the coating material and causing the vapor thereof to condense on the interior surface of said unheated portion of the bulb.

5. The process of coating a bulb with a reflecting surface, which consists in freeing the interior of oxidizing gas, heating a portion of the bulb, cooling the remaining portion and heating a supply of coating material so that the vapor thereof will condense on the interior surface of said cool portion of the bulb.

6. The process of making a bulb with reflecting surface which consists in forming the bulb, roughening the interior surface, freeing the interior of oxidizing gas, and causing a vapor to condense on the interior surface.

7. The process of making an incandescent lamp which consists in forming the bulb, adding the filament, exhausting the interior, heating the filament, and a portion of the bulb and causing a vapor to condense on the interior surface of the unheated portion.

8. The process of making an incandescent lamp which consists in forming the bulb with a roughened interior surface, adding the filament, exhausting the interior, heating the filament and a portion of the bulb, and causing a vapor to condense on the interior surface of the unheated portion of the bulb.

9. The process of making an incandescent lamp which consists in forming the bulb, roughening a portion of the interior surface, adding the filament exhausting the interior, heating the filament and the non-roughened portion of the bulb and causing a vapor to condense on the said roughened surface.

10. The process of coating a bulb with a reflecting surface which consists in freeing the interior of oxidizing gas, placing a movable cover over a portion of the interior surface heating a supply of the coating material and causing it to condense on the interior surface of the uncovered portion of the bulb.

In testimony whereof, I hereunto affix my signature in the presence of witnesses.

EMERSON L. CLARK.

Witnesses:

Ira J. Adams,
H. G. Grover.

DEFENDANT'S EXHIBIT No. 35

[TRANSLATION]

1913 No. 6.

Annalen der Physik

Vierte Folge Band 41.

Pages 1-26

1. CONCERNING THE PRESSURE OF CATHODE RAYS.

By ERNEST V. ANGERER.

[1]

With William Crookes[1] originated a celebrated experimental arrangement with which he believed it possible to detect the mechanical impact of cathode ray particles; in a vacuum tube is enclosed a small paddle-wheel whose axis runs on two glass rods. Two electrodes are so arranged that the cathode rays emitted from one of them impinge on the uppermost blade. It then resulted that the wheel rolled forward when subjected to radiation from the cathode. As Crookes assumed, under the influence of "materie radiante".

Later Puluj repeated this investigation and devised another experimental arrangement.[2]

Furthermore E. Riecke[3] has published a quantitative investigation of this problem. He measured the counter impact imparted to the cathode by the ejected electrons. Of Riecke's results the most important is that (under the assumption of $\varepsilon/\mu \sim 10^7$ electromagnetic units) the intensity of the cathode rays would have to be about 80 times as great as the intensity of the total current in order to account for the mechanical action. In reality it could amount only to a small fraction of the total current.

Finally there is an experimental investigation by [2] Starke[4] in which Starke showed that the effects which took place in the above mentioned work demanded much greater forces than those called into existence by the impact or emission of electrons.

He recalls a work of Warburg[5] who finds that in gaseous discharges the cathode is subjected to forces which may amount to 10^4 times the expected effect. Besides the observed turning moment admits of explanation by electrostatic forces and also in particular by a radiometer action from the surface of the heated blade.

The pressure p in its relation to the number n of the electrons (e) and the accelerating potential V is given by the following formula which admits of easy derivation

$$p = \frac{n \varepsilon \sqrt{2V}}{\sqrt{\frac{\varepsilon}{\mu}}}$$

$n . \varepsilon = i$ can be measured with a galvanometer. If we take for ε/μ a new value for the most recent work.

$\left(\frac{\varepsilon}{\mu}\right)$ 5000 volt $= 1.74 \times 10^7$ electromagnetic units then, for example at $V = 5000$ volts $= 5 \times 10^{11}$ electromagnetic units and $i = 10^{-5}$ amperes $= 10^{-6}$ electromagnetic units.

$$p = \frac{10^{-6} \times 10^{+6}}{4.17 \times 10^3} = 3.40 \times 10^{-4} \text{ dynes.}$$

The torsion balance was placed by Starke in an electrostatically shielded space and connected through a galvanometer to ground. In order to avoid as much as possible disturbances from radiometer action, he utilized very thin sheets of foil as receivers (targets) in the expectation that the temperature of the absorbing front surface would then differ little from that of the rear surface. In spite of this he got too large deflections which became smaller with higher evacuation. To exclude [3] radiometer action with certainty he employed instead of the torsion balance a circular disk of aluminum foil which by the impact of the obliquely incident cathode rays was rotated on its vertical axis while the radiometer force, acting perpendicularly to the surface, tended to turn the disk on a horizontal axis.

With this arrangement Starke obtained scale deflections of several millimeters but the deflections were so irregular that he could not accurately measure them. As a result of his investigation he gives the observed pressure under a radiation of 10,000 volts and 10^{-7} amperes as less than 10^{-4} dynes (calculated 2.0×10^{-6} dynes).

During the twelve years which have passed since this work of Starke's our knowledge of cathode rays has been extraordinarily widened by experiment and theory. Since Joffé6) has recently shown the magnetic action of cathode rays, the measurement of its radiation pressure is the only fundamental research which has not been satisfactorily carried out. On the other hand the experimental technique has undergone substantial improvement; we can by aid of Dewar's coconut charcoal produce very high vacua in which radiometer effects are very small, we can also by means of the Wehnelt oxide cathode produce intense cathode rays in high vacuum and finally we can exactly measure low gas pressures of this order with the absolute manometer of Knudsen.

I have therefore taken up again the investigations of Starke. Unfortunately as yet I have no decisive results to offer. Since, however, my work must be interrupted for other reasons, it may be permissable in the meantime to publish the results already reached.

DESCRIPTION OF THE EXPERIMENTAL ARRANGEMENT.

The Cathode Ray Apparatus of the Preliminary Experiment.—It seemed the most promising to repeat Starke's experiments with the disk. The disk S (Fig. 1) [4] consisted of aluminum foil of 0.008 cm. thickness and had a diameter of 3.4 cm. It was coated with rust7) and dusted with a rather finely pulverized "Sidotblende" to disclose the point of impact R of the cathode rays. In its center was soldered a hard drawn brass wire which supported a mirror. This system was suspended by a "Wollaston" wire of 0.007 mm. thickness and had a vibration period of 23 seconds. It was insulated and suspended in a brass box F which was fitted into a glass vessel G. The cathode rays left the Wehnelt cathode W,8) passed through an opening in the box and fell upon the disk at a near angle of 45°. A shield A which was placed in part of the box, served as an anode. The anode, the Faraday cage, in which the rotatable disk hung, and the latter itself were all insulated from one another and connected individually to ground and a galvanometer could be inserted in each of the circuits to ground. In this way the intensity of the absorbed as well as the reflected rays could be measured.

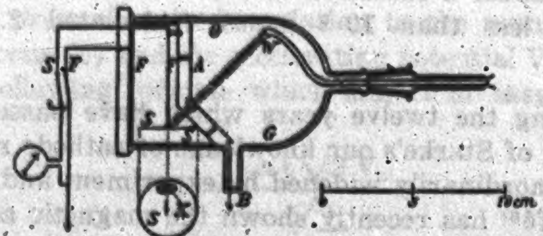


Fig. 1.

The vacuum was produced by charcoal in liquid air and measured by means of a Knudsen galvanometer whose final form is described later (p. 10). The tube B led to the pump, the charcoal container and to the manometer.

Experiments with this apparatus gave the following results:

A vacuum of about 0.0001 mm. Hg was maintained, while the cathode was in activity. The rays are emitted [5] not in a narrow bundle as at high pressures, but diverge greatly from the cathode. The current derived from the disk was about 10^{-5} amp. The intensity of the reflected rays was (at 3000 volts) just as great as that of the absorbed rays. When the Wehnelt cathode glows, the disk turned about 90° in the absence of any cathode rays. When voltage was applied, so that cathode rays impinged upon the disk, the deflection was greater.

It is evident that this rotation was due to a radiometer effect between the glowing platinum sheet and the disk. A small part of the gas molecules which were ejected in all directions from the cathode at the high velocities corresponding to their high temperature, struck the rotating disk through diaphragms. It need only be assumed that the surface of an aluminum cathode such as used by Starke is hot, in order to attribute the deflections observed by him to the same sources of error.

In order to eliminate disturbances, the hole in the anode shield was closed through aluminum foil which was as thin as possible. The rotation did not disappear entirely, as the foil becomes heated by radiation and so a small difference in temperature remains between it and the disk.

One is inclined to explain the greater angle of turn given the disk when cathode rays start, as the effect of their pressure. But this conclusion is not admissable for as Wehnelt and Jentsch[9)] have shown, the temperature of a glowing wire may rise when it emits cathode rays (because positive ions fall upon it). This rise in temperature may cause the greater deflection, as shown above. To perform the experiment properly, the cathode rays would have to be deflected to one side by a magnet, until the disk has taken a position and then the rays be permitted to fall on it. This could not be easily done [6] with the apparatus described owing to the strong divergence of the rays.

One great disadvantage of this arrangement is the strong reflection of the cathode rays occurring when the angle of incidence is acute. For the reflection, as is well-known, is neither strictly geometrical nor completely diffuse[10] the receiver may even emit more electrons than it receives.[11] For accuracy, it is desired that all the electrons possible be absorbed. Since the rotating disk corresponded so little to this requirement the experiments were stopped in order to set up a new arrangement for avoiding the above errors as much as possible.

The Final Cathode Ray Apparatus.—It should be noted that careful attention must be given to the elimination of electrostatic disturbances. For the potentials on the tube may easily affect a sensitive torsion balance. In apparatus, which will not be described here, cathode rays were made to fall on the wall of a glass tube and the latter attracted the torsion balance; in other experiments two (freshly ground) aluminum wires of the balance made a contact in the atmosphere but not in a vacuum so that the torsion balance was charged. With the apparatus to be described, which is illustrated in Fig. 2 and used for the later experiments, the above errors were avoided as much as possible.

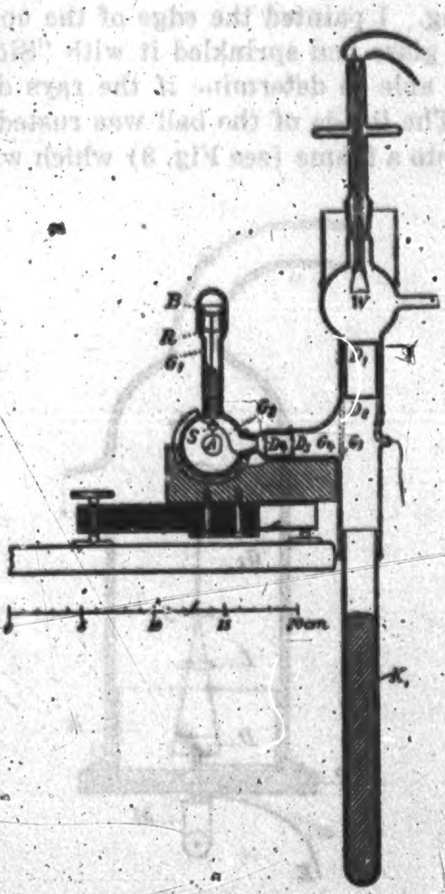


Fig. 2.

a. *The Torsion Balance.*—A Faraday cage was used as the receiver of the torsion balance in order to avoid as much as possible the disturbing reflection of the cathode rays.

The receiver A consisted of a hollow aluminum sphere 16 mm. in diameter, which had a round hole 9.4 cm. in diameter. To the ball were soldered two thin, hard drawn copper wires.12) The ball was etched with concentrated caustic potash until the thickness which was originally 0.5-0.8 mm. had been so reduced that at points small holes were made; it then weighed about

[7] 120 mg. I painted the edge of the opening with a little water glass and sprinkled it with "Sidotblende" in order to be able to determine if the rays did not touch the edge. The inside of the ball was rusted. The wires were bent into a frame (see Fig. 3) which was reinforced

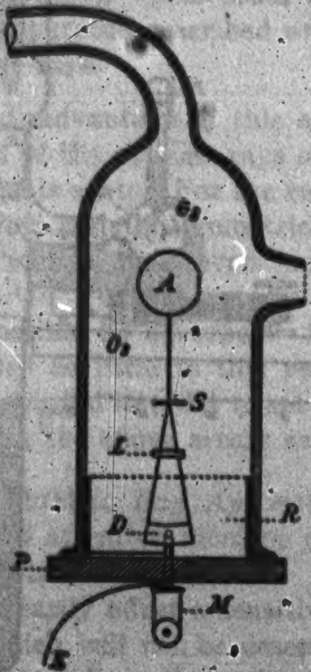


Fig. 3.

and supported a mirror S in the middle while at the end farthest removed from the ball it supported a small piece of sheet silver D, which vibrated between the poles of a small electromagnet M with a damping which could be regulated. With the mirror the torsion balance weighed 510 mg. L is a small sliding weight of copper foil which was necessary to bring the opening in the ball in the path of the rays and at the same time to make the silver disk oscillate freely between the magnet poles separated by 0.8 mm. *The distance from the axis of rotation to the middle point of the ball was 3.0 cm.* This system was suspended by a well gilded hook from a Wollaston wire 0.015 mm. in diameter and 54 mm. long, and its period of oscillation was 42.3 sec. A gilded brass ring R which was clamped to the glass tube C_1 (Fig. 2) and provided with a grounded wire leading outward, was used as the torsion head. On this ring was placed an iron, gilded crossbeam B in the middle of which the suspension wire was fastened. By bringing a magnet close, the beam B and with it the vibrating system could be turned. The glass vessel G_2 containing the torsion balance was fastened, together with a wooden base cut out in a corresponding manner, to a tripod equipped with adjustable screws. To the polished front surface of the container a mirror plate P was soldered containing two holes for the poles of the damping magnet M. G_2 was silvered inside and rusted and was electrically connected with the iron of one pole by means of a brass ring R. On the outside of the mirror plate a wire E led from this pole directly or through a galvanometer to ground.

b. *The Discharge Tube.*—The cathode rays had to be separated from the gas molecules ejected from the Wehnelt cathode, which had caused such disturbances [8] in the first apparatus, by a *magnetic field.* For this reason the discharge tube G_3 was placed vertically. Opposite the glowing cathode and not separated from it by narrow canals, was the carbon K_1 which was cooled with liquid air. At the low pressure used, the mean free path was considerably greater than the distance from the cathode to the carbon so that most of the gas molecules were hurled to the absorbing surface of the carbon without colliding with others. On the other hand a magnetic field whose lines of force are to be imagined perpendicular to the plane of the drawing deflected the cathode rays to the horizontal branch G_4 which was soldered to the container G_2.

[9]

The *Wehnelt cathode W* consisted of platinum foil 0.005 mm. thick which had been glowed out then pressed into a round cup. It had been found that the divergence of the rays was minimized by using a hollow cathode of this kind. The metal was heated by electricity and a crystal of calcium nitrate melted in it. It was important to have a uniform coating of calcium oxide which was not too thin. The surface of the oxide spot was about 0.3 cm². On the glass sphere inclosing the cathode was soldered a tube filled with cooling water.

The rays then hit diaphragms D_1 and D_2 which formed the anodes, were bent, passed through diaphragms D_3 and D_4 and finally reached the inside of the aluminum ball to be absorbed.

The magnetic field was produced by a horse-shoe electromagnet the exciting current of which could be controlled within wide limits from the observer's position by a regulating resistance.

The discharge tube G_3 and G_4 was silvered over on the inside as far as the diaphragms D_1 or D_4. The diaphragms were in the form of caps pressed from copper 0.9 mm. thick, and they fitted into the tube under strong tension. Immediately before being inserted they were cleaned with concentrated nitric acid, washed with distilled water and dried. They were electrically connected by the layer of silver and were grounded with it through D_2. After the diaphragms were inserted, the tube G_3G_4 was coated inside with rust.

The discharge tube was insulated from the container G_2. The circuit was arranged so that a galvanometer could be put in the circuit of the grounded line from the torsion balance or in that from G_2 containing the balance as in previous experiment.

DETERMINATION OF THE DIRECTION OF THE FORCE OF THE SUSPENSION WIRE.

We shall calculate the force perpendicular to the axis of rotation at a distance k from it which causes by rotating the system a deflection of the image in the mir-
[10] ror amounting to the angle α.

For this purpose a pendulum instead of the torsion balance was suspended on the Wollaston wire; this consisted of an aluminum wire 8.41 cm. long, 1.390 mm. in diameter, and weighed 0.221_5g. Its moment of inertia K was therefore 1.306 g x cm². In the middle was a very light hook of glass thread. The period of oscillation of the wire was $t = 16.10$ sec.

By combining the two formulæ for the determination of the modulus of torsion by oscillation and by torsion[13] we have:

$$D = \frac{\pi^2 R \alpha}{h t^2} \text{ dynes.}$$

Since in all experiments the perpendicular distance between the mirror and the scale was 1705 mm., the arc value of one millimeter of the scale in absolute measure is:

$$\alpha \text{ mm} = \frac{1}{2 \times 1705}$$

Accordingly, the force at the point of impact of the cathode rays ($h = 3.0$ cm.) which causes a scale deflection of 1 mm. is:

$$D = \frac{\pi^2 \times 1.306}{3.0 \times (16.1)^2 \times 2 \times 1705} = 4.8_{61} \times 10^{-6} \text{ dynes.}$$

The Knudsen Absolute Manometer.—At pressures which are so small that the mean free path of the molecules is large in comparison with the dimensions of the container, *the disturbing radiometer force* to which the blade of the torsion balance is subjected is *proportional* to the number of molecules and hence *to the gas pressure. The true radiation pressure (in an absolute vacuum) can therefore be found from the decrease in the apparent cathode-ray pressure with the gas pressure.* Then in order to calculate it the ratio of the (very slight) gas pressures during the experiments must be known.

An instrument which measures more accurately the
[11] pressure in question is Knudsen's "absolute manometer"[14] which measures the radiometer force between two plates of different temperatures in a vacuum. As just mentioned this force is proportional to the gas pressure provided that most of the molecules pass from one plate to the other without colliding. On this hypothesis Knudsen derives the following formula:

$$\text{The unknown pressure } p = \frac{2\,K}{\sqrt{T_1/T_2} - 1}$$

This equation assumes the following more simple form if the difference in the temperature of the plates is small in comparison with their absolute temperatures:

$$p = 4k\,\frac{T_2}{T_1 - T_2}$$

K is here the force with which each square centimeter of the movable plate is repelled and T_1 and T_2 are the absolute temperatures of the plates.

2

Knudsen demonstrated experimentally the correctness of his formula for different gases and different temperatures. In the work noted he gives five different forms of the manometer without explaining the details of construction.

The fourth arrangement gives the greatest sensitivity, as he considers, and this is illustrated diagrammatically in Fig. 4 as seen from above. A are two platinum foil strips which can be heated by electricity. B is a mica plate which repelled by both strips turns about the axis 0. It is suspended by a fine thread at 0 which is to be imagined perpendicular in the plane of the drawing. In my first instrument of this kind the platinum foil was stretched taut by a brass frame. High vacua could not be obtained with this manometer, probably because of the relatively large masses of metal in it which constantly give off some gas. In the final form shown

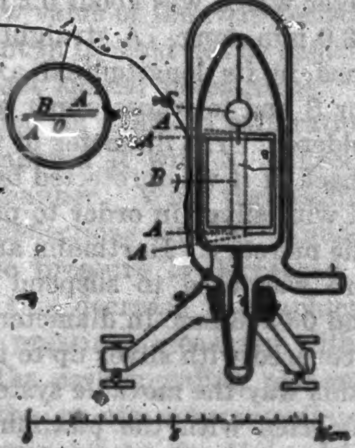


Fig. 4. **Fig. 5.**

in Fig. 5 as little metal as possible was used. The instrument was soldered to an iron tripod with adjusting [12] screws. At the top and bottom of the frame shown as cross hatched, which consisted of glass tubing, two horizontal platinum wires were fused which were separated from one another by the thickness of the glass tube (3 mm.). To these wires were soldered with silver strips of platinum foil 0.005 mm. in diameter. The left strip projects 1.5 mm. in front of the plane of the drawing and the other the same distance behind it. The heating current entered at the lower left-hand side by the left strip, was conducted through the two upper wires to the upper end of the right strip and was led out at the lower right hand. In order to prevent a short circuit between the lower wires a piece of fuse glass was inserted between them and the strips. The strips are 37.7 mm. long, 10.6 mm. wide and the distance between their inner edges, 5.0 mm. Including the leading in wires their resistance was 0.4 Ω.

A platinum wire was fused to the highest point of the cross hatched glass frame and the movable system was suspended by it. The latter consisted of a mica plate B coated with silver which was about 0.2 mm. thick, 26.7 mm. wide and 33.0 mm. long. A straight piece of brass wire was fastened in its longitudinal axis which supported the mirror S and to whose upper end the suspension wire was soldered. The diameter of the mirror was 10 mm. and the back of it was protected by a glass which was also covered with silver in order to prevent any disturbance from the mercury. Hartmann and Braun phosphor bronze wire was used to suspend it, which was 15.0 mm. long and 0.0208 mm. in diameter.[15] The glass framework was covered with silver up to the upper platinum wires. In this way the movable system was conduc- [13] tively connected with the platinum strips. The oscillation period was 1.68 seconds.

After the glass frame had been mounted in the manner described it was placed in the outer glass tube (not shaded) into which it fitted with precision. Then the leads being passed through thin capillary tubes which were sealed on, were sealed in and finally the upper opening of the outer tube was sealed and blown to form a hemisphere.

Opposite the mirror was a plane glass plate which by a special process in accordance with a communication from Herr Gundelact von Zeiss was fused on with the aid of cement. But since the sealing composition only withstands a temperature of 60° at the most and furthermore is attacked by benzol, the Zeiss process does not appear to have substantial advantages over the use of plain sealing wax.

In using this instrument we assume with Knudsen that the movable plate maintains its initial temperature T_1. We will later (p. 15) see how far this assumption is fulfilled. The temperature of the platinum strips was to be calculated from their increase in resistance. But later experiments showed that at the minimum pressures reached the movable system was strongly deflected when the excess temperature amounted to only a few degrees. Owing to the low value of the strip resistance an increase of a few per cent in it could not be sufficiently accurately measured without special precautions. For this reason I had to abandon an absolute calibration of the manometer, and compared it with a McLeod manometer in the following manner: With the heating current held constant the deflections of the Knudsen manometer diminish as the pressure is decreased from a certain maximum. If this decrease is graphically represented by plotting the pressures measured with the McLeod as abscissae and the corresponding manometer deflections as ordinates, the points corresponding to the lowest pressures determinable by the McLeod lie on a straight line which seems to pass through the origin. This [14] straight line was used for exterpolating to the lowest pressures which could not be measured by the McLeod manometer, but could be by the Knudsen. This method is not reliable for it is based on the hypothesis that with a constant heating current the temperature of the strips remains constant, even when the gas pressure varies. And this is by no means the case.[16)]

No other means was left except to measure the temperature of the strips by a thermocouple made of an iron and a constantine wire 0.050 mm. in diameter and touching one of the platinum strips in the upper third part of its distance, the soldered joint forming a feeble spring. The couple was connected with a moving coil galvanometer which gave a deflection of 7:45 divisions per degree of temperature difference.

In order to calculate the sensitiveness of the manometer the method described on p. 10 was used. The pendulum used here had a moment of inertia of 6.45 g x cm² and a vibration period of 9.5 seconds. The weighted points of the surfaces of the mica sheets were 0.9757 centimeters from the axis. This gives the value of one scale division as 1.754 x 10^{-4} dynes.

The "effective surface" on which the sheet mica and the platinum foil stood opposite one another was 6.6 cm² (both blades) and one scale division amounted to 1.5 mm. With these values the unknown gas pressure which makes a deflection of α scale divisions is given in accordance with Knudsen's formula:

$$p = \frac{\alpha T_1}{T_2 - T_1} \; \frac{4 . 1.745 . 10^{-4}\, 1.5}{6.6} = \alpha \frac{T_1}{T_2 - T_1}\, 1.5_{93}\, 10^{-4} \text{ dynes/cm}^2$$

$$= \alpha \frac{T_1}{T_2 - T_1}\, 1.2\, 10^{-7} \text{ mm Hg.}$$

In one example the spot of light was deflected 1.2 scale divisions and the thermocouple galvanometer 410 scale divisions, corresponding to 55°. This gives the following:

$$p = 1.05.10^{-3} \text{ dynes/cm}^2 = 7.6.10^{-7} \text{ mm Hg.}^{17)}$$

Calculation on the basis of calibration by the McLeod [15] manometer (see p. 13) gave 3.6 x 10^{-6} mm. of mercury. Since the temperature becomes greater than assumed as the pressure is decreased, the pressure values are too high. The pressure of the radiation emitted from the heated platinum strip in this experiment is calculated (under simplifying assumptions) as 7.2 x 10^{-5} dynes, or 5.2 x 10^{-8} mm. of mercury, and hence is negligible.

When the maximum radiometer effect was obtained (by choosing the proper pressure) the thermocouple galvanometer gave a reading 4.5 scale divisions $= 0.6_{05}$ degrees and at the same time the manometer gave a reading of 112 scale divisions. It follows that the optimum radiometer effect is 8500 times as great as in the first example (at the lowest pressure reached).

The two following checking tests made with the instrument may be mentioned:

We determined whether at a constant pressure the deflection of the spot of light was proportional to the difference in temperature. The following values were obtained.

Intensity of the heating current	0.2	0.3	0.5	Amps.
Temperature difference $T_1 - T_2$	7.94	14.4	53.1	Degrees
Manometer deflections	3.0	7.0	19.5	
Pressure (calculated)	1.31	1.39	1.28x10^{-5}	mm. Hg.

As one observes the pressures vary 4.5% from the average, but do not display any regular tendency.

We then endeavored to determine how rapidly the movable mica plate is heated by radiation and convection. The heating effects a reduction in the temperature difference $T_1 - T_2$ and this is not taken into consideration. Therefore during a long period of heating the measured pressures are too low. This is illustrated by the following table:

Readings - - -	1	2	3	4	5	Min. after heating current is stopped
Temperature of the platinum strip exceeding its surroundings	51.1	55.4	57.9	59.2	60.3	degrees
Manometer deflection - - - - -	18.7	20.0	20.4	20.8	21.0	Scale div.
Pressure calculated	1.06	1.05	1.02	1.02	1.01 x 10^{-5}	mm. Hg.

The pressure which was actually kept constant is therefore measured 5% too low 5 minutes after the current is started. [16]

The great advantages of a Knudsen manometer are that its range covers the lower pressures better than the McLeod manometer, and especially that changes in pressure are indicated almost instantly. A disadvantage is that the pressure can not be read directly from the scale deflections but must be calculated from the readings of two instruments. I have also found it especially disadvantageous that with the chosen construction the final temperature of the wire loops is not reached until about a quarter of an hour after the heating current is stooped. Only when the heating current is reduced through a loop of wire so that the thermocouple shows a constant temperature does the spot of light come to rest at a constant pressure. The instrument used by Koenigsberger and Kutschewski[18)] only known to me later is free from this complication. But it has a disadvantage that the surface of the warm plate opposite the movable plate, contrary to the requirements of the theory, has a very small extent and a possible disadvantage is the fact that the hot water is put into the instrument in the neighborhood of the electrostatic high voltage.

DEVICE FOR PRODUCING THE VACUUM

The high vacuum which was a fundamental condition for the success of this research was obtained by Dewar's method of the absorption of the residual air by means of cooled coconut charcoal.

The charcoal employed was obtained from Kallbaum from the shell of a coconut. To remove the tar contained in it it was heated for several hours in a nitrogen current (until it gave off no more combustible vapor). Then it was placed in the absorption tubes (each 34 g.), cut [17] up in small pieces and carefully freed of dust. These cylindrical tubes of glass of a very high melting point 25 mm. in diameter and 270 mm. long could be heated in an electric furnace built for this purpose to red heat (about 650°) and then fitted in the neck of Dewar flasks of 2 liter capacity. First one and then the other carbon could be connected with the pump through a triple cock, and finally the two carbon retorts could be connected together. If then one of them (the "front carbon") is cooled with liquid air it absorbs from the other one (the "principal carbon" of the discharge tube), which was at a high temperature, the last residuum of air, (later the principal carbon as long as it was heated was evacuated by the pump and for about 15 hours before the experiment was connected with the cooled front carbon). In the last part of the experiment I had a Gaede pump. It was necessary to heat the carbon until the initially noticeable emission of gas had become so slight that the pressure did not rise noticeably in the first vacuum of the Gaede pump in an hour's time. This occurred after 5-7 hour. If the heating was interrupted earlier and continued on the next day the pressure was much lower if the carbon had again reached the same high temperature and the carbon gave off less gas per unit of time than when the experiment was interrupted. If the amount of gas evolution had become imperceptible it could again be started by raising the temperature. For this reason and because the gas was liberated more rapidly, I used as high a temperature as possible, which resulted in distorting somewhat the walls of the carbon retort owing to the external pressure. Whether a still higher vacuum could be obtained by higher temperatures, or how much gas remains behind when this method is used could not be determined.

White sealing wax was used for soldering purposes [18] as furnished by Liliendahl-Neudietendorf. The cock was packed with a very tough "Gummifett" used by Ramsay.

THE REST OF THE APPARATUS.

A Du Bois Rubens armored galvanometer was used to measure the current intensity i. Its internal rseistance was 4142 ohms. The frequency of the (weighted) system was chosen as small as possible and the damping was measured so that the spot of light came to rest 5 seconds after the circuit was closed. The sensitiveness was 3 x 10^{-9} amperes per scale division. For the galvanometer and the Knudsen manometer an abjective reading was preferred, the two spots of light playing on the same glass scale. For generating the cathode rays we had a high potential storage battery of 3000 volts and a Toepler influence machine of 30 plates driven by a motor. The voltage at the terminals of the tube was measured by a Kelvin electrometer for 20,000 volts which had previously been connected by the writer with the Kirchhoff balance to the standard cell. The heating current for the Wehnelt electrode was furnished by a small local battery of four cells. Since the anode was grounded this heating current circuit had to be charged to a high potential to ground. The cells and a small Ruhstrat variable resistance were highly insulated by porcelain insulators. Finally a box was constructed of metal and grounded which contained the entire vacuum apparatus and left only the discharge tube outside.

EXPERIMENTS.

In general, good results were obtained with this arrangement so that it appeared that a quantitative solution of the problem might be possible. However, various defects still showed themselves which I did not succeed in overcoming until I was about to stop this investigation.

1. One substantial advantage over the former arrangement was that much higher vacua could be ob-

tained. The lowest pressure which I have measured was 8×10^{7} mm. Hg. (of the example of p. 14). The [19] lowest pressure found by the Reichsanstalt19) which can be obtained with coconut carbon and liquid air was 7×10^{-6} (As measured with a McLeod manometer). Of course, these values for vacua of such high order must not be accepted without careful criticism. For instance, it must be remembered that in such cases where the free paths are much greater than the dimensions of the apparatus the pressure is not the same in the parts of the apparatus which are of different temperatures but that rather the pressures according to Knudsen 20) vary as the roots of the absolute temperatures. (In the tube cooled with liquid air the pressure is only half as great and in the neighborhood of the glowing cathode it is greater than in the other parts of the apparatus which are at room temperature). Further, it is not impossible that the platinum strips of the Knudsen manometer liberate gas upon being heated which is again absorbed by them upon cooling. To investigate this the strips were heated one at a high vacuum to a red heat. The torsion balance was deflected in the direction of a stream of gas flowing from the manometer to the carbon. The pressure measured after the strips were cooled was, however, no lower than before they were heated. This work must be continued in order to furnish an answer to the questions arising regarding the condition of this vacuum must await the continuation of this work—as to whether the carbon itself absorbs as many gas molecules per unit of time as it emits, whether a constant stream of gas molecules which may be liberated from the walls is absorbed in the carbon and whether the remnants of gas consist essentially of heavy molecules (sealing wax and grease vapors) or of hydrogen and helium. Also we have not investigated whether a considerably higher vacuum can be obtained by heating the glass tubes and avoiding soldered joints. The manometer could readily be made 100 times more sensitive by using a much finer suspension.

2. If now the Wehnelt cathode was heated the pressure (especially with fresh oxide coatings) was raised in the first minute so greatly that the spot of light [20] of the manometer was moved over the entire scale scarcely one-half a second after the circuit of the cathode heating current was closed. The torsion balance was also set in vibration, but after a few minutes came to rest at its former zero point. But it was scarcely possible with the cathode glowing to obtain better vacua than about 4×10^{-5} mm. of mercury, especially when cathode rays were emitted. It is to be noted, however, that at such low pressures current intensities of about 0.1 milliampere passed through the tube.

In his most recent work Fredenhagen[21] has expressed the view that in the case of the Wehnelt cathode the surrounding gas is essential in producing discharge. In fact, I at one time observed a considerable increase of the intensity of the cathode rays as the gas pressure was raised; this is given in the following table:

Pressure	4.2	16.0	17.0	17.6	19.0	20.0	21.0×10^{-5} mm. Hg.
Current at the receiver	<0.15	1.5	2.0	2.4	2.6	3.4	4.4×10^{-7} Amprs.

But all later experiments to confirm this result showed, however, *that the discharge current does not vary with the pressure of the gas* (up to pressures of 4×10^{-5} mm. of mercury). The increase in the current observed could be explained on the hypothesis that the calcium oxide becomes dissociated in a high vacuum into $Ca_2 + O_2$ and emits more electrons according as it becomes regenerated with rising pressure.

3. Intense cathode rays of 20,000 volts and more velocity could be produced by the influence machine which excited an intense yellowish green florescence on the glass wall. As long as the rays were not deflected

by the magnet the torsion balance did not display the slightest deflection and the galvanometer and manometer also were at rest even when there was a violent sparking between the balls of the machine. At a higher temperature of the cathode (yellow heat) the voltage diminished very greatly, florescence ceased and the discharge space was perfectly dark. *In spite of this a cur-*
[21] *rent of 1 milliampere passed through the tube.* The pressure rose only slightly (with this current).

4. The position of the deflecting magnet was adjusted until the rays fell in the opening of the aluminum ball as much as possible without touching the edge. *The florescent spot* excited on a spot on the ball was surrounded by a diffused region due to the rays deflected from the wall of the tube. This region disappeared when diaphragm D_3 was used. In the last stage of my work, in order to find the best position for the torsion balance, I used a strip of glass coated with "Sidotblende" in place of the ball and mounted the magnet in such a way that a uniform sharply defined supply of florescence (8 mm. in diameter) appeared on this screen. The spot was located by two reading telescopes, the axes of which formed an angle with one another, and later the opening of the ball was moved to this position. With this adjustment the intensity of the reflected rays then diminished to 3.6—10%, whereas formerly they amounted frequently to 50% of the incident rays.

5. The intensity of the current conducted from the torsion balance was under the best conditions 1×10^{-5} ampere (therefore 1% of the total discharge current). We proved that the resulting charging of the torsion balance to about 0.04 volt did not produce any electrostatic attraction: A charge up to 2 volts gave a deflection on the scale of 0.4. We have taken into consideration a slight disturbance to the armored galvanometer, due to the deflecting magnet. The torsion balance was not perceptibly affected by it. On the other hand, the

torsion balance gave a small deflection to one side when the damping magnet was energized, and to the other side when it was taken out of the circuit. But the damping ratio did not have to be changed during an experiment.

6. In a poor vacuum of a few thousandths mm. Hg. the torsion balance was turned by the impact of cathode rays almost to the point of contact. At a low pressure (about 6×10^{-5} mm.) it gave a deflection which was equivalent to three or four times the pressure from the cathode rays, as soon as the image had come to rest, but instead of remaining constant at a constant radia-
[22] tion intensity it increased rapidly at first and after a few minutes more slowly. Apparently therefore the deflection was chiefly due to the radiometer effect of the receiving electrode as it becomes heated. Although by observation at two different pressures we have a means of eliminating the radiometer effect (see p. 10) yet an attempt was made to make it smaller.

The best means would have been to heat the rear side of the receiving ball a known amount. But the change aimed at would have been very difficult with the apparatus employed.

Lebedew, in his work on the pressure of light,[22] has given an ingenious suggestion for preventing radiometer disturbances. If the radiation is absorbed on the inside surface of the floor of a (nearly) closed box, the front of which is a material which does not absorb the radiation (a very thin mica foil) the molecular activity which causes the radiometer effects will take place only between the floor and the cover of the box and consequently will not set the receiving system in motion.

Of course the cathode rays—in contrast to light—are perceptibly absorbed by the very thin films. In spite of this I attempted to apply this suggestion. The opening of the ball was closed with aluminum stretched taut and 6×10^{-4} mm. in thickness, which was fastened down with water glass.

Favorable results were not obtained with this arrangement. The radiometer effect was reduced but the [23] reflection of cathode rays by the foil was no less, as Starke[23) also found with thick aluminum sheets. With slow rays produced by a high-voltage battery, it rose under certain conditions to more than 50%. Electrons are reflected even on the outermost surface film of the receiver. (In one experiment (No. 10), the *observed* pressure was 1.8×10^{-5} dynes; the *calculated* effect on the most favorable assumption that the number of reflected electrons, 50%, is to be doubled, was 2.4×10^{-5} dynes). After some experiments of this kind the aluminum foil was again removed because the action of the reflected rays can be taken into consideration only in an inaccurate manner.

Nichols and Hull[24) recommend that radiation be allowed to act only a very short time, as the radiometer effect always increased with increased duration of radiation; in other words, that the *ballistic deflection* of the torsion balance be observed. They derive the following formula for the case of radiation equal to *one-fourth the time of vibration:* the ballistic deflection, A, is

$$A = \frac{L}{\Phi} \sqrt{1 + r + \frac{2}{\pi} \sqrt{r} \log \frac{1}{r}} \qquad (4)$$

in which L is the moment of torsion of the radiation pressure, Φ the moment of the suspension wire, and r the radio of two constructive amplitudes. If the oscillations are practically undamped ($r = 1$), the ballistic deflection, A, is $\sqrt{2}$ times the static deflection.

This method was used for the ensuing cathode-rays experiments. The time of vibration of the torsion balance was 42.3 sec., and the length of exposure 10.6. The $\sqrt{}$ was found to be 1.885, corresponding to the ratio:

$$r = \frac{A_2}{A_1} = 0.796$$

For the heating the carbon preliminary to experiment, the electric furnace which had been used for a year became useless on account of the destruction of the asbestos insulation. After it had been rewound, the temperature it gave was found to be lower than previously. The carbon was therefore heated in this case for about eight [24] hours, until the front vacuum of the Gaede pump, which was in constant operation, displayed no further increase in pressure. But in the concluding experiments the vacuum was substantially poorer, contrary to expectation, than in all the former ones. Attempts to bring it to its former value by means of the "Vorkohle" or the Gaede pump, were unsuccessful, because the carbon acted like a large reservoir of air and besides the newly made cathode evolved much gas. The reflection of the rays was also greater as in many earlier experiments: at 3,000 volts about ⅕ of the rays were reflected, and at 15,000-20,000 volts about $\frac{1}{20}$.

Although the experiments had to be stopped for other reasons we made a series of measurements which are contained in the following table. However, owing to the relatively high pressure we did not proceed on the principle of determining the radiation pressure in an absolute vacuum by observations at two different gas pressures.

In the first column of the table is the number of the experiment, in the second the potential accelerating the cathode rays, and in the third the intensity of the current from the receiver. Then follows the ballistic deflection of the torsion balance and the pressure calculated from this. Then the pressure of the rays calculated from the current intensity and voltage (assuming that the reflected fifth (experiments 12-28) or twentieth (32-38) of the cathode rays are to be counted double). In the next to the last column is the quotient of the observed to the calculated pressure effect, and in the last column the gas pressure.

A study of the tables shows that the observed effect is always considerably higher owing to radiometer action than the calculated effect so that there can not possibly be any question of a "measurement" of the pressure of the cathode rays. (At any rate Starke found the ratio of observed to calculated cathode ray effect to be about 50 when he used the most favorable disk arrangement, while we found it to vary from 3 to 12). It is [25] also observed that the ratio increased with increasing pressure—as would be expected.

Number	Volts x 10^3	Amperes x 10^7	Deflection of Torsion Balance	Observed Pressure p x 10^6 dynes	Calculated Pressure p x 10^6 dynes	$\frac{\text{p Observed}}{\text{p Calculated}}$	Gas Pressure x 10^4 mm. Hg.
12	2,81	2,25	5	17,5	4,02	3,12	2,25
13	2,63	1,9	4,5	15,7	4,62	3,41	"
14	2,60	2,7	9,2	32,3	6,53	4,95	3,26
15	"	1,97	4,2	14,75	4,76	3,1	"
16	"	1,89	5,0	17,55	4,58	3,15	—
17	"	2,6	11,0	38,6	6,30	6,13	5,94
18	"	2,25	9,0	31,6	5,50	5,75	"
19	3,20	2,95	9,3	32,7	7,91	4,13	5,11
20	"	2,50	11,5	40,4	6,58	6,13	5,37
21	"	8,35	47,5	166,7	22,37	7,45	9,55
22	3,25	4,85	29,0	101,7	13,02	7,80	7,25
23	"	8,60	43,5	152,8	23,12	6,61	10,2
24	3,10	4,30	40,0	140,5	11,34	12,8	18,1
25	"	15,0	141	495	39,2	12,6	"
27	"	2,1	22	77,3	5,49	14,1	21,75
28	3,07	4,12	33	115,8	10,8	10,7	13,8
32	17,5	3,25	64	224,5	16,0	14,0	8,18
33	15,5	7,10	109	381,5	33,0	11,55	"
34	14,0	11,20	228	800	49,5	16,35	9,10
35	20,0	9,40	160	561	49,6	11,30	"
36	19,0	11,85	220	773	60,8	12,7	10,3
37	17,5	7,40	240	843	81,4	10,4	11,8
38	18,5	15,0	>240	>843	76,2	>11,1	14,5

Assuming that the cathode-ray pressure has the value required by the theory and that the radiometer [26] effect is proportional to the pressure 25) we may find by calculation from the values in the table that the radiometer action at a mercury pressure of 4×10^{-5} mm.

(at which we had observed intense cathode rays) amounts to about ⅗ of the cathode ray effect and at 5×10^{-6} mm. Hg. to $\frac{1}{20}$. Accordingly, we would have to calculate accurately up to within a few per cent the cathode-ray effect which is free from radiometric disturbances at these pressures. Next to these disturbances the reflection of the rays is most difficult to avoid and to take into account. Other sources of error, such as possible inaccuracy in the energy equation, the divergence of the cathode rays, and the retardation of the electrons by the gas residue, have little importance in comparison with this.

To conclude from these investigations,—the method described offers a possible means of measuring up to within a few per cent the pressures of cathode rays, but it does not appear probable that measurements can be made of sufficient accuracy to determine from the same data the value of ε/μ or to make a decision between the relative and absolute theory. As a side issue it is found that it is possible to maintain a vacuum of 8×10^{-7} mm. Hg. by means of charcoal in a Dewar flask containing liquid air, and to measure the vacuum by a Knudsen manometer and that with a Wehnelt cathode in action a vacuum of 4×10^{-5} mm. Hg. can be maintained.

Munich, December 1912.

NOTES

1. W. Crookes, Ann. de Chim. Phys. 19 p. 195-231 (p. 214) 18; Phil. Trans. 1, p. 152, 1879.
2. J. Puluj, Radiant Electrode Matter Physikal Societys Reprint of Memoris, p. 275; Wiener Ber. 81, p. 60, 1880.
3. E. Riecke, Wied. Ann. 66, p. 954. 1898.
4. H. Starke, Ann. d. Phys. 3 p. 101. 1900.
5. E. Warburg, Wied. Ann. 45, p. 1. 1892.
6. A. Joffé, Ann. d. Phys. 34, p. 1026. 1911.
7. O. V. Bayer, Phys. Zeitschr. 10. p. 178. 1909.
8. The cathode, the path of the ray, and the opening in the brass plates lay well back of the plane of the drawing, but are shown in the drawing to avoid the necessity of a second figure.
9. A. Wehnelt and F. Jentsch, Ann. d. Phys. 28. p. 537. 1909.
10. H. Starke, Ann. d. Phys. 3. p. 98. 1900. E. Gehrcke, Ann. d. Phys. 8. p. 81. 1902.
11. L. Austin and H. Starke, Ann. d. Phys. 9. p. 271. 1902.
12. We recommend aluminum solder put out by O. Nicolai, Boppard a. Rhein.
13. F. Kohlrausch, Lehrbuch der prakt. Physik. p. 225.
14. M. Knudson, Ann. d. Phys. 32. p. 809. 1910.
15. Donated by the firm.
16. M. Knudsen, Ann. d. Phys. 34. p. 593. 1911.
17. The more exact formula of Knudsen ($T_2 - T_1$ not $< T_1$) gives $7{,}9 \times 10^{-7}$ mm Hg.
18. J. Koenigsberger u. J. Kutschewski, Ann. d. Phys. p. 161. 1912.
19. K. Schiel u. W. Heuse, Zeitchr, f. Instrumentenk. 29. p. 46. 1909.
20. M. Knudsen, Ann. d. Phys. 31. p. 205. 1910.
21. K. Fredenhagen. Verh. d. Deutsch. Phys. Ges. p. 385. 1912.

22. P. Lebedew, Ann. d. Phys. 6. p. 433. 1901.

23. H. Starke, l c.

24. E. F. Nichols and G. F. Hull, Ann. d. Phys 12. p. 225. 1903.

25. This assumption implies that the receiver has absorbed no gas film, the thickness of which is independent of the pressure in the discharge tube. But such a coating could be removed by heating the receiver (by means of cathode rays).

DEFENDANT'S EXHIBIT No. 36.

J. H. CLOUGH.
INCLOSED ARC DEVICE.
APPLICATION FILED OCT. 30, 1915.

1,246,054. **Patented Nov. 13, 1917.**

Fig. 1.

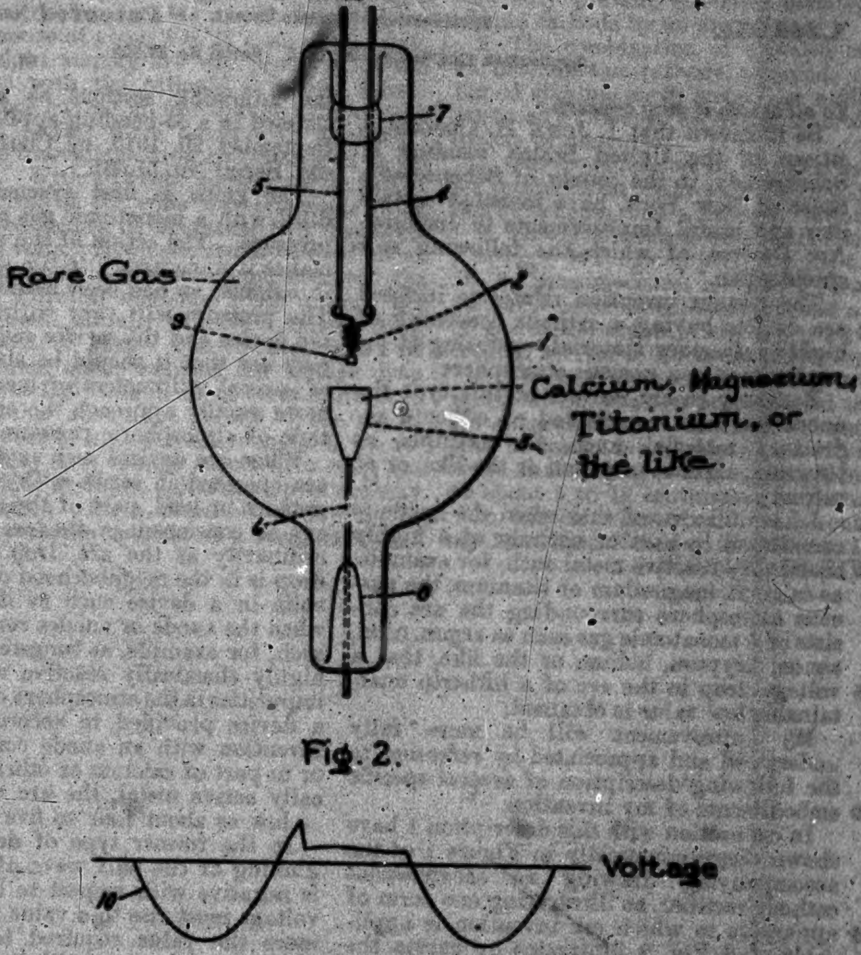
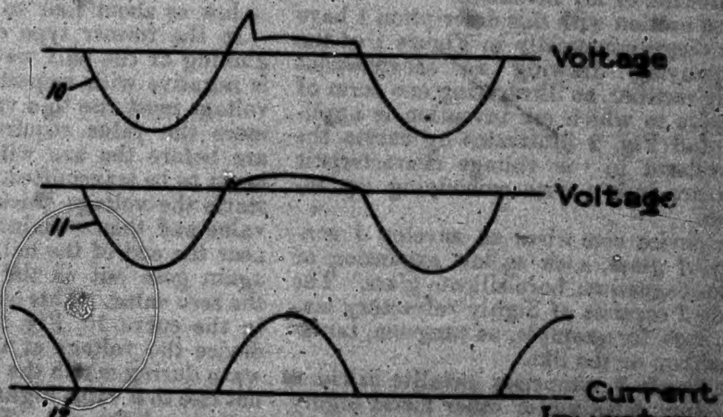

7
5
4
Rare Gas
2
9
1
Calcium, Magnesium, Titanium, or the like
3
6
8

Fig. 2.



Inventor:
John H. Clough,
by
His Attorney.

UNITED STATES PATENT OFFICE.

JOHN H. CLOUGH, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

INCLOSED-ARC DEVICE.

1,246,054. Specification of Letters Patent. Patented Nov. 13, 1917.

Application filed October 20, 1915. Serial No. 56,902.

To all whom it may concern:

Be it known that I, John H. Clough, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Inclosed-Arc Devices, of which the following is a specification.

The present invention relates to inclosed arc devices having a cathode consisting of highly refractory material, operating at incandescence in a gaseous atmosphere.

Formerly in arc devices of this type the anode has been constituted of either a refractory material, such, for example, as tungsten, carbon, tantalum or the like, or of mercury.

I have discovered that when the anode is constituted in part or entirely of a highly chemically reactive metal such, for example, as calcium, magnesium or titanium, the gaseous atmosphere surrounding the arc consists of a monatomic gas such as argon, neon, xenon, krypton, helium or the like, that a voltage drop in the arc of a hitherto unattainable low value is obtained.

My improvement will be more fully understood and appreciated by reference to the following description of several specific embodiments of my invention.

In connection with this description I have shown diagrammatically in Figure 1 of the accompanying drawing an incandescent cathode rectifier, as illustrating one form of apparatus to which my invention is applicable, and Fig. 2 illustrates by curves the improvement in the voltage characteristic on an arc in a device embodying my invention.

The device comprises an envelop 1 consisting of glass, such as low expansion or sodium-magnesium boro-silicate glass. The cathode 2 consists of highly refractory material, such for example, as tungsten, tantalum, carbon or the like.

The anode 3 comprises metallic calcium, magnesium, titanium or other metal highly reactive chemically to gases other than the inert so-called rare or monatomic gases. The cathode current supply wires 4, 5 and the anode conductor 6 are sealed into the stems 7, 8 in the usual manner. The cathode is preferably provided with a tip 9 having a somewhat greater diameter than the adjoining sections as described and claimed in a co-pending application filed on September 20, 1915, by Charles V. Ferguson, Serial No. 51,661.

The globe is first evacuated and then filled with a monatomic gas at considerable pressure. The action of the anode material makes it unnecessary to use such great care in exhaust as has been necessary formerly. The pressure will vary with the nature of the device and the service required of it. I may say that it should be above a pressure of several millimeters of mercury and will more usually approach the order of magnitude of atmospheric pressure.

When arc devices such as described above are operated in series with an external resistance or load, part of the impressed voltage is consumed in the arc itself, known ordinarily as the arc drop. This voltage drop is in the neighborhood of about twenty volts in a device such as described above when the anode or anodes consist of a metal such, for example, as tungsten, which is not highly chemically reactive with respect to impurities in the atmosphere of inert gas. In a device provided in accordance with my invention with an anode consisting wholly or in part of calcium or other highly chemically active metal, the arc voltage drop is as low as about four to five volts.

In the former type of device at the beginning of the half wave of current which is negative with respect to the cathode, the voltage must rise to a value about double or more the value required to maintain the arc before the arc will start and current begin to be transmitted. As soon as the arc starts the voltage quickly drops to a lower value and then remains nearly steady until near the end of the half wave when the arc again goes out as the voltage approaches the zero value. This condition is illustrated in the curve 10, Fig. 2. In my improved device the voltage at the beginning of the wave during which the arc is operating does not rise to a value higher than the operating voltage of the arc. This result as far as I am aware is entirely new. As illustrated by the curve 11, the voltage wave rises from zero to a value high enough to operate an arc, then as the arc starts the voltage drops to a slightly lower value for an instant and again rises to approximately the value at which the arc started and after rising slightly falls to zero while the current as shown in curve 12 rises from zero to a maximum value and falls again to zero. The high initial voltage peak observable in curve 10 is lacking.

The improvement effected by my invention may be illustrated by the following specific example. Argon was introduced into a device, such as above described, at a pressure of about 5 to 12 c. m. of mercury. An eight ampere arc was produced in the device with the cathode at bright incandescence having an arc voltage drop of 10.4 volts. After three hours with a calcium anode the voltage drop had decreased to 7.8 volts. With a twenty ampere arc an initial arc drop of 6.9 volts was observed which in three hours of operation had decreased to 4.5 volts. In a neon atmosphere of about ½ atmospheric pressure, purified by the usual chemical methods, a ten ampere arc was found initially to have a voltage drop of about 58 volts. The chemical effect of a calcium anode reduced the voltage drop to about 12.5 volts in about forty minutes.

Another advantage gained by the use of electrodes of highly reactive metal is the remarkably low voltage required to start the arc. For example, a fifteen ampere arc may be started with a potential as low as 14 volts with the cathode at a temperature of 2500° C.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination of a sealed envelop, a cathode of highly refractory material proportioned to operate at incandescence, an anode consisting in part at least of highly chemically active metal and a filling of rare gas having a pressure high enough to substantially prevent electrical disintegration of said cathode by an arc.

2. The combination of a sealed envelop, an incandescent cathode, an anode consisting of alkaline earth metal, and a filling of argon at a pressure exceeding several millimeters of mercury.

3. The combination of a sealed envelop, an incandescent cathode, an anode consisting of calcium, and a filling of argon.

4. The combination of a sealed envelop, a cathode of tungsten proportioned to operate at incandescence, an anode formed in part at least of metallic calcium and a filling of gas of the argon group at a pressure exceeding several millimeters of mercury.

5. The combination of a sealed envelop, a cathode of tungsten proportioned to operate at incandescence, an anode consisting in part at least of a highly chemically active metal and a filling of argon gas at a pressure of about 5 to 12 centimeters of mercury.

In witness whereof, I have hereunto set my hand this 29th day of October, 1915.

JOHN H. CLOUGH.

DEFENDANT'S EXHIBIT No. 37.

G. M. J. MACKAY.

IN[illegible]SED ARC DEVICE AND METHOD OF OPERATING THE SAME.

APPLICATION FILED OCT. 30, 1915.

1,208,597. Patented Dec. 12, 1916.

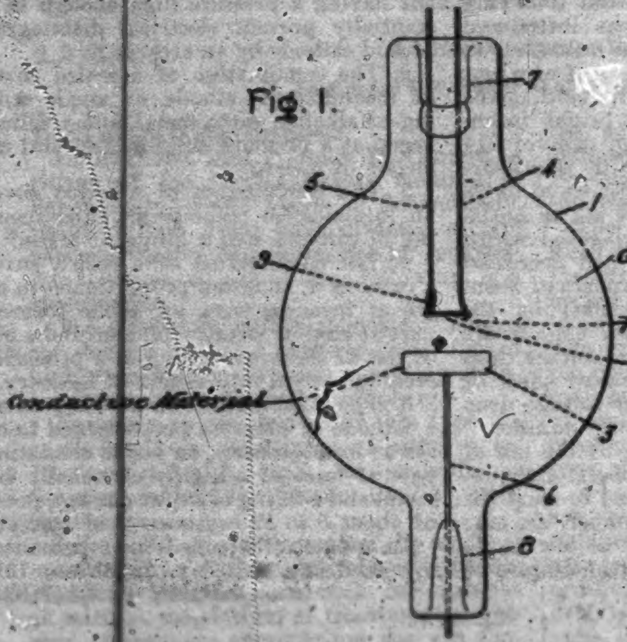


Fig. 1.
7
5
4
1
Gas Filling
9
Refractory Material
2
Conductive Material
3
6
8

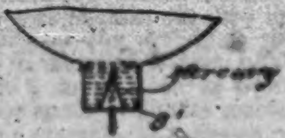


Fig.

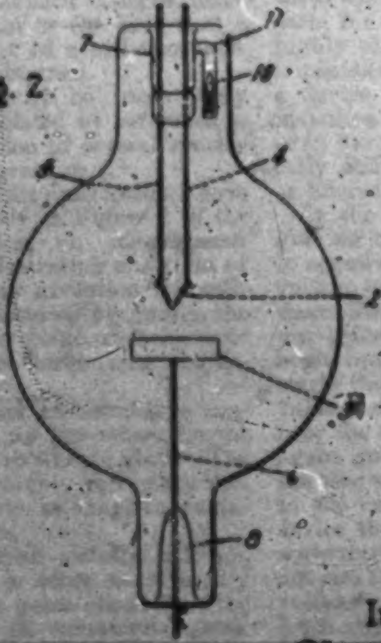


Fig. 2.
7
11
10
4
4
2
3
6
8

Inventor:
George M. J. Mackay.
by Albert
His Attorney

UNITED STATES PATENT OFFICE.

GEORGE M. J. MACKAY, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

INCLOSED-ARC DEVICE AND METHOD OF OPERATING THE SAME.

1,208,597. Specification of Letters Patent. Patented Dec. 12, 1916.

Application filed October 20, 1915. Serial No. 56,897.

To all whom it may concern:

Be it known that I, GEORGE M. J. MACKAY, a subject of the King of Great Britain, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Inclosed-Arc Devices and Methods of Operating the Same, of which the following is a specification.

The present invention relates to inclosed arc devices having a cathode consisting of highly refractory material operating at incandescence in a gaseous atmosphere.

I have discovered that a markedly lowered voltage drop or loss in the arc is secured in a device of this type containing gases protecting the electrodes from chemical deterioration and electrical disintegration when there is provided within the device a material as, for example, calcium and related alkaline-earth metals, magnesium, or non-metallic absorbents, such as phosphorous pentoxid, which, while having no affinity for the gaseous filling, is chemically active with respect to impurities in the gaseous filling, to produce compounds of negligibly low vapor pressure with the gaseous impurities. In the case of a filling of argon, the most deleterious of the gaseous impurities tending to increase the drop of potential in the arc appear to be water vapor, hydrogen and nitrogen.

My improvement will be more fully understood and appreciated by reference to the following description of several specific embodiments of my invention.

In connection with this description, I have shown diagrammatically in the accompanying drawing in Figure 1 by way of example, a device containing an incandescent cathode, upon which the material to be vaporized is applied and in Fig. 2 a device provided with a capsule containing the material to be vaporized. Fig. 3 shows a detail of a modification.

The device comprises an envelop 1 consisting of glass, such as low expansion or sodium-magnesium boro-silicate glass. The cathode 2 consists of highly refractory material having a melting point exceeding at least about 3000° C., such for example, as tungsten, tantalum, carbon or the like. The anode 3 consists of conductive material, for example, tungsten, carbon or other solids, but in some cases, a liquid such as mercury may be used, as indicated by anode 3′ in Fig. 3. The cathode current-supply wires 4, 5 and the anode conductor 6 are sealed respectively into the stems 7, 8 in the usual manner.

The globe is first evacuated and then filled with a suitable gas at considerable pressure. Removal of water vapor from the bulb by heating the bulb during evacuation is desirable but not so necessary as when no chemical addition is used in accordance with my invention. Various gases may be used depending on the character of the service required of the device. The monatomic gases of the argon group, also nitrogen, and carbon monoxid, have been used.

The gaseous pressure also will vary with the nature of the device. I may say that it should be above a pressure of several millimeters of mercury and will more usually approach atmospheric pressure in order of magnitude. In a device used for rectifying alternating current at low voltages, argon at a pressure of about 5 to 12 c. m. of mercury is found suitable.

The material chemically active with respect to deleterious gaseous impurities in the gas filling, or deleterious gases contained in the electrodes and the glass, may be vaporized by the cathode when heated to incandescence by passage of current, or may be simply placed in the globe in any convenient manner. Metallic calcium or magnesium may, for example, be introduced as a small strip of foil or wire 9 placed upon or wrapped about one of the cathode conductors and in proximity to the cathode so as to be vaporized by the heat of the arc or by the incandescent cathode. As shown in Fig. 2, the chemical addition may be placed in a small glass capsule 10 located in an open-ended tube 11. The tip of the capsule may be broken by shaking after the evacuation of the container is complete.

In devices containing a filling of nitrogen, phosphorous pentoxid is preferred for cleaning up water vapor and other gaseous impurities. In devices filled with a monatomic gas, such as argon, neon, krypton, xenon, or helium, I prefer to use calcium, magnesium or one of the related metals. Calcium vapor will absorb all gases except the very inert monatomic gases although phosphorous pentoxid may be also used with good results for purifying monatomic gases *in situ.* Solid phosphorous pentoxid, P_2O_5, in an argon-filled device will remove hydrogen, water vapor and apparently also nitrogen to some extent. Some of the pentoxid is reduced by the hydrogen, forming water vapor which is in turn absorbed by the remaining pentoxid to form a gummy phosphoric acid of very low vapor pressure.

The beneficial effect of the purifying agents used in accordance with my invention should not be confused with the chemical purification of the gases prior to their introduction into the envelop. The chemical agent placed in contact with the atmosphere within the arc device in addition to purifying the gas filling at the beginning of the operation of the device, acts continuously to remove traces of deleterious gas given off during its operation from the electrodes, and the glass envelop. Apparently the arc activates the gaseous impurities so that they combine more readily with the chemical agents within the bulb.

By the use of a gas-absorbing chemical agent in accordance with my invention, the potential drop, or loss in an incandescent cathode device is reduced to one-half, and in many cases even to less than one-half of the drop heretofore occurring in devices filled with the above mentioned gases purified most carefully only by known chemical methods upon their introduction into the device, thereby making in some cases a device efficient enough to be usable for commercial uses from which it would otherwise be excluded.

To give specific illustrations, I may state that an incandescent cathode device carrying about six amperes when filled with argon purified by ordinary methods has an arc drop of about 30 to 40 volts. When the envelop contains a small quantity of phosphorous pentoxid, as above described, the arc drop is reduced to about ten volts. Similarly a six ampere neon tube containing, at a pressure of about half an atmosphere, neon gas purified by the usual methods has an arc drop of about 50 volts. The same tube when provided with metallic calcium acting to purify the gas *in situ* in the manner above described has an arc drop of about 20 volts.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination of a sealed envelop, arcing electrodes therein, one of which is adapted to operate at incandescence, an atmosphere of gas chemically inert with respect to said electrodes and a material chemically active with respect to impurities in said gas acting to continuously combine with gaseous impurities evolved from the electrodes and walls of the envelop during the operation of an arc between said electrodes.

2. The combination of a sealed envelop, a cathode of refractory material adapted to operate at incandescence, a coöperating anode, a filling of gas inert chemically with respect to said electrodes and suppressing the electrical disintegration of the cathode and a material forming compounds of negligibly low vapor pressure with gaseous impurities tending to increase the fall of potential in the arc between said electrodes.

3. An arc device comprising the combination of a sealed envelop, a cathode of material having a melting point exceeding about 2000° C., a coöperating anode, a filling of monatomic gas having at the operating temperature of the device a pressure of at least several millimeters of mercury, and a material forming under the operating conditions of the device compounds of negligibly low vapor pressure with polyatomic impurities in said gas.

4. An arc device comprising the combination of a sealed envelop, a tungsten cathode, an anode, a filling of argon at a pressure materially greater than one millimeter of mercury pressure and a quantity of material chemically active with respect to water vapor.

5. The method of purifying the gaseous atmosphere surrounding an incandescent cathode and a coöperating anode in a closed envelop which consists in liberating during the operation of the arc in contact with said atmosphere a vapor having no affinity for said gaseous atmosphere but chemically active with respect to deleterious gaseous impurities given off by the envelop and said electrodes.

6. The method of lowering the voltage drop of an arc between an incandescent cathode and an anode in an atmosphere of argon which consists in vaporizing during the operation of the arc in contact with the argon a material combining with water vapor to form solid materials of low vapor pressure.

In witness whereof, I have hereunto set my hand this 29th day of October, 1915.

GEORGE M. J. MACKAY.

DEFENDANT'S EXHIBIT No. 38.

W. D. COOLIDGE.

TUNGSTEN AND METHOD OF MAKING THE SAME FOR USE AS FILAMENTS OF INCANDESCENT ELECTRIC LAMPS AND FOR OTHER PURPOSES.

APPLICATION FILED JUNE 19, 1912.

1,082,933. Patented Dec. 30, 1913.

Fig. 5.

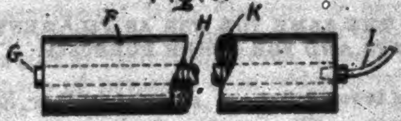


Fig. 3.

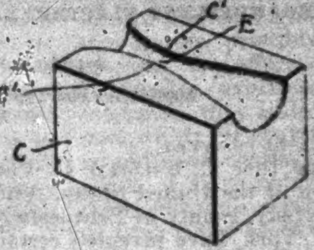


Fig. 1.

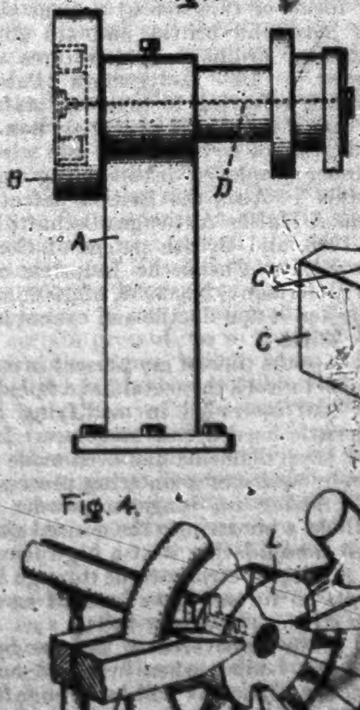


Fig. 2

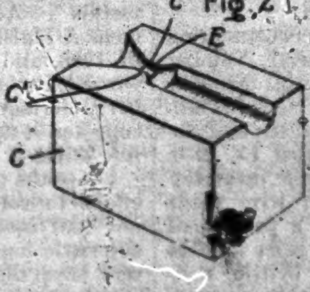


Fig. 6

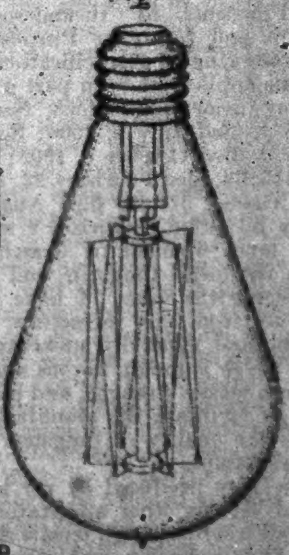
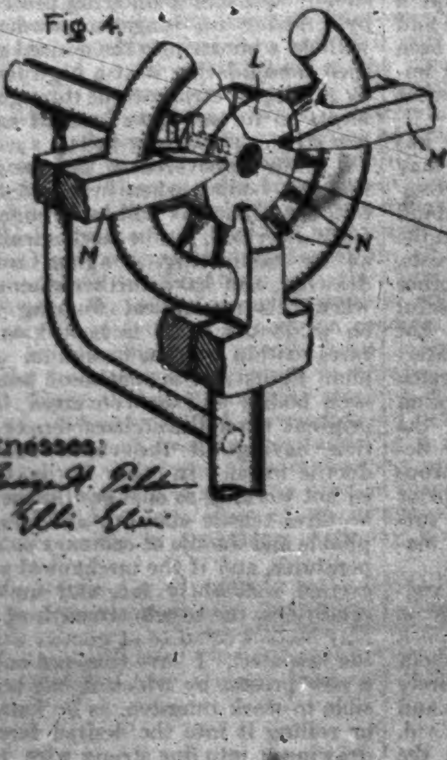
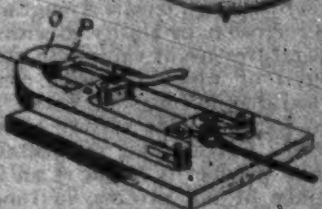


Fig. 4.





Witnesses:
George H. Tilden
J. Ellis Glen

Inventor:
William D. Coolidge,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

WILLIAM D. COOLIDGE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

TUNGSTEN AND METHOD OF MAKING THE SAME FOR USE AS FILAMENTS OF INCANDESCENT ELECTRIC LAMPS AND FOR OTHER PURPOSES.

1,082,933. Specification of Letters Patent. **Patented Dec. 30, 1913.**

Application filed June 19, 1912. Serial No. 704,[illegible]

To all whom it may concern:

Be it known that I, WILLIAM D. COOLIDGE, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Tungsten and Methods of Making the Same for Use as Filaments of Incandescent Electric Lamps and for other Purposes, of which the following is a specification.

This application is in part a continuation of my prior applicatons, Serial Number 324,335, filed July 2, 1906; Serial Number 521,220, filed October 6, 1909; Serial Number 545,974, filed February 23, 1910; and Serial Number 577,353 filed August 15, 1910.

My invention comprises a new incandescent lamp filament of drawn wire made from the metal tungsten, and a process of producing the same. I have been able to produce from this refractory, brittle, non-ductile and generally unworkable metal a wire which is tough, fibrous and elastic and of high tensile strength, and have thus been able to facilitate the manufacture and improve the quality of tungsten incandescent electric lamps.

The wire produced by my invention has found various other applications, and may be used wherever high tensile strength, freedom from corrosion, or ability to withstand high temperatures are of value. So also the new material of which the wire consists, fully worked ductile tungsten, has in other mechanical forms a wide variety of useful applications. Further, an incidental but valuable new product is found at an intermediate stage of my process, in tungsten which is wrought, but in which the working process has been interrupted before the above described properties have fully developed but at a point where desirable properties not found in any tungsten of the prior art have been developed to an amount sufficient for the purposes for which the material in question is to be used.

The metal tungsten is described in standard works on chemistry and metallurgy as obtained in the form of a steel-gray to black powder, having a fusing point of about 3200 degrees C. It is stated to be entirely non-ductile. Thus, for example, Roscoe and Schorlemmer's *Treatise on Chemistry*, vol. II, p. 1058, published in 1907, cites the work of Moissan, but states that: "The purest forms of tungsten at present obtainable are hard and brittle, and are not ductile either at ordinary temperatures or when heated." De Lodyguine's Patent No. 575,002, referring to tungsten, states (page 1) that it is "almost absolutely non-ductile" and "cannot be drawn out into wires in the manner employed in operating on ductile metals". Also, the British patent of Siemens & Halske Aktiengesellschaft, No. 5387 of 1908, and British patent of Consortium fur Elektro-Chemische Industrie of Nurnberg, Germany, No. 3938, of 1907, state that tungsten is non-ductile and cannot be drawn into wires.

Up to the time of my present invention all efforts to work the metal have failed, and no one had succeeded in modifying its characteristic hard brittle structure. Incandescent lamp filaments had been made of tungsten by means of a sintering process, that is, by pressing up tungsten powder with or without a binder into the desired shape, and then consolidating it at a high temperature by passing electric current through it. Filaments so formed have been of exceedingly low strength and very brittle.

I have discovered a process by which tungsten bodies, when prepared under certain conditions, as will be hereinafter more fully described, can be mechanically worked as by hammering, swaging, rolling and drawing, and have further discovered that when this mechanical working is carried on while the metal is heated to temperatures within certain maximum and minimum limits and is continued long enough, such bodies will be converted from their original crystalline character to a condition having all the characteristics of a ductile metal. In other words, the repeated hot working so changes the metal that it acquires tensile strength and also becomes pliable and ductile at ordinary or room temperatures, and if the mechanical working is carried sufficiently far, and under proper conditions, the tensile strength of the metal may become equal to or greater than that of the best steel. I have thus not only devised a new process by which it has become possible to work tungsten, as by hammering it or rolling it into the desired form, and by drawing it into fine strong wire, but I have also produced by the operation of this process a new product, viz: wrought tungsten, and, if the process be carried far enough, ductile tungsten, a material having properties and utilities different from those of any previously known substance. When it is desired to produce from this material an incandescent lamp filament, or any other body which in normal operation is to be operated at high tempertures, I use a special mode of preparation in order to minimize the tendency of the tungsten to revert to a brittle crystalline form. When this crystallization becomes excessive the crystals may, in the case of a filament, become so large as to extend across the entire section of the filament and thereupon the sections may move laterally upon each other and produce the condition known as "offsetting". I shall hereinafter describe more in detail the special method which I employ for minimizing the loss in ductility and for preventing this offsetting effect.

My process divides itself into two stages, first the preparation of an ingot or billet of tungsten, and second the working of the ingot, and I find that the more successfully the ingot is prepared the more quickly and readily it can be worked. Also, by using certain precautions in working I am able to handle ingots which have not been prepared in the best possible way. I have no doubt that with the progress of the art improvements will be made in my process whereby the ingot will be so prepared that its working becomes much easier than it now is, or whereby, through improvements in the working, less care and skill will be required in the preparation of the ingots. I will, however, first describe in detail a process which I have worked successfully on a large scale for the production of drawn tungsten wire of the highest quality suitable for filaments for incandescent lamps and by means of which a single tungsten wire seven miles long has been produced, and will thereafter describe certain of the numerous modifications of the process, within the scope of my invention, which may be resorted to as occasion requires.

In describing this process I will refer to the accompanying drawings in which—

Figure 1 shows a swaging machine, Figs. 2 and 3 are detailed views showing different forms of swaging dies; and Fig. 4 is a view of one form of wire-drawing apparatus, and Fig. 5 shows an electric furnace, and Fig. 6 is a view of an incandescent lamp made in accordance with my invention.

Starting with tungstic oxid (WO_3) as pure as commercially obtainable, I dissolve it in ammonia water and thus form ammonium tungstate, which is purified by crystallization over a steam bath and is then, after washing by distilled water and drying, decomposed by the application of moderate heat, say 400 to 500 degrees C. which drives off the ammonia and leaves purified tungstic oxid. The tungstic oxid thus purified is heated in a gas furnace for about five hours in a covered Hessian or Battersea crucible of the ordinary and well known type, after which step it is found to be coarser and of higher density and to contain matter, probably volatilized from the crucible, the effect of which, as will be hereinafter explained, is beneficial. The substances thus added to the oxid of tungsten, which for convenience I may designate as additions, consist largely of alumina, and silica. I have obtained best results when these additions occurred in the proportion of from 0.8 to 1.5 of one per cent.

If on analysis it is found that less than say 0.8 of one per cent. of additions is present, the operation of firing in the Hessian or Battersea crucible is repeated as many times as may be necessary, a new crucible being used each time. The material, which has somewhat melted and agglomerated into a mass, is ground after each firing.

The next operation is performed in a tube, for example of porcelain or fused quartz, having a diameter of one and one-half inches and a length of two feet. This tube is packed nearly full of tungstic oxid except that clear spaces are left at each end, and the tube is gradually raised by suitable gas burners or by electrical heating, in six or seven hours, to a temperature which may be between 900 degrees C. and 1150 degrees C. I may if preferred use the type of furnace described by Winne and Dantsizen in the *Transactions of the American Electrochemical Society*, vol. XX, 1911, pp. 289–90. Crystallinity in the metal powder is to be avoided and this result is aided by this slow raising of temperature. Pure, dry hydrogen passes through the tube during this heating operation for a period of say six to fifteen hours, and is preferably introduced through a small passage formed in the upper part of the charge next to the containing tube; which arrangement leaves a thick body of the charge to be acted upon by the hydrogen. In this operation the tungstic oxid, or as it is called the "yellow oxid," is progressively reduced to the blue oxid and then to the brown oxid and then to the pure metal. The powdered tungsten thus formed is inserted, in weighed quantities, into a steel mold and is by means of a hydraulic press pressed into sticks or rods which may for example be ¼ of an inch square and six inches long, though good results have also been obtained with octagonal rods.

The mold is of extreme strength and rigidity and is arranged to apply the pressure transversely of the stick to be formed. The powder is evenly placed in the mold so that the sticks shall be of uniform density from end to end.

When the pressure is removed the mold is split or opened and the pressed tungsten stick is gently slid on to a strip for example of molybdenum or tungsten and introduced into a tube of some such material as porcelain or alundum electrically heated by a winding of tungsten or platinum wire, in which apparatus the tungsten stick is fired in an atmosphere of hydrogen to a temperature of say 1200 degrees C., for from ten minutes to an hour, or long enough to permit the sticks to become strong, so that they may easily be handled. The molybdenum support may be withdrawn when the stick has been brought to a bright red heat.

The pressing operation which I have just described is performed with dry tungsten powder but I may if desired use a binder which must afterward be removed. If the binder is carbonaceous, the carbon may be removed by heating the sticks in moist hydrogen or if desired in hydrogen containing a small amount of air.

If the tube in which the heating or firing operation is performed is made of porcelain, I fire the stick on a "boat" of suitable material such for example as molybdenum.

The fired sticks are then placed, one at a time, in a closed treating vessel, ordinarily of copper and similar to those commonly used in sintering tungsten filaments, but larger and of more rugged construction, through which hydrogen or other reducing atmosphere is constantly passed, and an electrical current is passed through them sufficiently intense to raise them to a blinding white heat. This sinters the stick and converts it into a coherent slug of metal. While in the treating vessel the sticks are held in water-cooled spring clamps, one of which is carried by a fixed support while the lower one dips into a water cooled pool of mercury so as to adjust its position as the stick shortens up during sintering. In some cases I water cool the bottle itself, and I find it best to cover the lower edges of the bottle with a mercury seal.

I prefer with the ¼ inch rod six inches long to sinter at 1700 to 1800 amperes (alternating) for fifteen minutes, the current being gradually raised to this point in say about five minutes, and then to reduce the current by degrees until at the end of one minute or more it is cut off altogether, whereupon the rod may be withdrawn as soon as it cools sufficiently to allow the treating vessel to be opened. This slow reduction of the current is intended to prevent a sudden reduction of gas pressure in the treating or sintering vessel, which would tend to draw in air and produce an explosion. After the sintering operation, the ends of the slug held by the clamps and therefore but partially sintered, are broken off. This completes the preparation of the slug or billet.

The next step is the mechanical working, which, in the particular process I am now describing, is carried on as follows: In Fig. 1 A is a swaging machine which may be of the general type shown in United States patent to Dayton, No. 515,576, February 27, 1894. In this machine the head B is rotated and a pair of dies each like the dies shown for example in Fig. 2 or Fig. 3 are brought together and then separated several times in each revolution. The head B carries the swaging dies and their operating mechanism and through the machine extends a horizontal passage D for receiving the work as it passes through the dies. The dies C, unlike the ordinary swaging dies, have very short faces E, about equal in length to the diameter of the tungsten piece passing between them. The edges C' in the working surfaces are rounded or "backed off" to keep the die from digging into the rod. In some cases a die may be used having a peculiar form of face, shown in Fig. 3, in which the edges of the striking portion or face of the die are rounded off gradually.

In Fig. 5, F is a tube furnace of the type described in the Winne and Dantsizen article above referred to. It consists of a tube G of alundum or porcelain; a winding of wire H of platinum or preferably tungsten or molybdenum through which an electric current may be passed, and a heat insulating cover K of magnesite, fine silica or other suitable material held by a suitable shell or casing of asbestos, fire brick, sheet iron or the like. Hydrogen is passed through the tube G in any suitable way as by the pipe I. The operator grasps with a pair of tongs one of the tungsten billets or slugs and inserts it in the furnace, which is in some convenient location near the swager, and leaves it there until it attains a high temperature, say 1300 to 1700 degrees C., and at which, when the billet is removed from the furnace into the open air, it gives off a cloud of volatilized oxid of tungsten. He then takes the smoking hot billet with the tongs and quickly thrusts it as far as he can into the swaging machine and as quickly withdraws it. The swaging machine runs at high speed and care should be taken to keep the slug in rapid motion into and out of the dies so as not to cool it materially. The dies are chosen so that each shall produce only a slight decrease in the cross-section of the billet and if the billet is square it is necessary to use care in passing from the square to the circular form, which form is of course produced by the action of the dies, and ordinarily the dies should be so adjusted that several passes through different dies occur in the production of the circular form.

The billet after being inserted in the first dies is reheated in the furnace, then grasped by the other end and, without changing the dies, quickly thrust into the swaging machine, and quickly withdrawn as before. As many billets as may be ready for treatment are thus manipulated and then the dies are removed and other dies are inserted arranged to produce a somewhat smaller section, and so on.

Starting with the ¼ inch square billet, I am able with five (5) passes through the machine to obtain a circular rod of 210 mils. in diameter. From 210 mils. to 60 mils. I ordinarily proceed by ten steps. As the billet becomes longer and smaller in diameter I may use a gas furnace or heater instead of the electric furnace and a smaller size swaging machine, and the billet, which is now a wire or rod, is drawn by the action of mechanically driven feed rollers through the gas flame of a gas furnace, which is then located in front of the swager, and through the swaging dies, passing completely through the opening corresponding to D in Fig. 1, and when this arrangement is adopted only one pass is necessary with each die setting.

The swaging operation is continued, with continual reduction of the dies, until in six or seven more operations the wire has been reduced to thirty mils. diameter. The temperature to which the rod is heated, which was originally at white heat, is reduced at the diameter of about 40 mils. to a yellow red and this temperature is maintained to the end of the swaging operation; that is to say until a diameter of 30 mils. has been reached. At or by this time the material has become ductile at room temperature and can be bent and otherwise manipulated.

The wire drawing die L, Fig. 4, consists of a drilled diamond set in metal, held by supports M and heated by a number of gas jets N. The wire is pointed by dipping the end in fused potassium nitrite, as is disclosed in the Whitney Patent No. 1,008,762, and the pointed end is then inserted in the die and grasped by the clamp O, which may be heated at the point where it holds the wire by a gas jet P, or the operator may merely grasp by a pair of pliers the end of the wire where it emerges from the die and pull a few feet of it through the die and attach the end to a spool or spindle which is revolved by power. In this manner the whole length of the wire resulting from the swaged billet is drawn through the die, but before it passes through the die it should pass through a bath of a material known as aqua dag, which I understand is a deflocculated graphite suspended in water, or of oil dag, which is a similar preparation in which oil is used instead of water as a suspending medium. This is done in the manner set forth in the Dempster Patent No. 1,022,182. The die should be at a temperature of 600 to 650 degrees C. and the wire should be red hot both when going into the die and when emerging therefrom.

Further reduction is accomplished in the same way, the dies varying by one mil. steps down to 14 mils., making 16 drawing operations from 30 to 14 mils. At 14 mils. or thereabout the temperature of the dies may be reduced below a red heat, but the wire itself is run red hot through the die down to sizes approximating 3 mils.

From 14 to 5.5 mils. the dies should vary in steps of one-half of a mil., making 17 additional operations; from 5.5 mils. to 4 mils. there are five operations with steps of ¼ of a mil.; from four mils. to 2 mils. there are 0.2 of a mil. drafts; and from 2 mils. to 1.4 mils. there are six operations with steps of $\frac{1}{10}$ of a mil.; and from 1.4 mils. to 0.5 mil. there are 18 operations with one twentieth of a mil. draft.

As the wire reaches smaller sizes the method of pointing described in the Whitney patent above mentioned becomes inconvenient, and instead the wire is dipped in a strong solution of potassium cyanid, and current is passed through the wire in such a direction as to make it an anode. Of course the wire drawing may be stopped at any stage according to the size of wire desired.

The metal obtainable as the ultimate result of the operations above described is a new product differing radically from any form of tungsten heretofore obtained. Not only is it pliable and ductile at room temperature, but it is strong and tough. It is substantially non-oxidizing in moist air at ordinary temperatures and resists the action of acids to an unusual degree. Its specific gravity is higher than that of sintered tungsten and has been found in certain samples to run from 19.15 to 19.3. It has an exceedingly high tensile strength, as high in particular samples of .001″ diameter as 600,000 to 650,000 lbs. per square inch, is non-magnetic and not easily corroded, and is elastic and resilient.

The material has a wide variety of technical uses. If used for filaments of incandescent lamps, it may be mounted as described in the Feuerlein Patent, No. 819,009, April 25, 1906, as shown in Fig. 6 of the drawings hereto attached. Before this is done, however, the wire may if desired be freed from impurities on its surface in some suitable manner as by passing it through a bath of hot caustic soda and then through a suitable wiper. When run in the lamp the drawn tungsten filament made as described loses much of its strength but is then, if carefully prepared in accordance with the directions herein given, nevertheless a much stronger filament than that made by ordinary squirting processes. To guard against this loss in strength, the filament should not be run at a very high temperature in the lamp until the lamp has been sealed off from the evacuating pump.

If my new material is used as the target of an X-ray tube it gives the tube a life and constancy of vacuum far superior to that possible by the use of a target of any other known material. It presents many advantages for use as contacts for magnetos and other devices where making and breaking of a circuit occurs, and is for such purposes far preferable to platinum and other materials now in use.

For certain applications the complete working process resulting in an entirely ductile metal of great tensile strength is not required. For example, after a certain amount of rolling or swaging, depending on the amount of softness and strength which the metal should have for the purpose for which it is to be used, or without any swaging or rolling whatever if great strength is not necessary in the finished product, I can heat the metal, for example in an alundum tube furnace, and hammer it into any desired shape, shear it, or roll it into plates, and from these plates I can punch parts of any desired configuration provided that the material has been prepared in accordance with the directions above given, and that the operation, whatever it may be, is performed, except in cases where the fiber has been very thoroughly developed by long-repeated mechanical working, at a sufficiently high temperature. When I have desired to produce a number of identical pieces I have resorted to a drop-forging operation.

The metal produced even by incomplete working differs markedly from any form of tungsten heretofore known, for example, it is stronger and tougher and less liable to cracking on unequal heating and cooling. When the working is fairly complete, the crystals characteristic of sintered tungsten have been deformed, broken up and elongated to such an extent that the structure is fibrous. When the working is less complete the crystals are broken up, though to a less extent, and are deformed as by elongation or flattening, according to the nature of the working process. When, for example, the billet is hammered into a plate or sheet, the crystals are found to have become flattened.

An important point in practising the above described method of carrying out my invention is the temperature to which the metal is raised and at which the several operations are carried on. Where it is desired that the resulting metal shall have the properties of a wrought metal more or less pliable and ductile at ordinary temperatures, it is not only necessary to repeat the mechanical working a large number of times, but it is necessary to keep at all times within a certain range of temperature at least during the later stages of working. It is necessary, on the one hand, that the temperature be high enough to make it possible to mechanically work the body, but, on the other hand, too high a temperature is objectionable because if the temperature is too high a tendency appears to lose fiber already acquired and to pass to a state of brittleness from a state of ductility. The range of temperatures within which properly prepared tungsten bodies may be worked to produce ductility at room temperature in accordance with my invention varies with the particular material used, but according to my experience heating the metal to or working it at a temperature corresponding to white heat and materially in excess of about 1500° C. will tend to prevent, with any tungsten metal which I have been able to produce, the formation of fiber and will tend to destroy fiber which has been produced by previous working. On the other hand, an excessive amount of mechanical working tends to cause the bodies to become so fibrous and hard as to split up and break. I have found that this result may be obviated by carrying on the mechanical working during the early stages at such temperatures as enable the body to be worked and reduced in size but without causing any special change in the structure of the metal. These temperatures may correspond to a white heat or thereabout but should be above a temperature which I estimate at about 1500 degrees C. At the proper stages of the process the temperature is reduced to 1200 degrees C., or lower, whereupon as the mechanical working progresses the improvement in the structure of the metal begins.

The preparation of a tungsten body which is to be mechanically worked is an important feature of my invention, for it is not every tungsten body which is susceptible of mechanical working. For example, Moissan states (*Comptes Rendus*, vol. 123, pp. 13–16, 1896–7) that he obtained by heating tungstic acid and sugar carbon in a carbon crucible an ingot or melt which presented well fused superficial portions, but which was porous in its interior portions. Of this product Moissan says that when it is in a porous condition it has, like iron, the property that it may be consolidated (*la propriété de se souder à lui-même*), by hammering much below its point of fusion.

Subsequent investigators have expressed the opinion that the material which Moissan obtained was not pure tungsten, but tungsten contaminated by carbon. Certainly there is no indication that by hammering Moissan was able to do anything more than to close more or less the pores of the porous material, whatever it may have been, to which he refers; nor is there any indication that when he had gone thus far he had produced a material which could be worked.

I have found that in order that the swaging process may be carried on successfully it is necessary that the tungsten should be in a certain physical or molecular condition, such as is brought about by the treatments which I have discussed above. I find it particularly advantageous to work with tungsten powder which is coarse as distinguished from the exceedingly fine and impalpable powder such as has been used in the manufacture of lamp filaments. The operation of heating in the Battersea crucible coarsens the powder, as does also the reduction operation, particularly if it be carried on in the manner described, and if the hydrogen be passed rather slowly through the reduction furnace. While my invention has made it possible with certain precautions to work fine grained metal (especially if it contains oxids, which delay sintering), as by excessively small drafts and by surrounding the rod with a sheath or casing of some other metal, the condition of the tungsten which is characteristic of the coarse powder is one which is peculiarly adapted to the successful practice of my invention.

Though the operativeness of my invention obviously does not depend upon any theory of operation, I may state that I am at present of the opinion that the difficulty which is observed in swaging the rods pressed from the fine powder may well be due to the presence in such rods of certain impurities, probably gaseous impurities, as for example oxygen, which would probably occur as an oxid of tungsten. The atomic weight of tungsten is so high (184) that even a small percentage of oxygen will cause a very large percentage of the tungsten to exist as the oxid. It seems probable that in the sintering process the gaseous impurities are expelled more readily from the rod pressed from coarse powder, while in the case of a rod pressed from fine powder the tendency is to sinter quickly on the outside and so prevent or greatly retard the escape of impurities. This hypothesis is consistent with the fact that the smaller the rod the less the importance of using a specially prepared material.

My opinion that the coarseness of the structure has some effect on the sintering operation is confirmed by the fact that the effects characteristic of coarse grained powder are produced by any process by which a rod is formed which is coarse at the time it is exposed to the sintering operation. For example, I have produced rods from exceedingly fine tungsten powder which, after sintering, swage very well, by carrying on the baking operation in an iron tube furnace. The rods are packed in the tube in powdered silica and hydrogen is passed through the tube. The tube is heated by gas flames for 8 or 10 hours to a rather low temperature. This baking operation produces a rod of coarse grained structure, probably because of the fact that the oxid, naturally existing in considerable quantities in so fine a powder, requires prolonged heating to effect complete reduction and coarsens during this prolonged heating in the oxid stage.

It is desirable in all cases that the sintering operation should take place slowly, in order to give time for the action of the hydrogen to penetrate through the entire mass, and to facilitate the escape of impurities, as well as to prevent the center of the rod, by a too rapid increase of the heating current, from becoming much hotter than the outside and actually melting and running out.

The ultimate temperature reached in the sintering operation should be very high, a dazzling white heat probably not far from 2800° C. It is difficult to give any general rule except to state that if an insufficiently high temperature is reached the rod will break up in the swaging machine. Such a rod ordinarily shows a very finely grained fracture, while my experience is that the rods which are capable of being worked easily show a somewhat coarser and more crystalline fracture.

It is my belief that certain impurities in the sintered rod, such for example as oxygen and carbon, are highly detrimental and prevent the swaging operation from being successfully carried on. On the other hand I have stated above that certain additions are absorbed from the Hessian or Battersea crucible operation, and I find that these additions do not prevent the swaging while they exercise a highly beneficial action where the tungsten is to be exposed for long periods of time to high temperatures, particularly in the form of incandescent lamp filaments. It may be that "offsetting," a phenomenon which as above explained is characteristic of some drawn wire lamp filaments, is due to the crystallization of the metal and the segregation of impurities, whereby spots are developed at which this side lipping or offsetting occurs, and that the presence of the additions introduced from the Hessian or Battersea crucible retards or interferes with the diffusion of such impurities and thus retards crystallization. It is a fact that this treatment prevents offsetting.

I have succeeded in preventing offsetting in drawn tungsten filaments without using the Battersea crucible process by mixing with the tungsten powder certain refractory materials such as the oxids of thorium, zirconium, yttrium, erbium, didymium, or ytterbium. I have used with especial success thorium nitrate, which gives thoria when decomposed. A small amount of the above mentioned oxids, or of compounds or solutions which upon heating or other treatment will yield these oxids, may be mixed with the tungstic oxid before reduction or with the metal powder after reduction, or may even be introduced after the metal has been made into a stick, either by soaking the stick in a solution of a suitable substance or by heating the stick in the presence of a suitable material in the vaporous condition. When thorium nitrate is used, for example, I employ an amount which is equivalent to 2% or less of thoria referred to tungsten. The essential point seems to be that the material should be introduced before the tungsten is sintered. Such additions, particularly in the case of a filamentary body, may actually produce a certain amount of ductility and flexibility in the sintered filament without mechanical working. Usually, however, instead of directly adding these substances, I prefer to employ the treatment above described of simply firing the tungstic oxid in a Hessian or Battersea crucible, for this treatment is simple, successful and reliable.

While I have referred to a considerable extent to the manufacture of ductile tungsten in which so-called additions are introduced at some stage of the process in order that the resulting product may be especially valuable when used for filaments of incandescent lamps, and in connection with other uses where the metal is to be exposed for long periods of time to high temperatures, nevertheless operative and useful incandescent-lamp filaments may be made by carrying out my process as herein described, omitting the additions whether produced by direct introduction of additional material, as above described, or by the Battersea-crucible process; and where it is sought to obtain ductile tungsten for uses in which it is not likely to be exposed to high temperatures, the introduction of such additional substances may be entirely unnecessary. I do not however wish it to be understood that metal prepared with the additions can only be used in incandescent lamps and for similar purposes, as such metal can, as far as my present knowledge extends, be used for any purpose to which the ductile tungsten prepared without the use of the additions is applicable.

In connection with the swaging operation it should be noted that I have departed radically from the ordinary swaging process, in which the dies are long and the metal is held a considerable time in the machine or passed very slowly through it, so that a number of blows are struck at the same place on the metal, and a smooth surface is produced. I find it highly desirable, particularly in the earlier stages of the swaging process, to use a die with a very short working face such as I have shown in the drawings, and to pass the metal through the machine at high speed and so that it is still highly heated when it emerges from the dies. Indeed, it is best not to allow two successive blows to be struck at too closely overlapping places, because each impact of the die abstracts a certain amount of heat from the material and unless this precaution be observed there is great danger that a blow will be struck upon metal which is too cold to endure it without cracking. Preferably, then, the metal emerges from the swaging machine, not smooth, but showing every distinct blow of the hammer, and therefore with an irregular wavy surface.

The swaging operation, though the most successful at the moment, is not the only operation by which my invention can be practised. For example, I have succeeded, without any swaging operation whatever and using only wire-drawing dies, in producing perfectly ductile tungsten. In this case I have begun the operation with sintered conductors of relatively small size. For example, I have used ordinary sintered series tungsten incandescent lamp filaments of the diameter of 25 mils. Where the original body is so small in diameter it is relatively easy to expel injurious impurities in the sintering process, and the devices above described to facilitate this end, which are of importance in the case of the larger bodies which are required for economical large-scale production of lamp filaments, or for the preparation of larger articles, such as X-ray tube targets, projectiles, contacts, etc., become relatively unimportant where the original sintered body is of sufficiently small diameter. I point these filaments by the process of the Whitney Patent, No. 1,008,762, above referred to, and carefully insert the point into a die which is heated to 600 to 650° C. The pointed end is then seized with hot pliers (otherwise it would break) and the filament is then with great care and with a regular steady pull drawn through the die, the diameter of which should be not less than ½ a mil. (.0005 inch less than the maximum diameter of the filament at any point. The filament is then in a similar way drawn through a die having a diameter of ½ a mil. (.0005 inch) less than that of the first die, and so on down to 18 mils. Below this size the dies should vary in steps of one-quarter of a mil. until a size of say four mils is reached when the dies should then vary by one-eighth of a mil. or less. As the wire becomes smaller the temperature of drawing is reduced; at 18 mils. or thereabout the temperature is reduced from 600 or 650° to 500° C; at 10 mils. the temperature is reduced to 400° C. The dies are lubricated with aqua dag or oil dag, as in the wire-drawing process first described. After such a 25 mil. filament has been drawn to a diameter of 7 mils., it can, at room temperature, be bent around the finger without breaking, and will readily take a permanent set. As the tungsten is still further worked by drawing down to smaller sizes, the fibrous condition becomes more and more developed and the wire becomes more and more pliable, until, at a diameter of about 4 mils., it is in every sense ductile material, and could if desired be manipulated as any other ductile metal, and drawn through dies not heated above room temperature, though I ordinarily heat the dies during the last stages of the drawing process as well as during the first stages, since by the application of heat the drawing is rendered somewhat easier.

As a convenient means for keeping the tungsten hot during the drawing operation, I may, if desired, pass current through the material under treatment. The die and the portion of the wire which is hot may be inclosed in an evacuated space or in a hydrogen or other reducing atmosphere, although I do not find it necessary to do so. The lubricants mentioned herein themselves materially assist in protecting the wire from oxidation. So also I have succeeded in producing ductile tungsten by a rolling process. In carrying out such a process, at least until the metal has acquired a considerable amount of fiber, the rolling operation should be carried on with the metal at a high temperature, preferably between what is known as "bright red heat" and "white heat," and that the metal should retain this temperature as long as the rolls are acting upon it. Excessive temperatures, such as temperatures above 1500° C., are objectionable for the reasons and to the extent already explained. The rolls naturally abstract heat rapidly and therefore the metal should pass through the rolls at very high speed; it is also essential that the draft of the rolls should not be too great. Also, at least during the later stages of rolling, the temperature should not be higher than about 1200° C.; and preferably in the neighborhood of 1000° C. When a sufficiently fibrous condition has been obtained by rolling, the metal may be run through dies as above described, or the working may be continued exclusively by rolling.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. The process of producing tungsten having a fibrous structure which consists in repeatedly hot working a crystalline body of tungsten until the crystalline structure is broken down and a fibrous structure developed.

2. The process which consists in agglomerating tungsten powder, sintering the body thus formed, subjecting it to repeated hot working, and continuing such hot working until the body remains ductile when cold.

3. The process of producing ductile tungsten wire which consists in forming a sintered body of tungsten, hot swaging said body repeatedly until it becomes fibrous in structure, and then further reducing it by hot drawing.

4. The process of producing ductile tungsten wire, which consists in first forming a sintered body of tungsten free from oxygen carbon and other impurities which would render the body unworkable mechanically, then hot swaging such sintered and purified body repeatedly until it becomes fibrous in structure and then further reducing it by hot drawing.

5. The process which consists in mechanically working while hot tungsten which is brittle at room temperature until it becomes pliable at room temperature.

6. The process of forming bodies of coherent homogeneous tungsten which consists in agglomerating tungsten powder, sintering the body thus formed, and then subjecting it to hot mechanical working to such an extent as to improve the internal structure and to bring the body into a shape adapted for use in the arts.

7. The method which consists in first producing a body of tungsten sintered or compacted throughout and free from such impurities as would render the body unworkable mechanically, and then hot working said body to such an extent as to deform its crystalline structure and to bring it into a shape adapted for use in the arts.

8. The method of producing pliable tungsten wire for lamp filaments, which consists in first producing a body of tungsten in a sintered state and free from oxygen carbon and other impurities which would render the body unworkable mechanically and then subjecting this sintered and purified body to mechanical working many times repeated, with gradual reduction in diameter and elongation in length.

9. The method which consists in agglomerating relatively coarse tungsten powder into a porous mass, eliminating harmful impurities and compacting the mass by a sintering operation, and then mechanically working the resulting body while hot into the desired shape.

10. The method of producing ductile tungsten which consists in sintering an agglomerated mass of tungsten particles or

powder into a dense coherent and homogeneous form in such manner as to allow elimination of harmful impurities, and then mechanically working said body until it is brought into the desired condition.

11. The process which consists in agglomerating tungsten powder, treating the body thus formed so as to eliminate any oxygen present therein and to produce therefrom a sintered body, and then hot working such sintered body.

12. The process which consists in reducing tungsten oxid to coarse tungsten powder, agglomerating said powder into a coherent porous body, heating said body to drive out impurities and sinter the body, and then subjecting the body to hot mechanical working.

13. The process which consists in firing tungsten oxid in a refractory crucible of the Hessian or Battersea type, reducing the oxid to coarse metallic powder, agglomerating the powder into a coherent body, sintering the body, and then subjecting it to hot mechanical working.

14. The process which consists in forming a body of tungsten powder containing additional material which will prevent coarse crystallization of the tungsten at high temperature, sintering the body, and then subjecting it to hot mechanical working.

15. The step in the preparation of tungsten bodies which consists in firing tungsten oxid in a refractory crucible of the Hessian or Battersea type, and subsequently reducing the oxid to metallic tungsten powder.

16. The process which consists in producing tungsten containing beneficial additions, forming it into a billet, sintering it at high temperature, and mechanically working it a great number of times at high temperature, and reducing the temperature during the working.

17. The method of producing bodies of tungsten pliable and ductile at ordinary or room temperatures from bodies of tungsten which are brittle at ordinary or room temperatures, which consists in heating said brittle bodies to a temperature sufficient to render them susceptible of mechanical working, repeatedly working the bodies while so heated, and during at least the last stages of mechanical working carrying on the working at temperatures such that the mechanical working has the effect of producing ductility in the finished product.

18. The method of producing bodies of ductile tungsten from bodies of tungsten which are non-ductile, which consists in mechanically working the non-ductile bodies of tungsten within a temperature range at the lower limit of which the body to be worked is soft enough to be susceptible of such working while the upper limit, at least during the later stages of the working, is sufficiently low to cause the body thus worked to retain to a greater or less degree the effect of the mechanical working.

19. The method of producing ductile tungsten which consists in repeatedly hot working a tungsten body within a range of temperature in which the body is sufficiently soft to be susceptible of such working, but maintaining the temperatures below those at which the effect of the mechanical working is lost.

20. The method of producing a body of ductile tungsten from a body of tungsten which is brittle when cold, which consists in mechanically working said body while heated to a temperature at which the body is softened and finishing the mechanical working at temperatures below those at which no ductility is imparted to the metal by the mechanical working.

21. The method which consists in mechanically working at a temperature above approximately 1500 degrees C. a tungsten body which is brittle cold, interrupting the operation before the body is brought into the form ultimately desired, and completing the mechanical working at a temperature below 1500 degrees C.

22. The method of securing a ductile metal body without previous melting of the metal, which consists in producing a compact body of metal from divided metalliferous material, consolidating said body by heating to a temperature less than the melting temperature and such as to produce a body of metal non-ductile when cold, subjecting the body to repeated mechanical working while in a heated condition, and continuing the working until the body is ductile without the application of heat.

23. The method of securing a ductile metal body without previous melting of the metal, which consists in producing from divided metalliferous material a compact body of metal, sintering said body and thereby producing a crystalline body brittle at room temperatures, and then subjecting the body to repeated mechanical working while hot, and continuing the working until the metal remains ductile when cooled.

24. A wire formed of ductile tungsten.

25. An incandescent electric lamp having a filament of drawn tungsten wire.

26. Substantially pure tungsten having ductility and high tensile strength.

27. A ductile tungsten wire having a fibrous structure.

28. A form of tungsten metal pliable at room temperature.

29. An incandescent electric lamp having a filament formed of ductile tungsten.

30. A lamp filament of tungsten which

resists offsetting and has high tensile strength.

31. A filamentary conductor of drawn tungsten so constituted as to be free from offsetting when operated as a filament of an incandescent lamp.

32. A filament for electric incandescent lamps consisting of tungsten wire which is pliable at ordinary or room temperature.

33. The material wrought tungsten, having a specific gravity of approximately 19 or greater, and capable of being forged and worked.

34. Wrought tungsten, a solid coherent material characterized by the presence of crystals deformed by mechanical working.

In witness whereof, I have hereunto set my hand this 19th day of June, 1912.

WILLIAM D. COOLIDGE.

Witnesses:

Newton A. Burgess,
Helen Orford.

DEFENDANT'S EXHIBIT No. 33.

ERAL ELECTRIC COMPANY
V.
FOREST RADIO COMPANY

NEW ZEALAND.

THE PATENTS, DESIGNS, AND TRADE-MARKS ACTS.

Patent Office,

Wellington, 8th April 1924.

I, JAMES CLARK LEWIS

Registrar of Patents, Designs, and Trade-marks, hereby certify that the annexed is a true copy of the Deed of Letters Patent as issued on the 29th July, 1915 in connection with an application of IRVING LANGMUIR for Patent No. 35611 dated the 3rd November, 1914. AND I FURTHER CERTIFY THAT the Deed of Letters Patent was sealed as of the 3rd November, 1914. AND I FURTHER CERTIFY THAT no entry of assignment, transmission or other instrument affecting the title of the Letters Patent has been made in the Register of Patents.

J. C. Lewis

I Andrew John Park Notary Public certify that the above signature "J.C. Lewis" is the signature and proper handwriting of James Clark Lewis who is Registrar of Patents Designs and Trade Marks in and for the Dominion of New Zealand and that the above seal is the seal of the Patent Office of New Zealand.

Andrew John Park
Notary Public

[illegible]

COPY.

Letters Patent Form Aa.

NEW ZEALAND.

No. 35611.

Letters Patent

IN FAVOUR OF

IRVING LANGMUIR

George the Fifth, by the Grace of God, of the United Kingdom of Great Britain and Ireland and of the British Dominions beyond the Seas King, Defender of the Faith, Emperor of India: To all to whom these presents shall come, Greeting:

Whereas IRVING LANGMUIR, of the General Electric Company, Schenectady, County of Schenectady, State of New York, United States of America, Electrical Engineer.

hath declared that he is in possession of an invention for

"Improvements in electrical discharge apparatus."

that he claims to be the true and first inventor thereof, and that the same is not in use by any other person to the best of his knowledge and belief; And whereas the said inventor hath humbly prayed that a patent might be granted unto him for the sole use and advantage of his said invention;

And whereas the said inventor (hereinafter, together with his executors, administrators, and assigns, or any of them, referred to as "the said Patentee") hath by and in his complete specification particularly described the nature of his invention: And whereas We, being willing to encourage all inventions which may be for the public good, are graciously pleased to condescend to his request: Know ye, therefore, that We, of our especial grace, certain knowledge, and mere motion, do by these presents, for us, our heirs and successors, give and grant unto the said Patentee our especial license, full power, sole privilege, and authority that the said Patentee, by himself, his agents, or licensees, and no others, may at all times hereafter during the term of years herein mentioned make, use, exercise, and vend the said invention within New Zealand and its dependencies, in such manner as to him or them may seem meet, and that the said Patentee shall have and enjoy the whole profit and advantage from time to time accruing by reason of the said invention during the term of ~~sixteen~~ fourteen years from the date hereunder written of these presents: and to the end that the said Patentee may have and enjoy the sole use and exercise and the full benefit of the said invention, We do by these presents, for us, our heirs, and successors, strictly command all our subjects whatsoever within New Zealand and its dependencies that they do not at any time during the continuance of the said term of ~~sixteen~~ fourteen years either directly or indirectly make use of or put in practice the said invention, or any part of the same, nor in anywise imitate the same, nor make or cause to be made any addition thereto or subtraction therefrom, whereby to pretend themselves the inventors thereof, without the consent, license, or agreement of the said Patentee in writing under his hand and seal, on pain of incurring such penalties as may be justly inflicted on such offenders for their contempt of this our Royal command, and of being answerable to the Patentee according to law for his damages thereby occasioned:

Provided always that these Letters Patent shall be revocable on any of the grounds from time to time by law prescribed as grounds for revoking Letters Patent granted by us, and the same may be revoked and made void accordingly: Provided also that if the said Patentee shall not pay all fees by law required to be paid in respect of the grant of these Letters Patent, or in respect of any matter relating thereto, at the time or times and in manner for the time being by law provided, and also if the said Patentee shall not supply or cause to be supplied for our service all such articles of the said invention as may be required by the officers or commissioners administering any department of our service, in such manner, at such times, and at and upon such reasonable prices and terms as shall be settled in manner for the time being by law provided, then and in any of the said cases these our Letters Patent, and all privileges and advantages whatever hereby granted, shall determine and become void, notwithstanding anything hereinbefore contained: Provided also that nothing herein contained shall prevent the granting of licenses in such manner and for such considerations as they may by law be granted: And, lastly, We do by these presents, for us, our heirs and successors, grant unto the said Patentee that these our Letters Patent shall be construed in the most beneficial sense for the advantage of the said Patentee.

In witness whereof we have caused these our Letters to be made Patent, and to be sealed as of the third day of November, one thousand nine hundred and fourteen

J.C.LEWIS

Registrar of Patents, Designs, and Trade-marks.

Entered: Register No. 24, folio 63.

NOTE.—The following renewal fees are payable in respect of these Letters Patent:—

£3 before end of three years from above date.
£6 six

L.S.

LETTERS PATENT

IN FAVOUR OF

IRVING LANGMUIR

FOR

"Improvements in electrical discharge apparatus."

No.35611.

NOTE.—This Patent is subject to the payment of the renewal fees mentioned herein.

PATENT OFFICE,
WELLINGTON,
NEW ZEALAND.

[illegible]

NEW ZEALAND

THE PATENTS, DESIGNS, AND TRADE-MARKS ACTS.

Patent Office,

Wellington, 8th April 1924.

I, JAMES CLARK LEWIS

Registrar of Patents, Designs, and Trade-marks, hereby certify that the annexed is a true copy of the complete specification and drawings as lodged on the 3rd November, 1914 in connection with an application of IRVING LANGMUIR for Patent No. 35611 filed on the 3rd November, 1914. AND I FURTHER CERTIFY THAT the application accompanied by such complete specification and drawings has been accepted as on the 3rd November, 1914.

J. C. Lewis

I Andrew John Park Notary Public certify that the above signature "J. C. Lewis" is the signature and proper handwriting of James Clark Lewis who is Registrar of Patents Designs and Trade Marks in and for the Dominion of New Zealand and that the above seal is the seal of the Patent Office of New Zealand

Andrew John Park
Notary Public

[Certificate of Registrar.]

[illegible]

NEW ZEALAND.

THE PATENTS, DESIGNS, AND TRADE-MARKS ACT, 1911.-

COMPLETE SPECIFICATION.

"Improvements in electrical discharge apparatus."

I, IRVING LANGMUIR, of the General Electric Company Schenectady, County of Schenectady, State of New York, United States of America, Electrical Engineer, hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:-

The present invention relates to electrical vacuum discharge devices and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization such as occurring, for example, in the ordinary Roentgen tube.

My present invention comprises improvements in electron discharge apparatus having a high load capacity and operable with the highest voltages. The novel features of my invention will be pointed out with greater particularity in the appended claims.

In the accompanying drawings various forms of apparatus are shown illustrative of my invention.

Fig. 1 illustrates an electron discharge tube with its parts assembled.

Figs. 2 to 5, inclusive, show alternative forms of electrode and grid constructions, and

Fig. 6 is a diagram of an electrical system illustrating one application of my electron discharge tubes.

In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas. In a Geissler tube, and a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas an ordinary X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

Scientific research has shown that under certain very carefully controlled conditions with extremely low current values of the order of magnitude of .01 of one milliampere or lower and at low voltages, well below 100 volts, an electrical discharge current may take place in an evacuated space between a heated cathode and a co-operating anode without causing the residual gas to take part in the conduction of current. This effect also takes place in a vacuum when an unheated electrode consisting of certain materials, for example, potassium, is subjected to the influence of light, particularly to ultra-violet rays. The discharge current is carried by negative charges called electrons, which pass through the vacuous space under the influence of the impressed voltage. In the presence of gas these electrons, when moving with proper velocity, collide with gas molecules and give rise to gas ionization which completely changes the phenomena accompanying the discharge. The gas molecules are split up into electrons and larger and more slowly moving positive ions. The positive ions take part in the conduction of current, giving at first erratic readings on measuring instruments connected in circuit. As gas ionization continues at higher voltages a blue glow may appear. The cathode under these conditions is electrically disintegrated, technically is "Sputtered", which causes its rapid destruction. The bombardment of the cathode by positive ions also causes heating of the cathode.

The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device known as the "Audion".

This device has been used as a receiver for radiotelegraphy and depends in its operation upon the rapid change of the discharge current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the Audion begins somewhere between 20 and 30 volts. No prior hot- cathode devices are known to me operating with currents as great as about 5 milliamperes with voltages as high as about 200 volts.

In devices made in accordance with my invention, gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas.

The cathode is not heated by the discharge itself. Blue glow and in fact all visible indications of a discharge are absent. Glass fluorescence is absent in a device operating with a pure electron discharge. The discharge current passing through a given space with the cathode at a sufficiently high temperature so as to give a sufficient electron emission for a given voltage varies directly with the 3/2 power of the impressed voltages. If the electron emission is not sufficient, as for example when with the cathode at a given temperature the voltage exceeds the lowest value at which all the electrons are emitted are utilized, then a further increase in voltage produces substantially no change in current. The discharge is independent of the vacuum, providing the pressure is below the minimum at which gas ionization by collison will take place. As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterised by regularity and reproducibility with given conditions.

Devices made in accordance with my invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents with currents thousands of times greater than the minute currents at which the devices above referred to were operable.

The gas occluded in metals and driven out by the electrons impinging thereon appears to be especially liable to ionization, as it may be observed that gas eliminated from the anode even when below the pressure permissible for residual gas produces the effects accompanying gas ionization. In fact, gas thus eliminated from the anode may not even produce a difference in the reading of a McLeod vacuum gauge and yet produce ionization effects.

I have found that deleterious gases may be removed by electron bombardment even at a low temperature, which is advantageous as the device may not be adapted to receive a high energy input, or current of sufficiently high voltage may not be available.

As shown in Fig. 1, the various parts of the apparatus may be mounted in a tube, or globe E 1 upon a pedestal 2 similar to the mount employed for incandescent lamps. The cathode construction is shown in Fig. 2. It consists of a substantially straight filament 4 consisting of highly refractory material, preferably tungsten, and provided with terminals 5,5'. The filament 4 is mounted, preferably attached to a light spring 6, between two oppositely disposed supports 7 and 8 constituting a framework, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this framework is wound a wire 9, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. By means of this grid 9, potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge. The supporting framework for the cathode and grid is attached to a rod 10, mounted upon the stem of the tube. Adjacent to the cathode grid is the anode 11 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 12 upon fork-shaped supports 13 and 14 but it is not necessary that it should assume this particular form.

both anode and grid preferably consist of tungsten, but other gas-free refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 15, 15'. The cathode terminals 5, 5' are supplied with current through leading-in wires 16, 16'. Although it is not necessary for all purposes to provide connections for each end of the grid, it is desirable to do so when the potential applied to the grid is small, and in the case of a straight or linear cathode the potential gradient along the grid may to advantage be the same as that on the filament. In this manner the potential drop from grid to cathode is the same along its length. The grid is indicated in Fig. 1 as being attached to leading-in conductors 17, 17' at opposite ends.

In some cases it is desirable to use a V-shaped incandescing conductor for the conductor for the cathode and to attach to its bight a spring as shown at 18, 19 in Fig. 8. In this manner contact of the conductor with the grid by sagging when the metal is expanded at high temperature is prevented. In Fig. 3 a plurality of loops are used in order to increase the amount of cathode surface. The filaments are shown as connected in parallel by means of conductors 20, 20'. In some cases also it may be desirable to use a plate-shaped anode. 11^1 and 11^2 show such anodes which also preferably consist of tungsten and, if desired, may be connected electrically with each other. Current connections are made by conductors 16^2,16^3, the supports 3', 14' being merely indicated. If desired the grid may be omitted and only one cathode employed.

This construction, using plate-shaped anodes, is particularly suitable for rectifying alternating current. It is especially advantageous where currents of any considerable amount are employed.

If it is desired to rectify alternating current, the anodes may be connected to the terminals of the alternating current source which is to be rectified, such for example as the secondary winding of a transformer, which has not been shown. The direct current consumption circuit may be connected to substantially the centre point of the transformer winding and to the cathode, and the grid positively charged.

The action in this case is as follows:- When the cathode is brought to incandescence it emits electrons, which travel under the influence of the impressed electromotive force to a positive electrode. The electrons will, however, be repelled by a negative electrode. The anodes or electrode 11', 11^2 will be in turn made positive or negative and current will pass from the cathode to the positive electrode. The electrode connected to the opposite terminal of the alternating source and which will be negative would act to cut down the current passing from the cathode to the positive electrode. This effect, however, is prevented by the positively charged grid.

A rectified current will therefore be produced passing through one-half of the transformer, or alternating current source, winding and one of the ~~electrodes~~ electrodes which is positive for one-half of the alternating current wave and through the other half of the winding and the other electrode which is positive for the other half of the alternating current wave.

By a somewhat similar arrangement also if a source of direct current be connected to what I have called the direct current consumption circuit and the anodes be connected to the terminals of a winding, direct current may be converted into an alternating current which will flow in the winding. When it is desired to do this, auxiliary grids may be placed between the cathode and the anodes or electrodes. These grids may be connected to an alternating current so that they are charged alternately negatively and positively and therefore, as explained above, cause current to flow alternately from the cathode to one or the other of the electrodes in synchronism with the chargings of the auxiliary grids.

In Fig. 4 the cathode has been shown as being mounted in a frame 21, consisting of ferrochrome, tungsten, or other suitable metal upon which the wire 22 constituting the grid is wound. As the grid wire is thus wound upon a conductive frame, its turns are in parallel and electrical contact may be made directly to the frame 21 by conductor 23. The leading-in-conductors 6, 6 for the cathode are insulated from the frame by glass supports 24 as indicated.

Upon the frame 21 are placed mica sheets 25 and 26 which serve to insulate the wire 27 constituting the anode from the grid. The leading-in conductors 28, 28' to which the ends of the wires are anchored may be attached to glass beads 29 fused upon the frame 21.

In Fig. 5 not only the grid 32 is wound upon the frame 33 but also the cathode wire 34 is wound upon stout metallic conductors 35, 36, consisting preferably of tungsten. The conductors 35, 36 are attached respectively to an anchoring wire 37 and to two springs 38 and 39 serving to hold taut the turns of the tungsten wire constituting the cathode and to prevent them from coming into contact with the grid wire 32. A stranded copper conductor 40 may be used to conduct current to the cathode.

The asymetric conductivity existing between the heated and unheated electrodes of a device of the character described may be utilised for various technical purposes. Reference has already been made to the rectification of current. As shown in Fig. 6, an electron discharge tube may be used for detecting electromagnetic waves in radio-telegraphy. The grid g and heated cathode c of an electron discharge tube 41 are connected respectively to the terminals of the secondary of a transformer 42, the primary of which is included in the antenna circuit

43. The antenna is grounded through a condenser 44 in the usual manner. The cathode c is heated by a local source of energy, as battery b. A battery 45 in the grid circuit 46 has its negative terminal connected to the grid g. A condenser 47 shunts the secondary of the loosely coupled transformer 43. The inductance of the transformer and the capacity of the condenser are adjusted to make the receiving circuit resonant to the frequency of the oscillations to be received. The oscillations set up by the incoming signals are superimposed upon the negative grid potential and causes a variation of current transmitted between cathode c and anode a by a local source of energy such as a battery 48 included in the local or plate circuit 49, 50 of the discharge tube. This circuit is connected, to an ordinary telephone receiver 51, preferably shunted by means of a condenser 52, whereby the signals are detected.

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for exampl a Gaede molecular pump, which removes vapours as well as gases. Chemical evacuating means such as electrically vaporised calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. In fact, the heating may take place in a suitable vacuum furnace, the temperature preferably being raised to 2500° C or even higher. However, heat alone will not remove all the gas liberated by the electron discharge, but this gas is driven out even at ordinary temperatures by the discharge itself. The discharge appears to effect especially the surface of the metal. Heating is a valuable aid in bringing gases from the interior of the metal body into the sphere of action of the discharge but may be omitted when the devices are not heated during normal operation.

The bombardment is carried out when the evacuation has proceeded to a high degree applying a potential between the cathode 8 and the anode 12, Fig. 1, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionization, and , as already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon. The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out, the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased, thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50, 000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating voltage. In the case of a plate-shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes. In the case of a device in which the anode normally operates at low temperature bombardment without heating may suffice. After the metal has been freed from occluded gas, reabsorption of gas will not take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated without further electron bombardment of the anode or anodes.

The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionisation by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow, disintegration of the cathode, and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance. It is also true then when the anode has been carefully freed from gas, residually free gas, even if present in a sufficient amount to cause some gas ionisation when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:-

1. An electrical discharge device comprising a gas-tight envelope, an electron-emitting cathode, and a co-operating anode, the space in said envelope being evacuated to below the pressure at which gas ionization takes place constituting a device in which the current passed over the normal working range of voltage and temperature varies with the 3/2 power of the impressed voltage for voltages above a minimum voltage depending on the electron emission of the cathode.

2. The device as claimed in claim 1, having an incandescent cathode and a gas-free anode.

3. A high vacuum electron discharge device comprising an envelope, an incandescent cathode and an anode, the space in said envelope being evacuated to such degree that the current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

4. The device as claimed in claims 1, 2 or 3, a rigid framework located adjacent to the anode, and a conductor constituting a grid wound back and forth on the framework and located between cathode and anode.

5. An electron discharge apparatus comprising an

evacuated envelope, a refractory conductor, connections for transmitting energy to incandesce said conductor, bars located on opposite sides of said conductor, a wire wound with closely adjacent turns on said bars to constitute a grid, but out of contact with said incandescing conductor, a second set of bars closely adjacent to the first set but insulated therefrom and a conductor constituting an anode mounted thereon in a plane substantially parallel to said grid, and leading-in conductors to said grid and anode.

6. In a device as claimed in claims 4 or 5, means for maintaining the grid at a substantially uniform positive potential.

7. In a device as claimed in claim 6, means for producing a negative charge in the vicinity of the cathode.

8. The process of removing ionizable gas from an anode of an electron discharge device which consists in subjecting said anode to prolonged electron bombardment at an impressed voltage below the value at which considerable gas ionization occurs and coincidentally removing the gas thereby disengaged.

9. The method of preparing an electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence and a co-operating anode

which consists in removing gas as completely as possible from the envelope, impressing between the cathode while at incandescence and the anode a voltage adapted to produce an electron discharge but insufficient to produce appreciable gas ionization as indicated by a blue glow, continuing evacuation, progressively raising the discharge voltage as gas is removed, and sealing said envelope when the normal operating voltage has been exceeded.

10. In a process or method as claimed in claims 8 or 9 producing the electron bombardment with an energy input below the value necessary to appreciably heat the anode.

11. An electrical disharge apparatus operating and arranged substantially as described in reference to Figs. 1, 2, 4, 5 and 6 of the drawings.

12. An electrical discharge apparatus operating and arranged substantially as described in refermnce to Fig. 3 of the drawings.

Dated at Wellington this 3rd day of November, 1914.

HENRY HUGHES, LTD.
per (Sgd.) W. ALEXANDER
AGENT FOR THE APPLICANT.

Fig. 1.

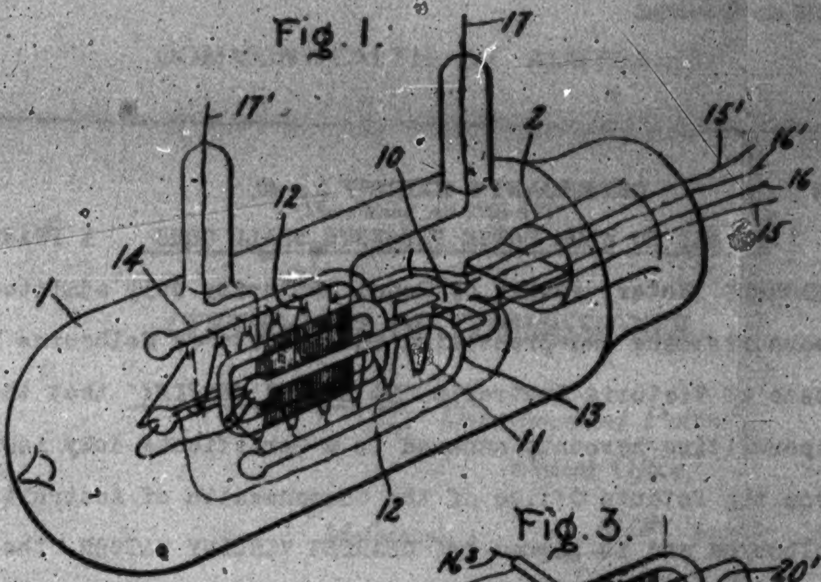

17
17'
15'
16'
16
15
2
10
12
14
1
13
11
12

Fig. 2.

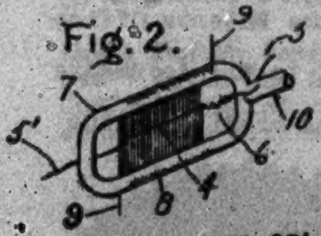

9
5
7
5'
10
6
4
8
9

Fig. 3.

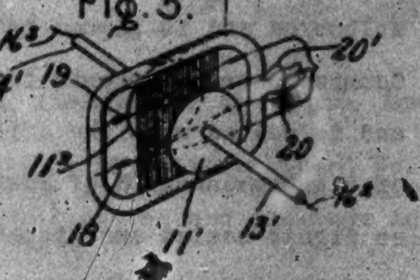

14²
14'
19
20'
20
11²
18
11'
13'
16²

Fig. 4.

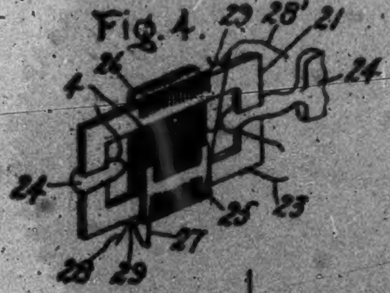

26
29
28'
21
4
24
24
25
23
28
29
27

Fig. 5.

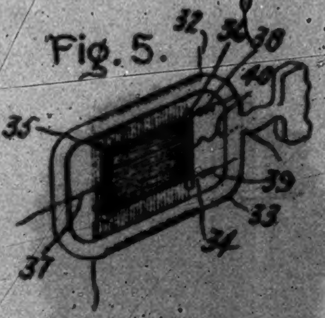
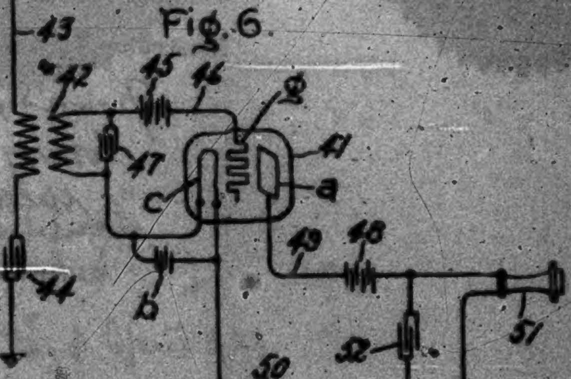

32
30
38
40
35
39
33
34
37

Fig. 6.


43
42
45
46
41
47
c
a
49
48
b
44
52
51
50

pr N. Alexander

DEFENDANT'S EXHIBIT No. 40.

TO ALL TO WHOM THESE PRESENTS SHALL COME I FRANK SHAW FITCHETT Notary Public by Royal authority duly admitted and sworn residing and practising in the City of Melbourne in the State of Victoria Australia DO HEREBY CERTIFY that the --- paperwriting hereunto annexed is a Certificate duly issued from the Patents Office of the Commonwealth of Australia at Melbourne and is signed by CHARLES VINCENT WATSON the Commissioner of Patents for the Commonwealth of Australia and is sealed with the official seal of the Patents Office of the Commonwealth of Australia and that to all documents so signed sealed and issued full faith and credit are due in judicature and thereout.

IN FAITH AND TESTIMONY whereof I the said Notary have hereunto subscribed my name and affixed my seal of office this Fifteenth day of April in the year of our Lord One thousand nine hundred and twenty-four.

Frank S. Fitchett
Notary Public
Melbourne

Letter Form No. 18

COMMONWEALTH OF AUSTRALIA.

Patents.

The Patents Act 1903-1921.

CERTIFICATE OF COMMISSIONER.

Department of Patents,
Patent Office,

Melbourne, 24th April, 1924.

I, Charles Vincent Watson, *Commissioner of Patents, hereby certify that the annexes* are true copies of Letters Patent No. 14677, dated the 22nd October, 1914, granted to GENERAL ELECTRIC COMPANY, and of the complete specification and drawings in connection with said Letters Patent.

This is the Certificate referred to in my annexed certificate
Dated this 18th day of April 1924.
Frank F. Cook
Notary Public
Melbourne

Chas. Watson
Commissioner of Patents.

582

[Form E.

COMMONWEALTH OF AUSTRALIA.

LETTERS PATENT.

No. 14677

GENERAL ELECTRIC COMPANY

DATED 22nd October 1914

Entered in the Register of Patents.

Vol. 36 Fo. 136

(Sgd) C.A.Graham.

FEES (to be Paid in Cash at the Commonwealth Patent Office).

	£	s.	d.
On or before the Expiration of the Seventh Year of the period of the Patent	£5	0	0
On Enlargement of Time for Payment of Renewal Fees—			
Not exceeding Three Months	2	0	0
" " Four "	2	13	4
" " Five "	3	6	8
" " Six "	4	0	0
" " Seven "	4	13	4
" " Eight "	5	6	8
" " Nine "	6	0	0
" " Ten "	6	13	4
" " Eleven "	7	6	8
" " Twelve "	8	0	0

By Authority: Albert J. Mullett, Government Printer, Melbourne.

[illegible]

(Form E.

COMMONWEALTH OF AUSTRALIA.

Letters Patent.

No. 14,677

George the Fifth, by the Grace of God of the United Kingdom of Great Britain and Ireland and of the British Dominions beyond the Seas KING, Defender of the Faith, Emperor of India: To all to whom these Presents shall come GREETING:

Whereas GENERAL ELECTRIC COMPANY, carrying on business as Electrical Engineer, at Schenectady, State of New York, United States of America, by its duly authorised officer, Henry William Darling, Treasurer of said Company

has pursuant to the *Patents Act* 1903-1921, made application for Letters Patent of an Invention for "Improvements in and relating to Electrical Discharge Apparatus.

and has made a declaration in the prescribed form that it is the assignee of Irving Langmuir, of the General Electric Company aforesaid Electrical Engineer, the actual inventor of the said invention.

and has by a complete specification fully described and ascertained the Invention.

Now therefore we do by these Letters Patent give and grant to the said GENERAL ELECTRIC COMPANY

(hereinafter called the Patentee) our especial licence, full power, sole privilege, and authority, that the said Patentee by itself, its agents, or licensees, and no others, may at all times hereafter during the term of years herein mentioned, make, use, exercise, and vend the said Invention within the Commonwealth of Australia, in such manner as to it or them may seem meet, and that the said Patentee shall have and enjoy the whole profit and advantage from time to time accruing by reason of the said Invention, during the term of fourteen years from the date hereunder written of these presents:

Provided always that these Letters Patent are subject to the following conditions:—

(1) That these [illegible]tters Patent shall be void if it is made to appear that this grant is contrar[illegible]w, or is prejudicial or inconvenient to our subjects in general, or that the said Invention is not a new Invention, or that the Patentee is not the assignee of the said Irving Langmuir or that the said Irving Langmuir is not the actual inventor of the said invention. ; and

(2) That these Letters Patent shall cease and determine if the Patentee fails to pay the renewal fee hereunder set out on the date when it becomes due, or within such further time as may be allowed.

And we do grant unto the Patentee that these Letters Patent shall be construed in the most beneficial sense for the advantage of the Patentee.

In witness whereof we have caused these our Letters to be made patent this twenty-second day of October One thousand nine hundred and fourteen and to be sealed as of the twenty-second day of October One thousand nine hundred and fourteen

L.S.

GEORGE TOWNSEND,

Commissioner of Patents.

N.B.—The Renewal Fee is £5, and is to be paid to the Commissioner of Patents on or before the twenty-second day of October 1921

Department of Patents
Patents Act 1903-1909
Commonwealth of
Australia.

No. 14,677/14.

APPLICATION DATED

22nd October, 1914.

Actual Inventor ... ... Irving Langmuir, Electrical Engineer, of the General Electric Company, Schenectady, New York, U.S.A.

Applicant and Assignee of Actual Inventor ... General Electric Company.

Application and Complete Specification ... Received, 22nd October, 1914.

Acceptance ... ... Advertised, 15th July, 1915.

Classes 05.5; 06.1.

Drawing attached.

COMPLETE SPECIFICATION.

"Improvements in and relating to electrical discharge apparatus."

We, General Electric Company, carrying on business as Electrical Engineers at Schenectady, State of New York, United States of America, hereby declare this invention and the manner in which it is to be performed, to be fully described and ascertained in and by the following statement:—

The present invention relates to electrical vacuum discharge devices and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization such as occurring, for example, in the ordinary Roentgen tube.

Our present invention comprises improvements in electron discharge apparatus having a high load capacity and operable with the highest voltages. The novel features of our invention will be pointed out with greater particularity in the appended claims.

In the accompanying drawings various forms of apparatus are shown illustrative of our invention.

Fig. 1 illustrates an electron discharge tube with its parts assembled;

Figs. 2 to 5, inclusive, shew alternative forms of electrode and grid constructions, and

Fig. 6 is a diagram of an electrical system illustrating one application of our electron discharge tubes.

In order to distinguish electron discharge devices made in accordance with our invention from the prior art, we will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas. In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas an ordinary x-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

Scientific research has shown that under certain very carefully controlled conditions with extremely low current values of the order of magnitude of .01 of one milliampere or lower and at low voltages, well below 200 volts, an electrical discharge current may take place in an evacuated space between a heated cathode and a co-operating anode without causing the residual gas to take part in the conduction of current. This effect also takes place in a vacuum when an unheated electrode consisting of certain materials, for example, postassium, is subjected to the influence of light, particularly to ultra-violet rays. The discharge current is carried by negative charges called electrons, which pass through the vacuous space under the influence of the impressed voltage. In the pressure of gas these electrons, when moving with proper velocity, collide with gas molecules and give rise to gas ionization which completely changes the phenomena accompanying the discharge. The gas molecules are split up into electrons and larger and more slowly moving positive ions. The positive ions take part in the conduction of current, giving at first erratic readings on measuring instruments connected in circuit. As gas ionization continues at higher voltages a blue glow may appear. The cathode under these conditions is electrically disintegrated, technically is "sputtered," which causes its rapid destruction. The bombardment of the cathode by positive ions also causes heating of the cathode.

The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device known as the "Audion." This device has been used as a receiver for radio-telegraphy and depends in its operation upon the rapid change of the discharged current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the Audion begins somewhere between 20 and 30 volts. No prior hot cathode devices are known to us operating with currents as great as about 5 milliamperes with voltages as high as about 200 volts.

In devices made in accordance with our invention, gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas.

The cathode is not heated by the discharge itself. Blue glow and in fact all visible indications of a discharge are absent. Glass fluorescence is absent in a device operating with a pure electron discharge. The discharge current passing through a given space with the cathode at a sufficiently high temperature so as to give a sufficient electron emission for a given voltage varies directly with the 3/2 power of the impressed voltages. If the electron emission is not sufficient, as for example when with the cathode at a given temperature, the voltage exceeds the lowest value at which all the electrons emitted are utilised, then a further increase in voltage produces substantially no change in current. The discharge is independent of the vacuum, providing the pressure is below the minimum at which gas ionization by collision will take place. As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterised by regularity and reproducibility with given conditions.

Devices made in accordance with our invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents with currents thousands of times greater than the minute currents at which the devices above referred to were operable.

The gas occluded in metals and driven out by the electrons impinging thereon appears to be especially liable to ionization, as it may be observed that gas eliminated from the anode even when below the pressure permissible for residual gas produces the effects accompanying gas ionization. In fact, gas thus eliminated from the anode may not even produce a difference in the reading of a McLeod vacuum gauge and yet produce ionization effects.

We have found that deleterious gases may be removed by electron bombardment even at a low temperature, which is advantageous as the device may not be adapted to receive a high energy input, or current of sufficiently high voltage may not be available.

As shown in Fig. 1, the various parts of the apparatus may be mounted in a tube, or globe 1, upon a pedestal 2 similar to the mount employed for incandescent lamps. The cathode construction is shown in Fig. 2. It consists of a substantially straight filament 4 consisting of highly refractory material, preferably tungsten, and provided with terminals 5, 5^1. The filament 4 is mounted, preferably attached to a light spring 6, between two oppositely disposed supports 7 and 8 constituting a framework, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this framework is wound a wire 9, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. By means of this grid 9, potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge. The supporting framework for the cathode and grid is attached to a rod 10, mounted upon the stem of the tube. Adjacent to the cathode grid is the anode 11 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 12 upon fork-shaped supports 13 and 14 but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other gas-free refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 15, 15^1. The cathode terminals 5, 5^1 are supplied with current through leading-in wires 16, 16^1. Although it is not necessary for all purposes to provide connections for each end of the grid, it is desirable to do so when the potential applied to the grid is small, and in the case of a straight or linear cathode the potential gradient along the grid may to advantage be the same as that on the filament. In this manner the potential drop from grid to cathode is the same along its length. The grid is indicated in Fig. 1 as being attached to leading-in conductors 17, 17^1 at opposite ends.

In some cases it is desirable to use a V-shaped incandescing conductor for the conductor for the cathode and to attach to its bight a spring as shown at 18, 19 in Fig. 3. In this manner contact of the conductor with the grid by sagging when the metal is expanded at high temperature is prevented. In Fig. 3 a plurality of loops are used in order to increase the amount of cathode surface. The filaments are shown as connected in parallel by means of conductors 20, 20^1. In some cases also it may be desirable to use a plate-shaped anode. 11^1 and 11^2 shew such anodes which also preferably consist of tungsten and, if desired, may be connected electrically with each other. Current connections are made by conductors 16^2, 16^3, the supports 13^1, 14^1 being merely indicated. If desired the grid may be omitted and only one cathode employed.

This construction, using plate-shaped anodes, is particularly suitable for rectifying alternating current. It is especially advantageous where currents of any considerable amount are employed.

If it is desired to rectify alternating current, the anodes may be connected to the terminals of the alternating current source which is to be rectified, such for example as the secondary winding of a transformer, which has not been shewn. The direct current consumption circuit may be connected to substantially the centre point of the transformer winding and to the cathode, and the grid positively charged.

The action in this case is as follows: When the cathode is brought to incandescence it emits electrons, which travel under the influence of the impressed electromotive force to a positive electrode. The electrons will, however, be repelled by a negative electrode. The anodes or electrodes 11^1, 11^2 will be in turn made positive or negative and current will pass from the cathode to the positive electrode. The electrode connected to the opposite terminal of the alternating source and which will be negative would act to cut down the current passing from the cathode to the positive electrode. This effect, however, is prevented by the positively charged grid.

A rectified current will therefore be produced passing through one-half of the transformer, or alternating current source, winding and one of the electrodes which is positive for one-half of the alternating current wave and through the other half of the winding and the other electrode which is positive for the other half of the alternating current wave.

By a somewhat similar arrangement also if a source of direct current be connected to what we have called the direct current consumption circuit and the anodes be connected to the terminals of a winding, direct current may be converted into an alternating current which will flow in the winding. When it is desired to do this, auxiliary grids may be placed between the cathode and the anodes or electrodes. These grids may be connected to an alternating current so that they are charged alternately negatively and positively and therefore, as explained above, cause current to flow alternately from the cathode to one or the other of the electrodes in synchronism with the chargings of the auxiliary grids.

In Fig. 4 the cathode 4 has been shewn as being mounted in a frame 21, consisting of ferrochrome, tungsten, or other suitable metal upon which the wire 22 constituting the grid is wound. As the grid wire is thus wound upon a conductive frame, its turns are in parallel and electrical contact may be made directly to the frame 21 by conductor 23. The leading-in conductors 5, 6 for the cathode are insulated from the frame by glass supports 24 as indicated.

Upon the frame 21 are placed mica sheets 25 and 26 which serve to insulate the wire 27 constituting the anode from the grid. The leading-in conductors 28, 28¹ to which the ends of the wires are anchored may be attached to glass beads 29 fused upon the frame 21.

In Fig. 5 not only the grid 32 is wound upon the frame 33 but also the cathode wire 34 is wound upon stout metallic conductors 35, 36, consisting preferably of tungsten. The conductors 35, 36 are attached respectively to an anchoring wire 37 and to two springs 38 and 39 serving to hold taut the turns of the tungsten wire constituting the cathode and to prevent them from coming into contact with the grid wire 32. A stranded copper conductor 40 may be used to conduct current to the cathode.

The asymmetric conductivity existing between the heated and unheated electrodes of a device of the character described may be utilised for various technical purposes. Reference has already been made to the rectification of current. As shewn in Fig. 6, an electron discharge tube may be used for detecting electro-magnetic waves in radiotelegraphy. The grid g and heated cathode c of an electron discharge tube 41 are connected respectively to the terminals of the secondary of a transformer 42, the primary of which is included in the antenna circuit 43. The antenna is grounded through a condenser 44 in the usual manner. The cathode c is heated by a local source of energy, as battery b. A battery 45 in the grid circuit 46 has its negative terminal connected to the grid g. A condenser 47 shunts the secondary of the loosely coupled transformer 42. The inductance of the transformer and the capacity of the condenser are adjusted to make the receiving circuit resonant to the frequency of the oscillations to be received. The oscillations set up by the incoming signals are superimposed upon the negative grid potential and causes a variation of current transmitted between cathode c and anode a by a local source of energy such as a battery 48 included in the local or plate circuit 49, 50 of the discharge tube. This circuit is connected to an ordinary telephone receiver 51, preferably shunted by means of a condenser 52, whereby the signals are detected.

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube, preferably while still heated is carried out by means of a suitable evacuating means, for example a Gaede molecular pump, which removes vapours as well as gases. Chemical evacuating means such as electrically vaporised calcium or magnesium may also be used. Either before or during the evacuation the anode may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. In fact, the heating may take place in a suitable vacuum furnace, the temperature preferably being raised to 2500° C. or even higher. However, heat alone will not remove all the gas liberated by the electron discharge, but this gas is driven out even at ordinary temperatures by the discharge itself. The discharge appears to affect especially the surface of the metal. Heating is a valuable aid in bringing gases from the interior of the metal body into the sphere of action of the discharge but may be omitted when the devices are not heated during normal operation.

The bombardment is carried out when the evacuation has proceeded to a high degree applying a potential between the cathode 4 and the anode 12, Fig. 1, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionization and, already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon.

The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out, the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased, thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50,000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating voltage. In the case of a plate-shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes. In the case of a device in which the anode normally operates at low temperature bombardment without heating may suffice. After the metal has been freed from occluded gas, reabsorption of gas will not take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated without further electron bombardment of the anode or anodes.

The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionization by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow, disintegration of the cathode, and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance. It is also true then when the anode has been carefully freed from gas, residually free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated.

Having now fully described and ascertained our said invention and the manner in which it is to be performed, we declare that what we claim is:—

1. An electrical discharge device comprising a gas-tight envelope, an electron-emitting cathode, and a co-operating anode, the space in said envelope being evacuated to below the pressure at which gas ionization takes place constituting a device in which the current passed over the normal working range of voltage and temperature varies with the 3/2 power of the impressed voltage for voltages above a minimum voltage depending on the electron emission of the cathode.

2. The device as claimed in Claim 1, having an incandescent cathode and a gas-free anode.

3. A high vacuum electron discharge device comprising an envelope, an incandescent cathode and an anode, the space in said envelope being evacuated to such degree that the current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

4. The device as claimed in Claims 1, 2 or 3, a rigid framework located adjacent to the anode, and a conductor constituting a grid wound back and forth on the framework and located between cathode and anode.

5. An electron discharge apparatus comprising an evacuated envelope, a refractory conductor, connections for transmitting energy to incandesce said conductor, bars located on opposite sides of said conductor, a wire wound with closely adjacent turns on said bars to constitute a grid, but out of contact with said incandescing conductor, a second set of bars closely adjacent to the first set but insulated therefrom and a conductor constituting an anode mounted thereon in a plane substantially parallel to said grid, and leading-in conductors to said grid and anode.

6. In a device as claimed in Claims 4 or 5, means for maintaining the grid at a substantially uniform positive potential.

7. In a device as claimed in Claim 6, means for producing a negative charge in the vicinity of the cathode.

8. The process of removing ionizable gas from an anode of an electron discharge device which consists in subjecting said anode to prolonged electron bombardment at an impressed voltage below the value at which

considerable gas ionization occurs and coincidentally removing the gas thereby disengaged.

9. The method of preparing an electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence and a co-operating anode which consists in removing gas as completely as possible from the envelope, impressing between the cathode while at incandescence and the anode a voltage adapted to produce an electron discharge but insufficient to produce appreciable gas ionization as indicated by a blue glow, continuing evacuation, progressively raising the discharge voltage as gas is removed, and sealing said envelope when the normal operating voltage has been exceeded.

10. In a process or method as claimed in Claims 8 or 9, producing the electron bombardment with an energy input below the value necessary to appreciably heat the anode.

11. An electrical discharge apparatus operating and arranged substantially as described in reference to Figs. 1, 2, 4, 5 and 6 of the drawings.

12. An electrical discharge apparatus operating and arranged substantially as described in reference to Fig. 3 of the drawings.

Dated this 22nd day of October, 1914.

EDWD. WATERS & SONS,
Patent Attorneys for
GENERAL ELECTRIC COMPANY.

Witness—Percy Johnston.

22 Oct., 1914. AUSTRALIA. No. 19,677/14.

General Electric Company. *Electrical Discharge Apparatus.*

Fig. 1.

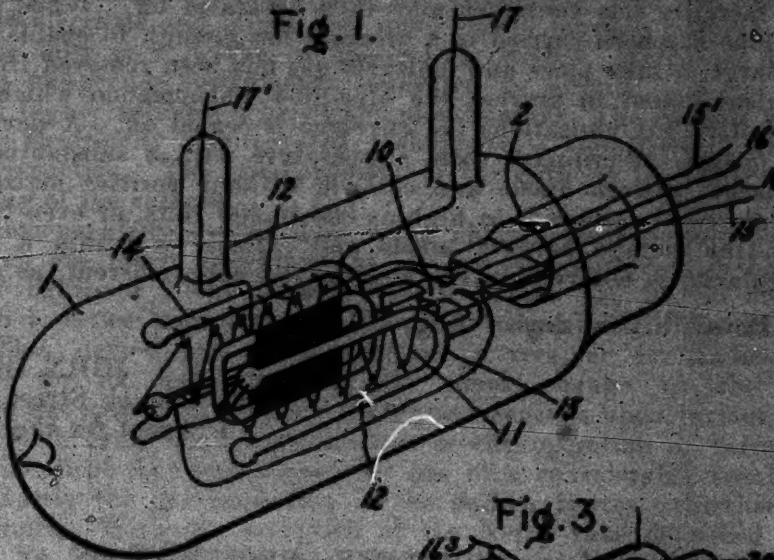

17
17'
2
15'
16'
16
15
10
12
14
1
13
11
12

Fig. 3.

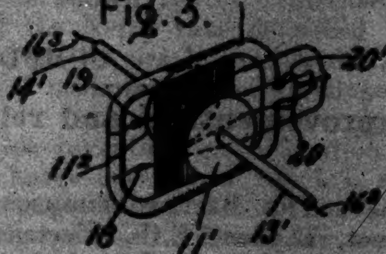

16³
14'
19
20'
11³
20
18
11'
13'
16²

Fig. 2.

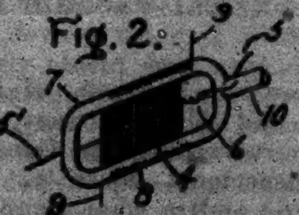

9
5
7
10
5'
6
9
8
4

Fig. 4.

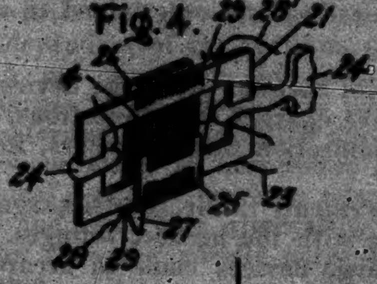

23
28'
21
24
24
26
23
28
25
27

Fig. 5.

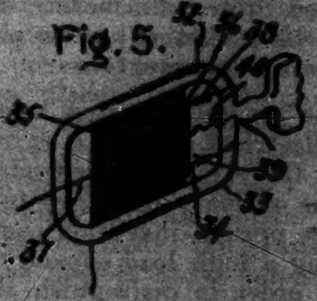
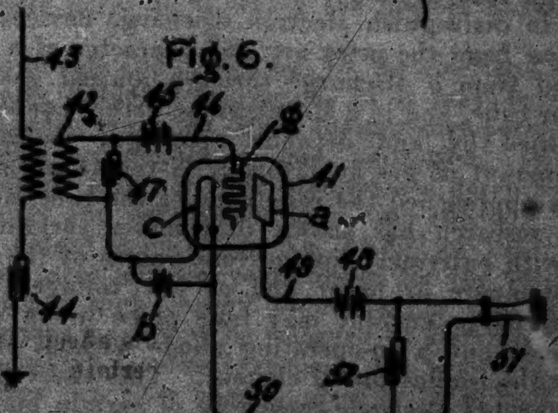

32
30
40
35
39
33
37
34

Fig. 6.


43
42
45
46
47
41
a
c
44
b
49
48
52
51
50

DEFENDANT'S EXHIBIT No. 41.

to form silver amalgam. At room temperature one or two days are required for the amalgamation. All excess unalloyed mercury must be removed from the tube. This may conveniently be done by warming the bulb slightly and surrounding the mercury side tube in a freezing mixture, or in liquid air. The mercury side container may then be sealed off. When evacuation of the envelope has been carried to a pressure low enough to enable the pure electron discharge to take place and ionizable gas has been removed from the anode to a sufficient extent to prevent the blue-glow phenomenon which is an indication of positive gas ionization, the envelope is sealed off. A device thus prepared will operate at ordinary room temperature with a substantially pure electron discharge between anode and cathode without positive ionization, even when the impressed voltage is as high as 300 to 400 volts, or even higher. However, when the voltage between anode and cathode is within a certain range an irregularity is observed in the electron discharge current, as already described.

Dated this 1st day of July, 1914.

JOHN GRAY,
83, Cannon Street, London, E.C.,
Agent for the Applicants.

COMPLETE SPECIFICATION.

Improvements in and relating to Electrical Vacuum Discharge Devices.

We, The British Thomson-Houston Company, Limited, of 83, Cannon Street, London, E.C., Electrical Engineers and Manufacturers, do hereby declare the nature of this invention (a communication from the General Electric Company, of Schenectady, County of Schenectady, State of New York, United States of America, Electrical Engineers) and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to electrical vacuum discharge devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gas ionization such as occurs, for example, in the ordinary Roentgen tube.

The present invention comprises improvements in electro-discharge apparatus having a high load capacity and operable with the highest voltages.

In order to distinguish electron discharge devices made in accordance with this invention from the prior art, the character of a pure electron discharge as distinguished from a discharge through ionized gas will be briefly described. In a Geissler tube, and in a Roentgen or Crookes tube, the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas an ordinary X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

Scientific research has shown that under certain very carefully controlled conditions with extremely low current values of the order of magnitude of .01 of one milliampere or lower and at low voltages, well below 200 volts, an electrical discharge current may take place in an evacuated space between a heated cathode and a co-operating anode without causing the residual gas to take part in the conduction of current. This effect also takes place in a vacuum when an unheated electrode consisting of certain materials, for example potassium, is subjected to the influence of light, particularly, to ultraviolet rays. The discharge current is carried by negative charges called electrons, which pass through the vacuous space under the influence of the impressed voltage. In the presence of gas these electrons, when moving with proper velocity, collide with gas molecules and give rise to gas ionization which completely changes the phenomena accompanying the discharge. The gas molecules are split up into electrons and larger and more slowly moving positive ions. The positive ions take part in the conduction of current, giving at first erratic readings on measuring instruments connected in circuit. As gas ionization continues at higher voltages a blue glow may appear. The cathode under these conditions is electrically disintegrated, technically is "sputtered", which causes its rapid destruction. The bombardment of the cathode by positive ions also causes heating of the cathode.

The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device invented by Professor Fleming described in Patent No. 24,850 of 1904 and also later in a device known as the "Audion" described in Patent No. 1427 of 1908. This device has been used as a receiver for radio-telegraphy and depends for its operation upon the rapid change of the discharge current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins somewhere between 20 and 30 volts. With the exception of the X-ray tube described in Patent Application No. 14,892 of 1913, no prior devices are known to the applicants operating with currents as great as about 5 milliamperes with voltages as high as about 200 volts.

In devices made in accordance with this invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionised gas. The cathode is not heated by the discharge itself. Blue glow and in fact all visible indications of a discharge are absent. Glass fluorescence is absent in a device operating with a pure electron discharge. The discharge current passing through a given space with the cathode at a sufficiently high temperature varies directly with the $3/2$ power of the impressed voltages. The discharge is independent of the vacuum, providing the pressure is below the minimum at which gas ionization by collision will take place. As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterised by regularity and reproducibility with given conditions.

Devices made in accordance with this invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents with currents thousands of times greater than the minute currents at which the devices above referred to were operable.

The gas occluded in metals and driven out by the electrons impinging thereon appears to be especially liable to ionisation, as it may be observed that gas eliminated from the anode even when below the pressure permissible for residual gas produces the effects accompanying gas ionization. In fact, gas thus eliminated from the anode may not even produce a difference in the reading of a McLeod vacuum gauge and yet produce ionization effects.

The above British Patent Application No. 14,892 of 1913 describes a novel electron discharge apparatus adapted particularly for the production of X-rays which is operable with a high energy input during the evacuating process. It is found that deleterious gases may be removed by electron bombardment even at a low temperature, which is advantageous as the device may not be adapted to receive a high energy input, or current of sufficiently high voltage may not be available.

Before describing the method of preparing the new type of apparatus, the structure of the apparatus illustrated in the drawings left with the Provisional Specification will be described. In the drawings:

Fig. 1 shows one form of electron discharge tube,

Figs. 2 to 6 inclusive illustrate various forms of cathode which may be used in the tube,

Figs. 7, 8 and 9 illustrate modified forms of discharge tube.

As shown in Fig. 1, the various parts of the apparatus may be mounted in a tube, or globe 1, upon a pedestal 2, similar to the mount used in incandescent lamps. The cathode 3 is centrally located and may consist of a short straight filament not shown in Fig. 1 but indicated by the position of terminals 5, 6 and shown plainly in Fig. 3. The cathode shown in Figs. 2 and 4 consist of one or more V-shaped conductors. Either form may be used, the particular form of cathode being ordinarily determined by convenience of construction. Preferably the cathode conductor is held taut by a spring 7 to avoid contact of the cathode conductor with the grid by sagging when the metal is expanded at a high temperature. The filament 3 is mounted between two oppositely disposed supports, 9, 9^1, in this case constituting a closed loop, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this frame-work is wound a wire 10, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. By means of this grid 10 potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge.

The supporting framework for the cathode and grid is attached to a rod 11, mounted upon the stem of the tube. Adjacent to the cathode and grid is the anode 12 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 13 upon fork shaped supports 14 and 15, but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other refractory metals may be used. By making the anode a continuous conductor it can be conveniently heated by the passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 16 and 17. The grid is indicated in Fig. 1 as being attached to leading-in conductors 18 and 19 at opposite ends, although but one terminal is ordinarily necessary.

In some cases it is desirable to use a plate-shaped anode; Fig. 2 illustrates such an arrangement suitable particularly for rectifying alternating current. The tube itself and other extraneous parts have not been shown in Fig. 2, as they are similar to Fig. 1. The cathode construction has already been referred to and the anodes 20 and 21 also preferably consist of tungsten and may be connected electrically with each other. Current connections are made by conductors 22, 23, the supports 24, 25 being merely indicated.

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapours as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at an elevated temperature during the normal operation of the device. In this case the temperature is preferably carried to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. In fact, the heating may take place in a suitable vacuum furnace, the temperature preferably being raised to 2500° C. or even higher. However, the heat alone, will not remove all the gas liberated by the electron discharge, but this gas is driven out even at ordinary temperatures by the discharge itself. The discharge appears to affect especially the surface of the metal. Heating is a valuable aid in bringing gases from the interior of the metal body into the sphere of action of the discharge but may be omitted when the devices are not heated during normal operation.

The bombardment is carried out when the evacuation has proceeded to a high degree by applying a potential between the cathode 3 and the anode 12, Fig. 1, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionization, and, as already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon. The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased, thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50,000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating voltage. In the case of a plate shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes. In the case of a device in which the anode normally operates at low temperature, bombardment without heating may suffice. After the metal has been freed from occluded gas, reabsorption of gas will not take place even though it is exposed to the air or other gases. For example anodes thus treated may be removed to other apparatus which then may be evacuated without further electron bombardment of the anode or anodes.

The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionization by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow; disintegration of the cathode and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance. It is also true that when the anode has been carefully freed from gas, residual free gas even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, and it is quickly removed by the gas clean-up effect when the device is operated.

Electron discharge apparatus thus provided with a gas-free pretreated anode or anodes may be constructed to handle currents at a very high voltage by proper mechanical design of the parts subjected to static strains, suitable proportioning of the parts and so forth.

As stated above in some cases it is desirable to use one or more V-shaped incandescing conductors for the cathode and to attach to the bights springs 7 to prevent contact of the conductor with the grid by sagging when the metal is expanded at high temperature. In Fig. 4 a plurality of loops are used in order to increase the amount of cathode surface. The filaments are connected in parallel by means of conductors 26 and 27.

In Fig. 5 the cathode 3 has been shown as being mounted in a frame 28, consisting of ferrochrome, tungsten, or other suitable metal upon which the wire 10 constituting the grid is wound. As this grid wire is thus wound upon a conductive frame its turns are in parallel and electrical contact may be made directly to the frame 28 by conductors 29. The leading-in conductors for the cathode are insulated from the frame by glass supports 30 as indicated.

Upon the frame 28 are placed mica sheets 31 and 32 which serve to insulate the wire 10 constituting the anode from the grid. The leading-in conductors to which the ends of the wires are anchored may be attached to glass beads 33 fused upon the frame 28.

In Fig. 6 not only the grid 10 is wound upon a frame but the cathode wire 3 is also wound upon stout metallic conductors 34 and 35 consisting preferably of tungsten. The conductors 34, 35 are attached respectively to an anchoring wire 36 and to two springs 37 serving to hold taut the turns of the tungsten wire constituting the cathode and to prevent them from coming into contact with the grid wire 10. A stranded copper conductor 38 may be used to conduct current to the cathode.

In the modified form of electron discharge device shown in Fig. 7, which is specially suitable for converting direct current into alternating current, the enclosing globe 1 has been shewn as partly broken away to disclose the interior arrangement of the electrodes comprising a V-shaped filamentary cathode 3, and plate-shaped anodes 20 and 21, such as illustrated in Fig. 2. Surrounding the cathode is a frame 38 of glass, upon which is wound fine wire constituting the grid 10 with closely adjacent turns surrounding the cathode 3. Located respectively between this grid and each of the anodes are grids 39 and 40, similar to those in Fig. 5, the function of which will be hereinafter explained. The cathode conductor is attached to terminal supports 41 and 42 which are in turn connected to leading-in wires 43 and 44, sealed into the stem 45 of the enclosing globe in the usual manner. The cathode filament is maintained taut by being anchored by its bight by means of the spring 7 attached to the frame 38 which together with the grid frames is carried by the pedestal 46. The anode stems 47 and 48 consist of tungsten or molybdenum and are held in position in the extensions 49 and 50 of the bulb by springs 51, which grip the walls of the bulb. Connection is made to the anodes in the usual manner by the leading in wires 52 and 53. Connection to the grid surrounding the cathode is made by leading in wires 54. The grids 39 and 40 are preferably wound upon metallic frames 31 and 32 consisting, for example, of ferrochrome which thus short circuit the turns of the grid. Electrical connection is made thereto by conductors 55 and 56.

Fig. 8 illustrates somewhat diagrammatically an electron discharge device suitable for rectifying alternating current in which a plate 57 is located between an electron-emitting cathode 58 and an anode 59. Heating current is supplied to the cathode conductor by a battery 60 and a source of energy, for example, a transformer 61, is connected between the cathode and the anode. Surrounding the cathode is a concave dished plate 62 which is maintained negatively charged, conveniently by connecting it to the cathode by means of a conductor 63. This ring serves to modify the static field so as to focus the electrons into a fairly well defined stream which passes through an aperture in the plate 57 to the anode.

By maintaining the plate 57 positively charged, for example by means of a battery 64, the passage of the electrons from the cathode to the anode is assisted. The potential of the battery 64 and hence the charge on the plate 57 may be only a fraction of the potential between supply conductors 65, 66. The electrons will be attracted to the plate 57 but will largely pass through the aperture in the same, as this represents the centre of static attraction. By making the potential of the plate 57 relatively low the loss of energy by the absorption of electrons on the part of the plate will be relatively small, and will be more than compensated by the increase in discharge current.

The rectified current may be utilised by load devices 67. If it is desired to utilise both half waves of the alternating current, two sets of devices of the type illustrated in Fig. 8 are used.

In the devices above described, the tube is exhausted to the highest possible degree of vacuum, the gas being driven out of the walls of the tube as well as out of all of the metal electrodes. Under these conditions the current flow in the tube between the incandescent cathode and the plate or anode is due to a pure electron discharge from the heated cathode and is not dependent upon the presence of residual gas as a conducting medium.

If however a certain amount of residual gas be present in the tube then the operation of the device becomes quite different. Such a construction and mode of operation is that characteristic of the "Audion". In the "Audion", if very low voltage be used in the local or plate circuit, the device is relatively very insensitive, or in other words the change of current in the local circuit is very small for a given change of potential on the grid. The device becomes more sensitive as the voltage in the local circuit is increased. There is a limit however to the voltage which may be used in the local circuit because as the voltage is increased ionisation of the gas in the tube increases, a blue glow appears followed by deterioration of the electrodes, disengagement of more gas therefrom and finally destruction of the operative qualities of the tube. The voltage impressed on the local circuit is therefore made as high as possible consistent with the avoidance of these limited conditions. In the "Audion" as thus constituted, a decrease of potential on the grid causes a decrease of current in the local circuit, while increase of potential on the grid causes an increase of current in the local circuit, but the decrease of current is of a magnitude very much greater than the increase of current caused by an increase of potential on the grid. The result is that when high frequency oscillations are impressed upon the grid their presence is made known by a decrease of current in the local or plate circuit, which decrease is detected by the telephone or other indicator placed in the local circuit.

It has been found that by maintaining within the evacuated container of a device of the general nature already described a certain definite pressure of gas, which in amount is very much less than that which is necessary to make the "Audion" operative, and not much higher than would be tolerated in a device such as described above, very remarkable results are secured in the relations which then exist between the current in the plate circuit and the changes of potential on the grid. With this definite pressure of gas or vapour in the device it is found that the variation of current in the plate circuit with variation of potential on the grid follows the law of a pure electron discharge tube such as that described above, except within a small range of voltage in the grid circuit. Within this small range there appears to be a condition of instability such that when high frequency oscillations are impressed upon the grid there always follows a sudden decrease of current in the local circuit. The explanation of this phenomenon is decidedly obscure but the existence of the phenomenon is very real. Within the range of voltage indicated, the application of high frequency oscillations or of continuous high frequency waves causes the current in the local circuit to decrease so suddenly that a very distinct signal is produced in the telephone receiver or other indicating device in the local circuit. The sharpness of the signal thus produced is such that the device illustrated in Fig. 9 is not only extremely sensitive to receive high frequency impulses but because of the sharpness of the signals the effect of "static" is not nearly so serious as in other detecting devices at present in use.

While this form of detector is dependent upon the presence of a small but definite gas pressure in the space including the electrodes, its operation is not accompanied by blue glow or any other well recognised evidences of positive gas ionization. The amount of gas or vapour present is perhaps not more than one-tenth of that which characterises the "Audion".

The sensitiveness of this device varies with the potential impressed upon the grid and becomes a maximum at a certain definite potential. To secure this maximum sensitiveness a definite potential which varies according to the particular device is impressed upon the grid circuit. As this potential is changed by the high frequency oscillations the current in the plate circuit is suddenly decreased, thereby producing the desired signal.

In producing and maintaining the desired gas pressure in this device it is not sufficient to leave in the tube a certain amount of residual gas during exhaustion since this gas does not remain constant in amount but generally will decrease upon operation of the device by the well-known clean-up action, though in some cases the amount of gas present increases rather than decreases, due to other causes. To secure the necessary definite gas or vapour pressure in the tube, a substance with the desired vapour pressure is provided and placed in the tube. Among other things it has been found that amalgam is suitable for the purpose. Mercury alone appears to be unsuitable as it has too high a vapour pressure at ordinary temperatures though by lowering the temperature of the mercury the desired vapour pressure may be obtained.

As shown in Fig. 9, the discharge device is very similar to that illustrated in Fig. 1 and comprises an enclosing envelope 1, in which are mounted an electron-emitting cathode 3 and an anode 12, both of which may, as before, consist of wire preferably of tungsten, tantalum, or other highly refractory metal. The anode need not be a wire but may be a plate properly freed from gas as described in connection with Fig. 2. The cathode 3 is a short V-shaped tungsten filament connected to terminal conductors 69, 70 and supported at its bight by a hook 68, both the supply conductors and the hook 68 being mounted on a frame 71 so that the filament is located in a plane passing through the side arms of the frame. The cathode supports 68, 69 and 70 are provided with small glass discs 72 which reduce the tendency of a short-circuit between the cathode and the grid by vaporised metal deposited on the frame 71. Around the outside of the frame is wound the grid 10 for varying the electric field near the cathode and thereby varying the electron current between the cathode and the anode. The anode wire 12 is supported by hooks 13 located upon a forked glass support 15. The frame 71 and the support 15 are mounted upon a glass stem 73 sealed into one end of the envelope. Leading-in conductors 74, 75, supply heating current to the cathode and the conductors 76, 77 are connected to the terminals of the anode and are sealed into the stem in the usual manner. The anode is provided with current connections at each terminal so as to enable it to be heated during the evacuation of the device. Only one electrical connection is made to the grid by means of conductors 78 sealed into the envelope as the grid may be sufficiently freed from gas without heating it by passage of current.

Before the envelope is sealed off there is placed in it (in a manner hereinafter described) a small amount of vaporisable material 79, for example an amalgam, sulphur, phosphorus pentoxide, tungsten hexachloride, and in general substances having a suitable vapour pressure at the operating temperature of the device. Substances having too high a vapour pressure, for example mercury, may be used if maintained during operating at a suitable low temperature, as in a side chamber. Gases at proper pressure will give the desired effect but the effective pressure, and possibly also the character of the gas are changed by some chemical or electro-chemical action in the tube so that gases act only temporarily. The material 79 is either loosely placed in the main envelope as indicated, or placed in a side chamber. The character of this material depends upon the temperature and voltages at which the device is operated, as will be hereinafter explained, its purpose being to maintain in the space vapour at a definite low pressure.

For the evacuation of the device the glass walls of the tube are heated so as to free them from moisture and both the anode and the cathode are heated by passage of current so as to drive out the gases. When an amalgam is to be used as the source of vapour, the metal to be amalgamated, for example silver, preferably is placed in the envelope before evacuation. The mercury is preferably placed in a side chamber which is kept cool during the preliminary bake-out. The evacuation of the tube is carried out, as described above with reference to the modifications illustrated in Figs. 1, 7 and 8, by the most approved methods of incandescent lamp exhaust, and the last traces of gas are removed by either a Gaede molecular pump or by some chemical evacuating means. The last traces of ionizable gases are also removed from the electrodes by heating them to incandescence and preferably at the same time operating the grid as the anode for an electron discharge, the impressed voltage being increased step by step as the gas is removed. After the parts of the device and the silver, or other metal to be amalgamated, has been freed from gas, mercury vapour is permitted to diffuse into the envelope: for example, clean mercury may be kept at a relatively low temperature in a side chamber during the exhaust. When the exhaust is completed the mercury may be permitted to reach room temperature, or even higher temperatures, thus diffusing into the main envelope to form silver amalgam. At room temperature one or two days are required for the amalgamation. All excess unalloyed mercury must be removed from the tube. This may conveniently be done by warming the bulb slightly and surrounding the mercury side tube in a freezing mixture, or in liquid air. The mercury side container may then be sealed off. When evacuation of the envelope has been carried to a pressure low enough to enable the pure electron discharge to take place and ionizable gas has been removed from the anode to a sufficient extent to prevent the blue-glow phenomenon which is an indication of positive gas ionization, the envelope is sealed off. A device thus prepared will operate at ordinary room temperature with a substantially pure electron discharge between anode and cathode without positive ionization, even when the impressed voltage is as high as 300 to 400 volts, or even higher. However, when the voltage on the grid circuit is within a certain range an irregularity is observed in the electron discharge current, as already described.

Having now particularly described and ascertained the nature of our said invention, and in what manner the same is to be performed, we declare that what we claim is:—

1. An electric vacuum discharge apparatus comprising a sealed envelope containing a cathode adapted to be heated, a cooperating anode and a conductor arranged in operative relation to the electrodes, the envelope being evacuated to such an extent that there are no visible or other indications of gas ionization when a discharge passes between the electrodes.

2. An electric vacuum discharge apparatus comprising a sealed envelope containing an electron emitting cathode and a rigid insulating framework mounted in proximity to the cathode and having a conductor wound upon a portion thereof constituting a grid and a second conductor wound upon another portion of the framework and constituting an anode, the envelope being exhausted to such an extent that there are no visible or other indications of gas ionization when a discharge passes between the electrodes.

3. In an electric vacuum discharge apparatus as claimed in Claim 1, a conductor in part at least surrounding the cathode and provided with means for maintaining it at a uniform positive potential with respect to the cathode and means for producing a negative charge in the neighbourhood of the cathode.

4. An electric vacuum discharge apparatus comprising a sealed highly evacuated envelope containing a cathode adapted to be heated, cooperating anodes located on opposite sides of the cathode, a grid connected to the positive terminal of a source of potential, surrounding the cathode in close proximity

thereto but out of contact therewith and two further grids connected to separate sources of potential arranged on opposite sides of the cathode between the first mentioned grid and the anodes.

5. An electric vacuum discharge apparatus comprising a sealed envelope evacuated to such an extent that substantially no gas ionization takes place when a discharge occurs within it, containing an electron emitting cathode and a co-operating anode, the electrons emitted from the cathode being first subjected to a static field, positive with respect to the cathode and then having their motion controlled by a field independent of the positive field.

6. In an electric vacuum discharge apparatus as claimed in Claim 1, means for maintaining within the envelope a gas at a definite pressure at which the apparatus possesses a critical region of sensitiveness to changes of the electrical field near the cathode while carrying current independently of gas conduction.

7. In an electric vacuum discharge apparatus as claimed in Claim 1, a vaporisable substance enclosed in the envelope having a vapour pressure of from about six to forty hundred thousandths of a millimeter of mercury.

8. An electric vacuum discharge apparatus comprising a sealed envelope containing a cathode adapted to be heated to incandescence, a co-operating anode, a conductor adapted to vary the electrical field near the cathode, and a vaporizable alloy such as a mercury silver amalgam, the envelope being deprived of ionizable gas to such a degree that it operates with a pure electron discharge free from positive ionization at impressed terminal potentials as high as 200 volts.

9. In an electric vacuum apparatus of the type hereinbefore described and claimed, the method of removing ionizable gas from the anode which consists in subjecting it to a prolonged electron bombardment with an energy input below the value necessary to appreciably heat the anode and at the same time removing the gas released thereby.

10. In an electric vacuum discharge apparatus of the type hereinbefore described and claimed, the method of obtaining a high vacuum which consists in evacuating the envelope to a high degree, impressing between the cathode and anode a voltage adapted to produce an electron discharge but insufficient to produce appreciable gas ionization as indicated by a blue glow at the cathode, and step by step raising the discharge voltage and continuing the evacuation until the anode will no longer disengage ionizable gas at the normal working current and voltage, and finally sealing the envelope when the normal operating voltage has been exceeded.

Dated this 1st day of February, 1915.

JOHN GRAY,
83, Cannon Street, London, E.C.,
Agent for the Applicants.

A.D. 1914. July 1. No 15,788.

BRITISH THOMSON—HOUSTON CO.'S PROVISIONAL SPECIFICATION.

SHEET 1.

[This Drawing is a reproduction of the Original on a reduced scale.]

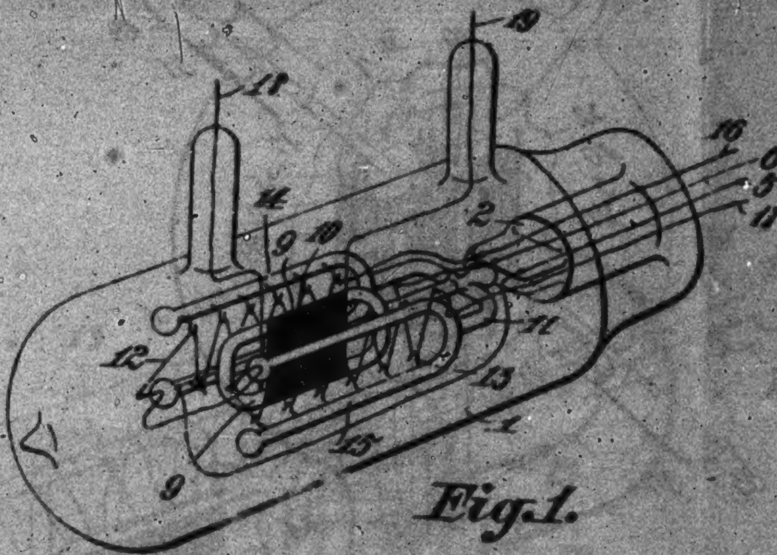

19
18
16
6
5
17
14
9
10
2
12
11
13
1
15
9

Fig. 1.

Fig. 2.

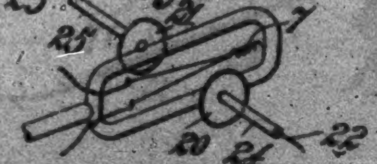
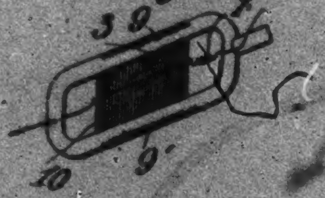

23
24
25
7
20
21
22

Fig. 3.



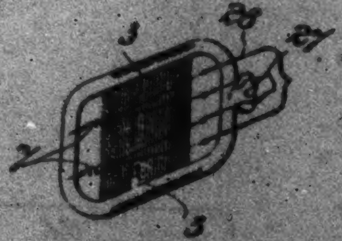


Fig. 4.

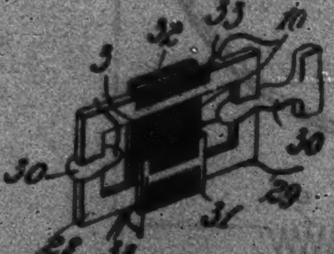

32
33
10
3
30
30
29
28
33
31

Fig. 5.

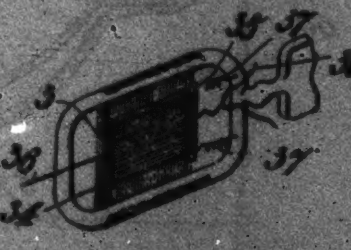
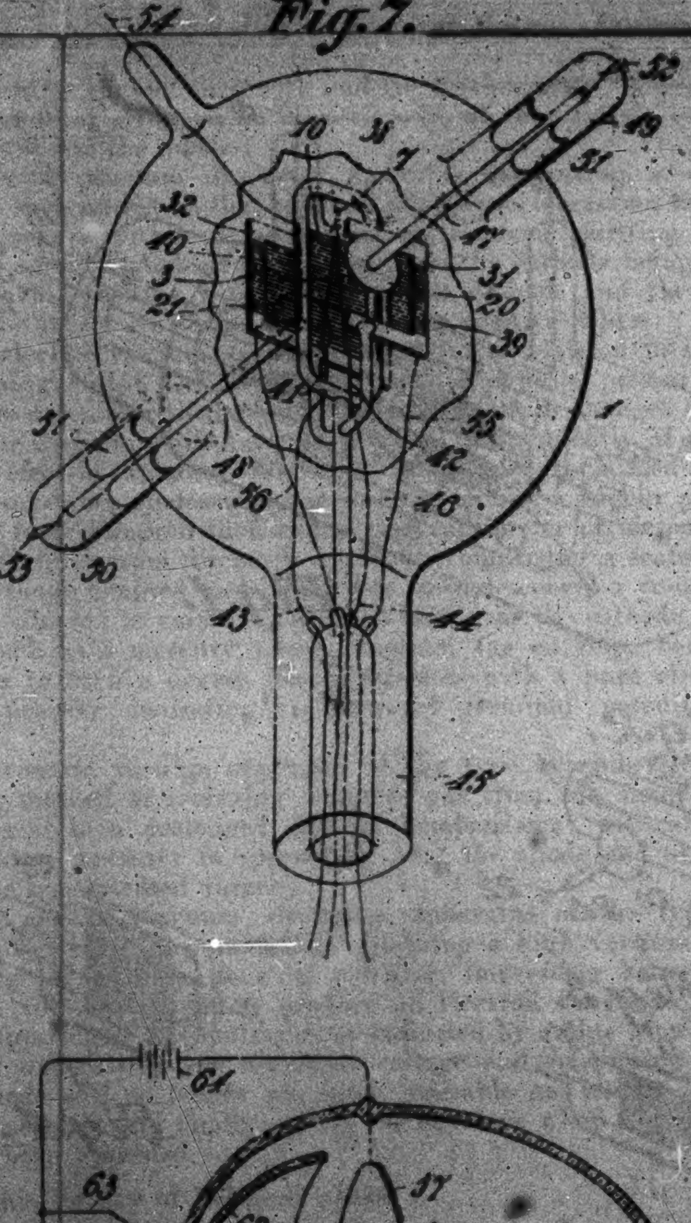

35
37
36
3
36
37
34

Fig. 6.

Fig. 7.



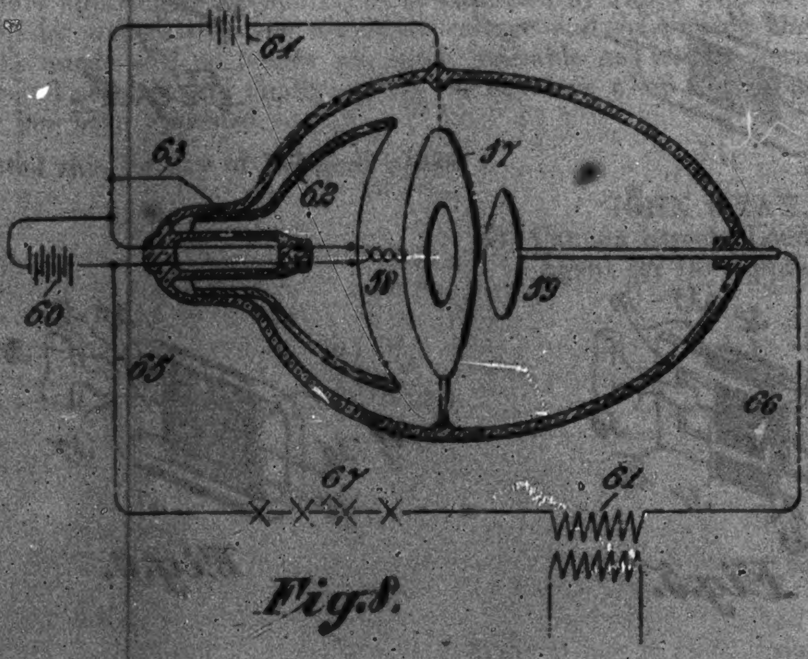


Fig. 8.

A.D. 1914. JULY 1. No 15,788.

BRITISH THOMSON—HOUSTON CO.'S PROVISIONAL SPECIFICATION.

(3 SHEETS)
SHEET 3.

[This Drawing is a reproduction of the Original on a reduced scale]

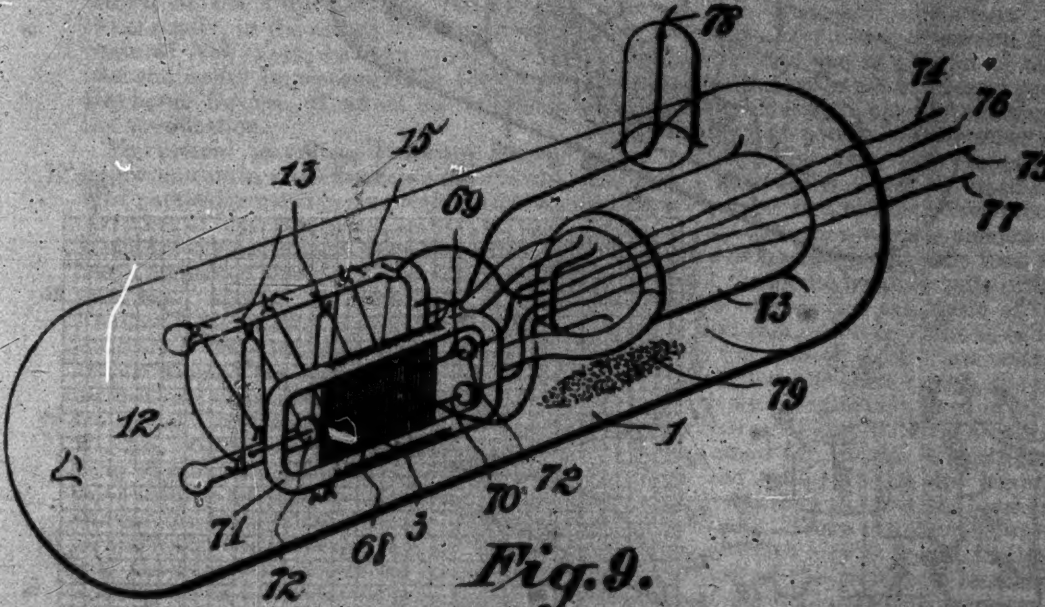

78
74
76
75
77
13
15
69
73
79
1
12
2
71
72
68
3
70
72

Fig. 9.

DEFENDANT'S EXHIBIT No. 42.

W. C. WHITE.

ELECTRICAL DISCHARGE DEVICE.

APPLICATION FILED MAR. 20, 1914.

1,159,807. Patented Nov. 2, 1915.

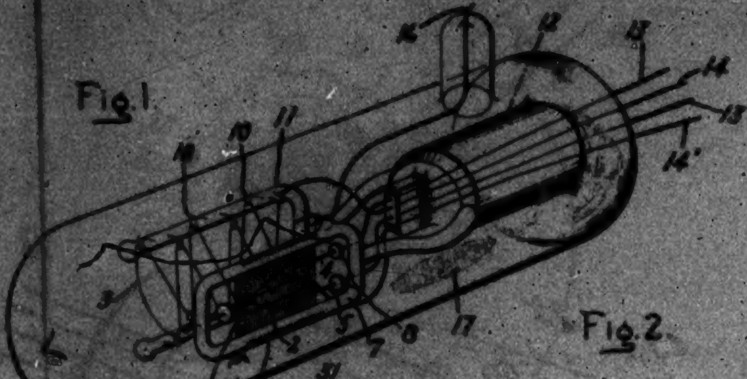
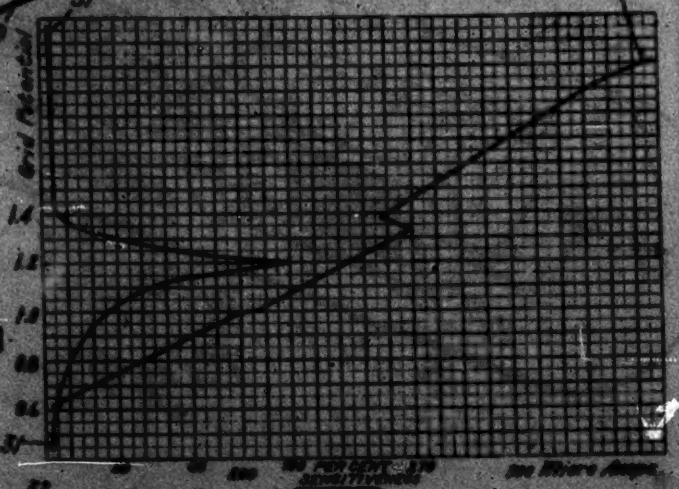


Fig. 1
16
12
13
14
13'
14'
10
11
18
3
2
5
7
8
17
4



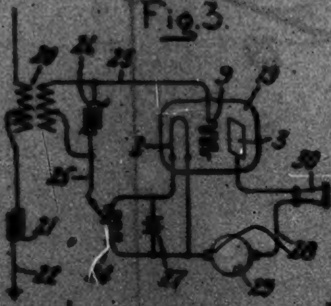


Fig. 3
20
24
23
9
13
3
3
25
30
21
22
26
27
28
29

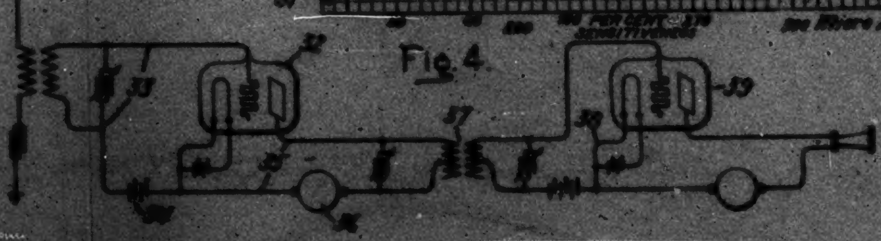


Fig. 4
32
33
33
37
38
35
36

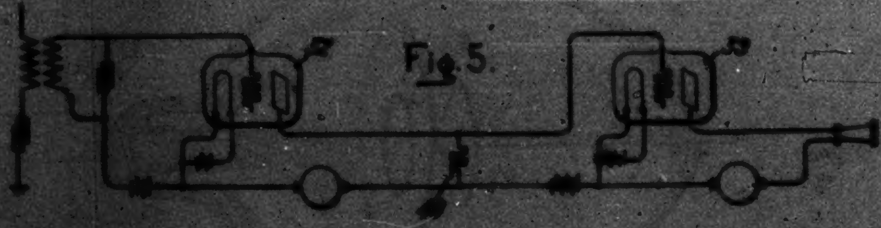


Fig. 5
32
33
40

Witnesses:

J. Ellis Glen

Inventor:
William C. White,
by Albert G. Davis
His Attorney

UNITED STATES PATENT OFFICE.

WILLIAM C. WHITE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRICAL-DISCHARGE DEVICE.

1,159,307. Specification of Letters Patent. Patented Nov. 2, 1915.

Application filed March 28, 1914. Serial No. [illegible].

To all whom it may concern:

Be it known that I, WILLIAM C. WHITE, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical-Discharge Devices, of which the following is a specification.

My present invention comprises certain improvements in vacuum electric devices and is of particular value in connection with the detection of high frequency oscillations used in electro-magnetic wave signaling systems.

My improved detector is in construction somewhat similar to the well-known "audion" set forth in U. S. patent to De Forest #879,532, and is also similar in construction to the vacuum tube device described and claimed in an application filed by Irving Langmuir, October 16, 1913, serial No. 795,810. In both of these prior devices an exhausted glass tube is provided having a cathode adapted to be heated to incandescence by some suitable source of current, an anode or plate connected in a local circuit with one terminal or leg of the incandescent cathode, and a conductor or grid located in proximity to the cathode and upon which a varying potential is impressed, the variations of which affect the amount of current flowing in the vacuum space between the cathode and the plate or anode. The change in current in this local circuit bears no necessarily definite relation to the change of potential on the grid, but is very greatly affected by the nature of the vacuous space in which the electrodes are located. Thus, in the vacuum relay or amplifier of the type shown in the said Langmuir application, the tube is exhausted to the highest possible degree of vacuum, the gas being driven out of the walls of the tube as well as out of all of the metal electrodes. Under these conditions the current flow in the tube between the incandescent cathode and the plate or anode is due to a pure electron discharge from the heated cathode, and is not dependent upon the presence of residual gas as a conducting medium. In a tube thus highly exhausted, current in the local circuit or plate circuit increases with increase of grid potential and decreases with decrease of grid potential, but the difference in the amount of increase for a given variation of grid potential is not so far different from the decrease caused by a decrease of grid potential as to make the device a good detector of high frequency oscillations. In other words, the asymmetry of current flow in the local circuit due to a series of high frequency oscillations is not sufficiently great to enable the device to operate effectively in connection with a telephone or other receiver for detecting such high frequency impulses. The device is more especially valuable as a relay or amplifier of such oscillations. If, however, a certain amount of residual gas be present in the tube then the operation of the device becomes quite different. Such a construction and mode of operation is that characteristic of the so-called audion. In the audion, if very low voltage be used in the local or plate circuit, the device is relatively very insensitive, or in other words, the change of current in the local circuit is very small for a given change of potential on the grid. The device becomes more sensitive as the voltage in the local circuit is increased. There is a limit however to the voltage which may be used in the local circuit because as the voltage is increased, ionization of the gas in the tube increases, a blue glow appears followed by deterioration of the electrodes, disengagement of more gas therefrom and finally destruction of the operative qualities of the tube. The voltage impressed on the local circuit is therefore made as high as possible consistent with the avoidance of these limited conditions. In the audion as thus constituted, a decrease of potential on the grid causes a decrease of current in the local circuit while increase of potential on the grid causes an increase of current in the local circuit, but the decrease of current is of a magnitude very much greater than the increase of current caused by an increase of potential on the grid. The result is that when high frequency oscillations are impressed upon the grid their presence is made known by a decrease of current in the local or plate circuit, which decrease is detected by the telephone or other indicator placed in the local circuit.

I have found that by maintaining within the evacuated container of a device of the general nature already described, a certain definite pressure of gas, which in amount is very much less than that which is necessary to make the so-called audion operative, and not greatly more than would be tolerated in a device such as disclosed in the Langmuir application, very remarkable results are secured in the relations which then exist between the current in the plate circuit and the changes of potential on the grid. With this definite pressure of gas or vapor in the device, I have found that the variation of current in the plate circuit with variation of potential on the grid follows the law of a pure electron discharge tube such as that of the Langmuir application, except within a small range of voltage in the plate circuit. Within this small range there appears to be a condition of instability such that when high frequency oscillations are impressed upon the grid there always follows a sudden decrease of current in the local circuit. The explanation of this phenomenon is decidedly obscure but the existence of the phenomenon is very real. Within the range of voltage indicated, the application of high frequency oscillations or of continuous high frequency waves, causes the current in the local circuit to decrease so suddenly that a very distinct signal is produced in the telephone receiver or other indicating device in the local circuit. The sharpness of the signal thus produced is such that my improved device is not only extremely sensitive to receive high frequency impulses but because of the sharpness of the signals the effect of "static" is not nearly so serious as in other detecting devices.

While my improved detector is dependent upon the presence of a small but definite gas pressure in the space including the electrodes, its operation is not accompanied by blue glow or any other well recognized evidences of positive gas ionization. The amount of gas or vapor present is perhaps not more than [illegible] of that which characterizes the so-called audion.

The sensitiveness of my improved devices varies with the potential impressed upon the grid and becomes a maximum at a certain definite potential. To secure this maximum sensitiveness, a definite potential which varies according to the particular device is impressed upon the grid circuit. As this potential is changed by the high frequency oscillations, the current in the plate circuit is suddenly decreased, thereby producing the desired signal.

In producing and maintaining the desired gas pressure in my improved device it is not sufficient to leave in the tube a certain amount of residual gas during exhaustion since this gas does not remain constant in amount but generally will decrease upon operation of the device by the well-known clean-up action, though in some cases the amount of gas present increases rather than decreases, due to other causes. To secure the necessary definite gas or vapor pressure in the tube, I therefore provide a substance with the desired vapor pressure and place this in the tube. Among other things I have found that amalgam is suitable for the purpose. Mercury alone appears to be unsuitable, as it has too high a vapor pressure at ordinary temperatures though by lowering the temperature of the mercury the desired vapor pressure may be obtained.

The novel features of my invention are pointed out with greater particularity in the appended claims, and for a better understanding of my invention reference may be had to the following description taken in connection with the accompanying drawing in which—

Figure 1 is a perspective view of one type of apparatus embodying my invention; Fig. 2 illustrates by means of curves some of the electrical characteristics of the device; Figs. 3, 4 and 5 are diagrams of connections illustrating how the new device may be used in radio-telegraphic receiving systems.

As shown in Fig. 1 the discharge device comprises an inclosing envelop 1, which may be of glass, in which are mounted an electron-emitting cathode 2 and an anode 3. In the device illustrated both the cathode and anode consist of wire preferably of tungsten, tantalum, or other highly refractory metal which can be readily freed from ionizable gas. The anode need not be a wire but may be a plate properly freed from gas and it has been thus diagrammatically indicated in Fig. 3. The cathode 2 is a short V-shaped tungsten filament connected to terminal conductors 4, 5 and supported at its bight by a hook 6, both the supply conductors and the hooks 6 being mounted on a frame 7 so that the filament is located in a plane passing through the side arms of the frame.

The cathode supports 4, 5 and 6 are provided with small glass disks 8 which reduce the tendency of a short circuit between the cathode and the grid by vaporized metal deposited on the frame 7. Around the outside of the frame is wound a wire 9 with closely spaced turns. This conductor 9 commonly called the grid, serves the purpose of varying the electric field near the cathode and thereby varying the electron current between cathode and the anode. The anode wire is conveniently supported by hooks 10 located upon a forked glass support 11. The frame 7 and the support 11 are mounted upon a glass stem 12 sealed into one end of the envelop. Leading-in conductors 13, 13′ which supply heating current to the cathode and the conductors 14, 14′ which are connected to the terminals of the anode are sealed into the stem 12 in the usual manner. The anode is provided with current connections at each terminal so as to enable it to be heated during the evacuation of the device. But one electrical connection is made to the grid by means of conductor 16 sealed into the envelop as the grid may be sufficiently freed from gas without heating it by passage of current.

Before the envelop is sealed off there is placed in it (in a manner hereinafter described) a small amount of vaporizable material 17, for example, an amalgam, sulfur, phosphorus pentoxid, tungsten hexachlorid, and in general substances having a suitable vapor pressure at the operating temperature of the device. Substances having too high a vapor pressure, for example, mercury, may be used if maintained during operation at a suitable low temperature, as in a side chamber. Gases at proper pressure will give the desired effect but the effective pressure, and possibly also the character of the gas are changed by some chemical or electrochemical action in the tube so that gases act only temporarily. The material 17 is either loosely placed in the main envelop as indicated, or placed in a side chamber. The character of this material, depends upon the temperature and voltages at which the device is operated, as will be hereinafter explained, its purpose being to maintain in the space, vapor at a definite low pressure.

For the evacuation of the device the glass walls of the tube are heated so as to free them from moisture and both the anode and the cathode are heated by passage of current so as to drive out the gases. When an amalgam is to be used as the source of vapor, the metal to be amalgamated, for example, silver, preferably is placed in the envelop before evacuation. The mercury is preferably placed in a side chamber which is kept cool during the preliminary bake-out. The evacuation of the tube is carried out by the most approved methods of incandescent lamp exhaust, and the last traces of gas are removed by either a Gaede molecular pump or by some chemical evacuating means, such as the use of vaporized calcium or magnesium. The last traces of ionizable gases are removed from the electrodes by heating them to incandescence and preferably at the same time operating the grid as the anode for an electron discharge, the impressed voltage being increased step by step as the gas is removed. After the parts of the device and the silver, or other metal to be amalgamated has been freed from gas, mercury vapor is permitted to diffuse into the envelop. For example, clean mercury may be kept at a relatively low temperature in a side chamber during the exhaust. When the exhaust is completed the mercury may be permitted to reach room temperature or even a higher temperature, thus diffusing into the main envelop to form silver amalgam. At room temperature one or two days are required for the amalgamation. All excess unalloyed mercury must be removed from the tube. This may conveniently be done by warming the bulb slightly and surrounding the mercury side tube in a freezing mixture, or in liquid air. The mercury side container may then be sealed off. When evacuation of the envelop has been carried to a pressure low enough to enable the pure electron discharge to take place and ionizable gas has been removed from the anode to a sufficient extent to prevent the blue-glow phenomenon which is an indication of positive gas ionization, the envelop is sealed off. A device thus prepared will operate at ordinary room temperatures with a substantially pure electron discharge between anode and cathode without positive ionization, even when the impressed voltage is as high as 300 to 400 volts, or even higher. However, when the voltage between anode and cathode is within a certain range an irregularity is observed in the electron discharge current, as already described. This voltage range is illustrated by curve 18 in Fig. 2, which will be more fully understood by first considering the connections shown in Fig. 3. In this figure a device 19 constructed as above described is connected in a secondary circuit of a transformer 20, the primary of which is included in series with a condenser 21 in a grounded antenna circuit 22. The grid 9 is connected by a conductor 23 to one terminal of the transformer and the negative terminal of the cathode 2 is connected through a potentiometer 24 and a conductor 25 to the other terminal of the transformer secondary. Connected in shunt to the secondary of the transformer is a variable condenser 26 so that by varying either the capacity or inductance of the circuit it may be tuned to resonance with the incoming oscillations to be detected. The battery 27 serves to heat the cathode to incandescence and also determine the potential of the grid 9 with respect to the cathode. In the plate circuit 28 between the cathode 2 and anode 3, is included a source of direct current, for example, a direct current generator 29 and also a suitable indicator, such as a telephone receiver 30.

In order to receive signals the potentiometer 24 is adjusted so as to maintain the grid at a certain definite potential with respect to one end of the cathode. With a suitable potential between the cathode and anode, for example, 50 to 250 volts, a steady direct current will flow in the plate circuit which will not affect the telephone receiver. When oscillations are received by the antenna and superimposed upon the potential of the grid the electric field about the cathode is changed correspondingly and a decrease of current is noted with each oscillation or series of oscillations, thereby producing sounds in the receiver. With a given electron detector it will be observed that the sensitiveness varies very markedly with the grid potential, there being a certain point at which the signals may be most strongly heard and a variation of grid potential above or below this value produces a decrease of audibility of the signals.

In Fig. 2 there are shown for the purpose of illustration curves of the characteristics of one particular detector made in accordance with my invention. For the curve 18 the ordinates represent grid potentials with respect to negative end of filament and the abscissæ the relayed current in micro-amperes. The curve indicates the current values obtained with a given terminal voltage between the cathode and the anode for the indicated range of grid voltages with respect to the cathode. This current is commonly known as the "plate current." The sensitiveness of the device is indicated by curve 31 which is plotted with the ordinates in grid potential and the abscissæ in percentages of maximum sensitiveness. In other words this curve indicates the degree of change in plate current produced by impressed oscillations at different grid potentials. It will be observed at 1.2 volts the curve of sensitiveness reaches a maximum. It will also be observed that for a certain range of grid voltage on each side of this critical value the plate current exhibits an irregularity and then at higher grid voltages again increases at the rate it had increased before the period of irregularity or off-set in the curve.

In the device here illustrated a sudden change of grid potential as produced by impressed oscillations produces a marked decrease of current in the plate circuit 28 providing the grid potential is not far from 1.2 volts positive. With a pure electron discharge device such as described in Langmuir application, Serial No. 795,610 an increase of positive grid potential will produce an increase of plate current. In the Langmuir device a positive impulse or charge on the grid produces a corresponding increase in the proportion of electron current taken by the grid itself.

On either side of the region of greatest sensitiveness indicated by the off-set of the curve 18 of grid potential the characteristic of my device is substantially that of a pure electron discharge. The vapor pressure necessary to produce this peculiar effect varies with the character of the material used. For mercury vapor in the type of apparatus illustrated the pressure should be between the limits of .00006 and .00040 millimeters of mercury. Sulfur, for example, operates best at a pressure of .0002 to .008 millimeters of mercury. If a greater responsiveness to the received oscillations is desired than can be obtained with the connections illustrated by Fig. 3, my new detecting device may be used in cascade with the pure electron discharge apparatus or relay described in the Langmuir application above referred to. Electrical connections suitable for this purpose are shown in Figs. 4 and 5.

In Fig. 4 the electron relay 32 has its grid circuit included in a local tuned circuit 33, the various parts of which correspond to those described in connection with Fig. 3. It need only be noted that the potential of the grid is determined by a battery 34. The plate circuit 35 contains a generator 36 or other suitable source of direct current of desired voltage. The variable plate current is impressed upon the primary of an air core transformer 37, the secondary of which is connected to the grid circuit 38 of a detector 39 made in accordance with my invention. The incoming oscillations are magnified by the relay 32 which produces in its plate circuit an amplified current similar in character to its received oscillations which is then transformed and detected as already described in connection with Fig. 3. In some cases the relay 32 and my novel detector 39 may be to advantage coupled through a resistance 40 instead of a transformer, as shown in Fig. 5.

In the operation of my novel detector it is not necessary that the source of current in the electrode circuit should be of invariable voltage. An ordinary generator even though its voltage varies slightly due to commutation, and so forth, may be used as indicated in Fig. 3. When using an audion a current source with a steady voltage is necessary as an ordinary generator will cause noises in the telephone. The device is also less affected by "static," or atmospheric disturbances than devices depending on gaseous ionization. It can be operated under the most sensitive conditions without the danger of static causing the discharge to burst into blue glow.

The high apparent resistance of the device renders changes of resistance in the external circuit of little effect. For example, two or three telephone receivers or more may be used in series in the receiver circuit without any noticeable change in the loudness or clearness of the signals.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electrical discharge device comprising a gas-tight envelop and an electron-emitting cathode and an anode, the space within said envelop being evacuated to such degree that current conduction can take place from cathode to anode by means of substantially pure electron discharge, and means in said envelop for maintaining therein a gas at a definite pressure at which the device possesses a critical region of sensitiveness to changes of electrical field near the

cathode while carrying current independently of gas conduction.

2. A device for detecting high frequency oscillations comprising a cathode adapted to be heated, an anode, a grid located near said cathode, an inclosing envelop, and means for maintaining within said envelop gas at a substantially constant pressure at which the device possesses a region of maximum sensitiveness to oscillations impressed on said grid when said grid is at a critical potential with respect to the cathode, the gas pressure being so low that a discharge between cathode and anode is substantially independent of positive ionization at grid charges materially more positive than said critical potential.

3. A detector for high frequency signals comprising a highly evacuated envelop, a cathode adapted to be heated to incandescence, an anode, a discharge-controlling conductor, and means for maintaining in said envelop gas of such character and pressure that there is a decrease conductivity for variations of potentials of the discharge controlling conductor from a critical potential, the electrodes of said device being freed from gas so completely and the gas pressure therein being so low that the electrical characteristics at current values both lower and higher than the critical region substantially follow the law of pure electron conduction.

4. An electrical discharge device comprising an envelop, an electron-emitting cathode, an anode, a discharge-controlling conductor located near said cathode, said device being deprived of gas to such degree as to be capable of operation with a substantially pure electron discharge at several hundred volts and a vaporizable substance in said envelop.

5. A device for detecting high frequency oscillations comprising an envelop, a cathode adapted to be heated to incandescence, an anode, means for varying the electrical field near the cathode, said device being deprived of ionizable gas to such degree as to operate with a pure electron discharge free from positive ionization at impressed terminal potentials as high as 200 volts and an alloy of mercury and silver in said envelop.

6. An electrical discharge device comprising an envelop, an electron-emitting cathode, an anode, the interior of said envelop being deprived of gas to such low pressure that positive ionization is substantially absent when normally operating and a substance in said envelop exposed to the evacuated space having a vapor pressure of about six to forty hundred-thousandths of a millimeter of mercury.

7. An electrical discharge device comprising an envelop, an electron-emitting cathode, an anode, the interior of said tube being deprived of gas to such low pressure that positive ionization is substantially absent at impressed terminal potentials of several hundred volts, and an amalgam in said envelop exposed to the evacuated space, said amalgam having a vapor pressure at ordinary temperatures of about .00005 to .0004 millimeters of mercury.

8. The method which consists in producing an electron discharge in a space evacuated to such degree that positive ionization of gas present in said space is absent, supplying to said space gas at a constant pressure too low to cause appreciable ionization but high enough to cause a sudden decrease of electron current when the electrical field near the cathode is increased or decreased by high frequency waves.

In witness whereof, I have hereunto set my hand this 19th day of March, 1914.

WILLIAM C. WHITE.

Witnesses:
BENJAMIN B. HULL,
HELEN ORFORD.

DEFENDANT'S EXHIBIT No. 43.

H. DE F. ARNOLD.

METHOD OF REPRODUCING ELECTRICAL VARIATIONS.

APPLICATION FILED JULY 16, 1913.

1,118,172.

Patented Nov. 24, 1914.

Fig. 1.

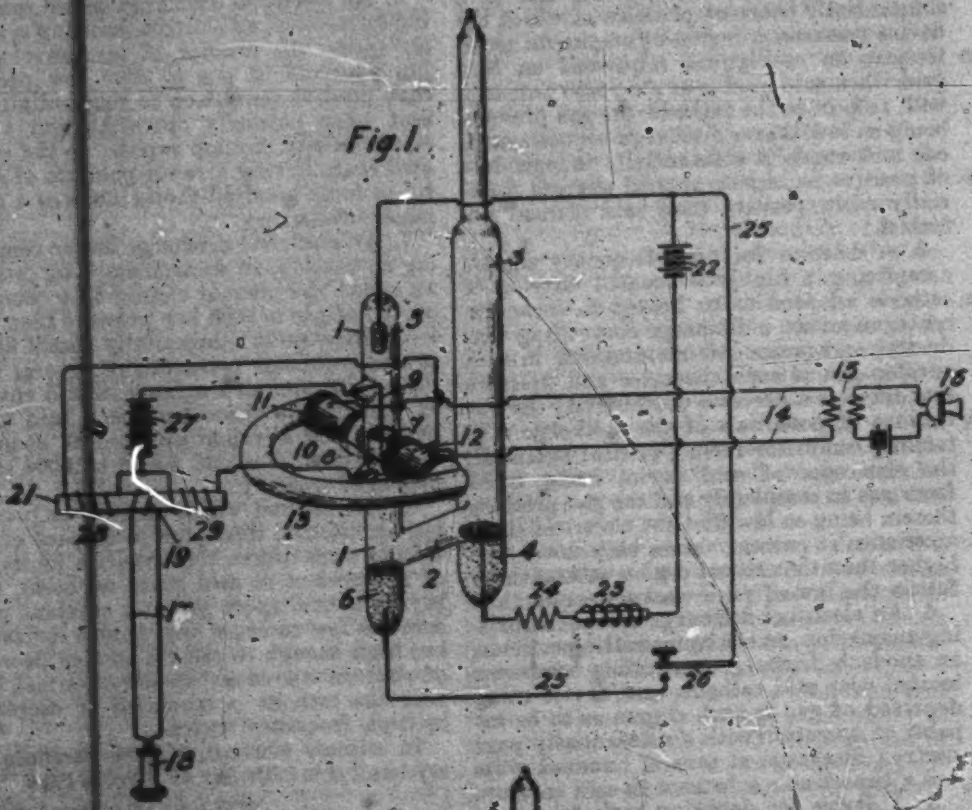
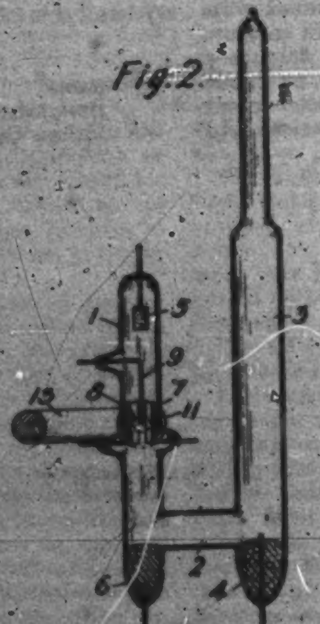

1
5
3
25
22
9
11
7
10
8
12
27
21
28
29
19
13
1
2
6
4
24
23
25
26
14
15
16
17
18

Fig. 2.


3
1
5
9
8
7
11
13
2
6
4

Witnesses:

W. J. Hoffman

Inventor:

Harold DeF. Arnold.

by John G. Roberts

Atty.

UNITED STATES PATENT OFFICE.

HAROLD DE FOREST ARNOLD, OF BELLEVILLE, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, OF NEW YORK, N. Y., A CORPORATION OF ILLINOIS.

METHOD OF REPRODUCING ELECTRICAL VARIATIONS.

1,118,172. Specification of Letters Patent. **Patented Nov. 24, 1914.**

Application filed July 15, 1912. Serial No. 709,644.

To all whom it may concern:

Be it known that I, Harold De Forest Arnold, a citizen of the United States, residing at Belleville, in the county of Essex and State of New Jersey, have invented a certain new and useful Improvement in Methods of Reproducing Electrical Variations, of which the following is a full, clear, concise, and exact description.

This invention relates to the art of reproducing electric variations; its objects are to secure amplified reproduction of variations of current energy, reproduction without distortion, sensitiveness to minute currents, efficiency, reliability, and noiseless operation.

Among other uses the invention is applicable to telephony, for the purpose of obtaining in an outgoing circuit an amplification of voice currents originating in an incoming circuit.

It is also applicable to telegraphy, and signaling systems generally where amplification is desirable in receiving, recording or reproducing impulses of electrical energy.

In carrying out the invention use is made of the principle of deflection by an electromagnet or other suitable means of an ionized stream which may be produced in any of a number of ways. The mercury arc has been found to be a suitable agent for the purpose. The current variations to be reproduced or reinforced may be impressed on the coils of an electromagnet so situated that the variations of magnetism induced therein produce corresponding deflections of the ionized stream. The invention does not depend upon any effect in current flow which such deflection may have on the circuit of the ionized stream but involves a novel method, which will now be explained, of detecting and utilizing the variations produced by the deflecting agent.

The detecting means of this invention involves the use of an auxiliary circuit which is non-arcing in character and independent of the circuit for establishing the ionized stream, except that it traverses a portion of the vapor of the stream. This auxiliary circuit is maintained by means of an auxiliary cathode or pair of such cathodes immersed in the stream and connected to a source of electro-motive force which may be separate and distinct from the source producing the stream itself, the circuit being completed through an anode which may likewise be immersed in the stream. There is thus established in the vicinity of the auxiliary cathode or cathodes an electrical field, which causes in the auxiliary circuit a flow of current the intensity of which is directed dependent upon the distribution of ionization in the auxiliary cathode field.

The invention will be more fully understood by reference to the accompanying drawings wherein—Figure 1 shows a system of circuits and apparatus by which the method hereinafter claimed may be carried out and Fig. 2 shows in elevation and cross section the apparatus of Fig. 1 separated from the circuits.

Referring to the drawings, the means for producing the ionized stream, which in this instance I have shown as a mercury arc apparatus, comprises a main chamber 1, with a horizontal branch 2 and a condensing chamber 3 together with a mercury cathode 4, an anode 5 of carbon or other suitable material, and a starting mercury anode 6. Supported within the main chamber 1 are a pair of auxiliary cathodes 7, 8 which are shown semi-cylindrical in form and slidably separated from each other and from the walls of the chamber. Extending downwardly between the auxiliary cathodes is an auxiliary anode 9. The auxiliary cathodes and the auxiliary anode may be of platinum, or other suitable conducting material. Leading in conductors preferably of platinum wire are provided for the several electrodes of the device.

As the means for deflecting the ionized stream, I have shown an electromagnet 10, the means of support of which is not shown. Such magnet comprises a pair of coils 11, 12, surrounding inwardly extending pole pieces the outer ends of which are joined by a semi-circular yoke 13. The pole pieces present their faces to opposite sides of the main chamber 1 in the region of auxiliary cathodes 7, 8 so that the lines of force between the pole pieces are in a direction transverse to the direction of flow of the ionized stream in the chamber 1 and operate to deflect the stream in the direction of one auxiliary cathode or the other, according to the direction of the current in the magnet coils.

The system shown in Fig. 1 comprises five circuits—(1) an incoming circuit 14 including the coils 11, 12 of the electromagnet 10 and the secondary of an induction coil 15, the primary of which is in (2) a local circuit containing a source of current and a transmitting device such as the telephone transmitter 16; (3) an outgoing circuit 17 including a receiving device such as the telephone receiver 18 and the secondary winding 19 of a transformer 21; (4) an energizing circuit for the mercury arc comprising a battery 22, impedance coil 23 and resistance coil 24, this circuit being connected, one terminal to the anode 5 and the other terminal to the cathode 4, and having a starting branch 25 connected, one terminal to the battery 22 and the other to the starting anode 6 and including a starting key 26; and finally (5) the auxiliary detecting circuit including a battery 27, one terminal of which is connected to the auxiliary anode 9 and the other branching through balanced primary windings 28 and 29 of the transformer 21 to the auxiliary cathodes 7 and 8 respectively.

The impedance coil 23 and resistance coil 24 provide a balance for the mercury arc circuits to maintain a steady flow of current therein which, when once established as by tipping the tube, closing the circuit at the starting key 26 over the path 22, 23, 24, 4, 2, 6, 25, 26, 25, 22 and then releasing the key 26 is maintained automatically over the path 22, 23, 24, 4, [illegible], 1, 5, 22 which includes the ionized arc stream in the main chamber 1. This stream passes by and in contact with the auxiliary cathodes 7 and 8, filling the region between them, and rendering the auxiliary circuit conductive so that current flows from the battery 27 dividing through the primary windings 28 and 29 of the transformer 21 to the auxiliary cathodes 7 and 8, to and through the ionized vapor therebetween and by way of the auxiliary anode 9 back to the battery 27. It is noteworthy of this auxiliary circuit that it is non-arcing in character and that the potential difference existing between the auxiliary electrodes is independent of, and in fact may be very much greater than, that existing between the electrodes of the arc stream. At the same time the current flow in the auxiliary circuit may be very much less than that in the arc circuit. For example, in one particular embodiment of the apparatus the potential difference existing between the auxiliary anode 9 and the auxiliary cathodes 7 and 8 was 1[illegible]0 volts whereas that between the anode 5 and cathode 4 of the arc was 30 volts. The current flow in this instance was .04 ampere in the auxiliary circuit and one ampere in the arc circuit. The primary coils 28, 29 of the transformer 21 are wound differentially in the auxiliary circuit, that is to say, in such a direction with respect to each other that the core thereof under normal conditions of the circuit is not magnetized. The normal current flows equally or approximately so in the two branches, this being due to the symmetrical arrangement of the auxiliary cathodes 7, 8 with respect to the ionized vapor in the space between them. When, however, the electromagnet 10 is energized by current received over the incoming circuit, 14, a magnetic field is produced which deflects the stream toward one electrode or the other. The effect of this is a change in the distribution of ionization in the field or region adjacent the auxiliary cathodes and current will flow with increased strength through one primary winding of the transformer and with decreased strength through the other thereby inducing current in the secondary winding which is transmitted over the outgoing circuit 17 and recorded or made manifest in the receiving instrument 18. In this manner minute variations of current energy such as those transmitted over great distances by a telephone or signaling device and delivered to the instrument by the incoming circuit 14 are reproduced and amplified in the outgoing circuit 17. The extremely small mass of the ionized vapor which is deflected by the electromagnet enables the reproduction of current variations to be accomplished without distortion. By reason of the non-arcing character of the detecting circuit the relaying of current variations is accomplished without disturbing or "noisy" currents in the outgoing circuit, this being of especial importance in telephone transmission systems.

I have illustrated and described two auxiliary cathodes and a branched circuit through balanced primary windings 28 and 29, for the reason that I have found that such arrangement produces the best results. My fundamental invention would, however, be embodied in an arrangement in which only one auxiliary cathode and one primary winding are employed. Also the auxiliary anode 9 may be omitted and the battery 27 may be connected with the anode 5, without departing from the spirit of my invention. Moreover, while I prefer to use two magnet coils 11 and 12, one of them may be omitted, and indeed, the arc stream may be caused to be deflected by electro-static instead of electromagnetic means.

I claim:

1. The method of reproducing electrical variations which consists in establishing an ionized stream, maintaining a circuit including a transverse path within said stream, applying at a point within said path a variable deflecting force to said stream, and producing thereby current variations in the said circuit.

2. The method of reproducing electrical variations which consists in establishing an arc, maintaining an auxiliary non-arcing circuit in a transverse path within said arc, applying at a point within said path a variable deflecting force to said arc, and producing thereby current variations in said auxiliary circuit.

3. The method of reproducing electrical variations which consists in establishing an ionized arc stream, maintaining an auxiliary non-arcing circuit including a transverse path within said stream, applying at a point within said path a variable deflecting force to said stream and producing thereby current variations in the said auxiliary circuit.

4. The method of reproducing electrical variations which consists in establishing an ionized stream, maintaining a balanced non-arcing circuit having two paths through a portion of the ionized vapor of said stream, deflecting said stream to and fro between said paths in accordance with current variations in an incoming circuit and transforming in an outgoing circuit the current variations thereby produced in the balanced circuit.

In witness whereof, I hereunto subscribe my name this 13th day of July A. D., 1912.

HAROLD DE FOREST ARNOLD.

Witnesses:

Murray V. Conaty,
Fred Dethloff.

Copies of this patent may be obtained for five cents each, by addressing the "Commissioner of Patents, Washington, D. C."

DEFENDANT'S EXHIBIT No. 44.

P. C. HEWITT.

VAPOR ELECTRIC APPARATUS.

APPLICATION FILED MAR. 23, 1906.

1,025,464.

Patented May 7, 1912

2 SHEETS—SHEET 1.

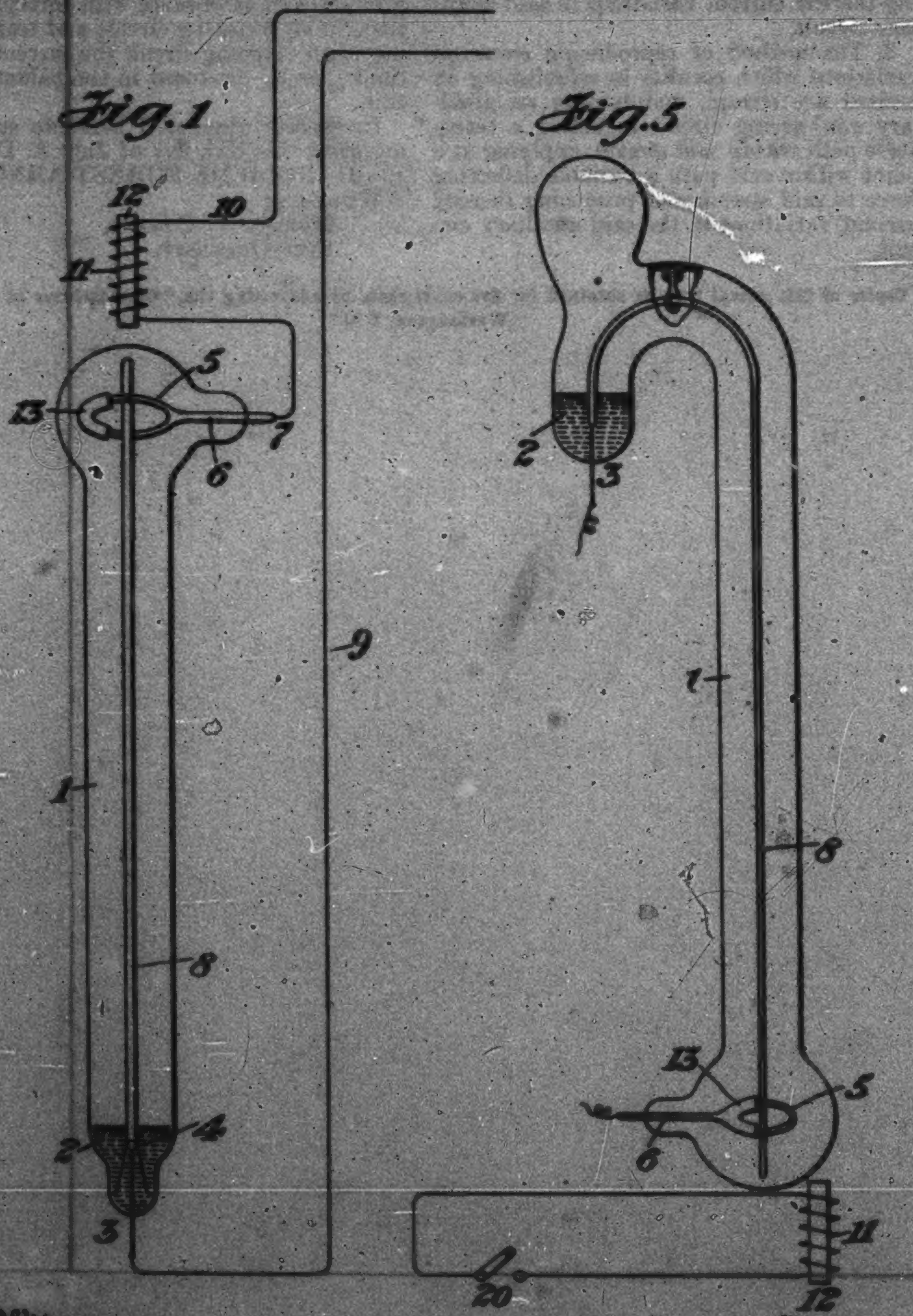


Fig. 1
12
10
11
5
13
7
6
9
1
8
2
4
3
Fig. 5
2
3
7
8
13
5
6
11
20
12

Witnesses:
Chas. J. Blagitt
Thos. H. Brown

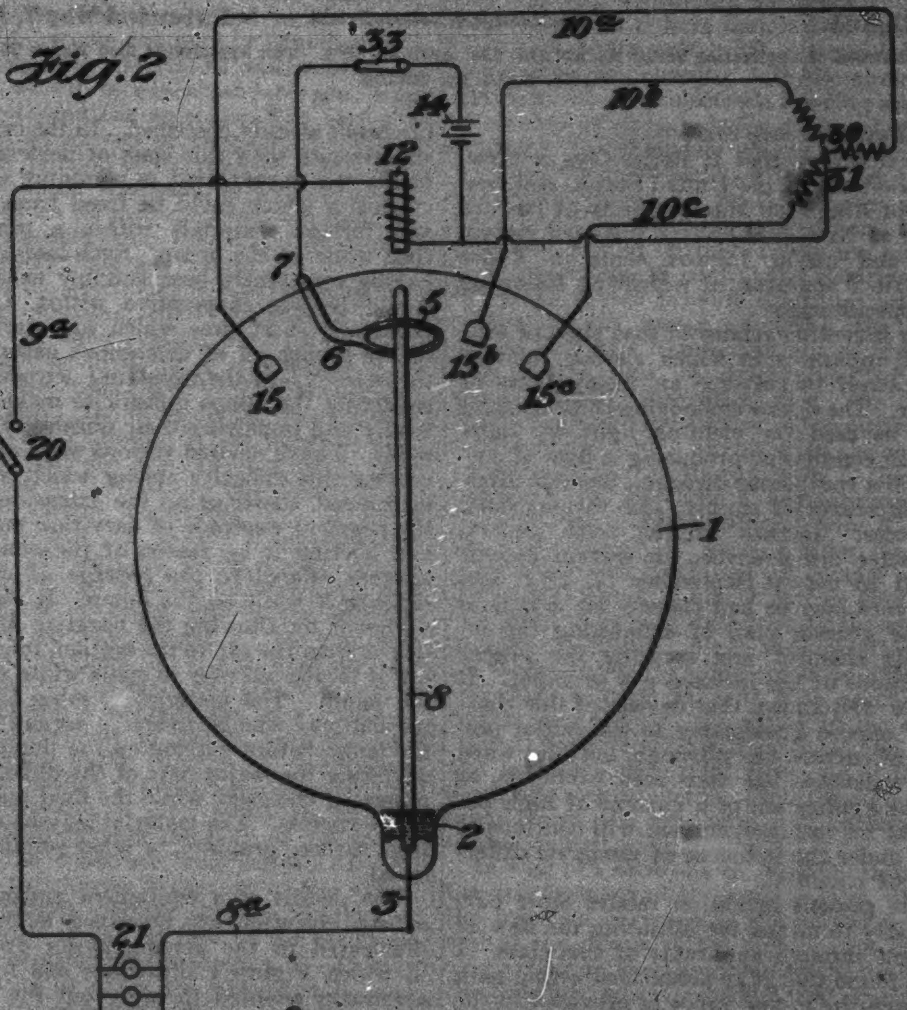
Inventor
Peter Cooper Hewitt
By his Attorney
Charles A. Terry

P. C. HEWITT.
VAPOR ELECTRIC APPARATUS.
APPLICATION FILED MAR. 23, 1903.

1,025,464.

Patented May 7, 1912.
2 SHEETS—SHEET 2.

Fig. 2


10a
33
14
10b
30
31
12
10c
7
5
6
15
15b
15c
9a
20
1
8
2
3
8a
21

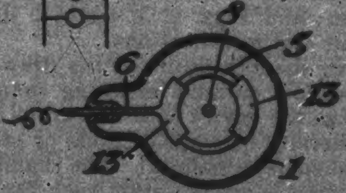


Fig. 3

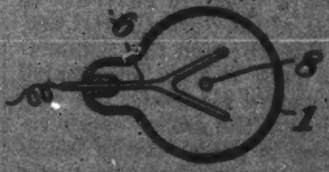


Fig. 4

Witnesses:
Chas. J. Clagett
Thos. H. Brown

Peter Cooper Hewitt Inventor
By his Attorney
Charles A. Terry

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF RINGWOOD MANOR, NEW JERSEY, ASSIGNOR TO COOPER HEWITT ELECTRIC COMPANY, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

VAPOR ELECTRIC APPARATUS.

1,025,464. Specification of Letters Patent. Patented May 7, 1912.

Continuation of application Serial No. 206,179, filed April 21, 1904. This application filed March 23, 1908. Serial No. 422,618.

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and resident of Ringwood Manor, county of Passaic, State of New Jersey, have invented certain new and useful Improvements in Vapor Electric Apparatus, of which the following is a specification.

My invention relates to that class of electrical apparatus in which electric currents are caused to traverse an inclosed gas or vapor. The device embodying these features may be used for yielding light or, under certain conditions, producing a flow of current in a continuous direction from an alternating source of supply, and various other purposes. Devices of the same general character are described in certain patents issued to me on September 17, 1901, and reference may be had thereto for details as to the general plan of exhausting the inclosing chamber and securing the proper conditions of the inclosed gas or vapor. It is now well-known that devices of this character oppose a resistance to the initial passage of current therethrough, but that when this resistance has once been overcome, as by the application of a current of high potential for instance, current will continue to flow under the influence of moderate difference of potential.

The present invention relates more particularly to means for initiating the flow of current through apparatus of this class. I have found that if an actual conducting path through the gas or vapor is provided in the first instance from a negative electrode to a positive electrode of the device, and if current is caused to flow through this conducting path and the path is then interrupted at or near the negative electrode, the current will flow through the gas or vapor between the electrodes in preference to jumping or bridging the comparatively small gap between the separated terminals of the interrupted conducting path. In practice, I have adopted a form of apparatus in which the negative electrode is provided with a conducting prolongation or extension which makes contact either with the other electrode or with an extension therefrom, and I have provided automatic means for the opening of the conducting path thus formed inside the containing vessel, with the result already described. In the original experiments with this class of devices, difficulty was encountered in obtaining a solid conductor which could be freed from gases and foreign materials within a practical time while on the pump. Such lamps after having apparently been suitably exhausted would become inoperative within a comparatively short time which was attributed to the giving off of deleterious gases from the extension of the negative electrode, thus rendering the lamps difficult to make practically and impairing their durability when made. I have devised various ways of overcoming this difficulty among which may be mentioned, constructing the extension from the negative electrode of very thin material and heating it by reason of the ohmic resistance offered to the passage of current through it while on the pump. It was also overcome by allowing the negative flame to lick it from the top to the bottom, thus heating it locally all over in spots while still on the pump. The material forming this extension may also be treated externally from the lamp, before putting on the pump, thus obviating the major part of the difficulty of removing the gases while the final pumping is in progress. The material may be of soft iron, carbon, graphite, or other suitable material.

The details of a convenient embodiment of my invention are described herein and illustrated in the accompanying drawings in which Figure 1 illustrates one form of apparatus adapted to carry out the invention; and Figs. 2, 3, 4 and 5 illustrate details and modifications.

In the first figure of the drawings, 1 represents a suitable inclosing chamber which, when the device is to be used as a lamp, will generally be made of glass or other suitable transparent material. The chamber contains a suitable gas or vapor, such for example, as mercury vapor. In the present instance, I have shown a negative electrode, 2, as consisting of a small quantity of mercury, and have shown this electrode as being connected with an external conductor 9, by a leading-in wire, 3. The latter is flexibly connected with the base of the extension 8, which is surrounded by the mercury and in electrical connection therewith. The rod, 8, which is thus in contact with the mercury extends longitudinally through the container 1, forming, so to speak, a prolongation or extension of the negative electrode. The extension 8 may conveniently consist of a relatively stiff piece of conducting material such, for instance, as iron, carbon, chromium, or other suitable conductor. Should some nonmagnetic material be selected for the extension 8, its remote end may be provided with a magnetizable material to constitute an armature, as will be explained later on. Near its remote end the extension 8 is here surrounded by a loop or ring, 5, constituting the main portion of the positive electrode of the apparatus. The said loop or ring is connected by an extension, 6, with a leading-in wire, 7, constituting the means of connection with the external circuit.

When the apparatus is mounted, say in a vertical position, the extension 8 rests against the inner edge of the ring electrode 5, thereby completing a conducting path through the container 1 by way of the leading-in wire 7, the extension 6, the ring electrode 5, the extension 8, the negative electrode 2, and the leading-in wire 3. The connection of the positive electrode 5 to the external circuit conductor, 10, is made through a coil, 11, having a magnetizable core, 12. To start the device into operation, the circuit 9—10 is closed and current passes through the device by way of the conducting path already described. In this way the electro-magnet 11—12 is vitalized and acts magnetically upon the adjacent end of the extension 8 whereby the said extension will be lifted out of contact with the ring 5. Thereupon the current will pass from the ring through the intervening vapor path to the extension 8, after which the current very quickly chooses the path of gas or vapor in the container, and instead of continuing to traverse a portion of the extension 8, passes directly through the gas or vapor path to the surface of the electrode 2. The position of the magnet 11—12 may be such as to draw the extension 8, over against an insulating block or coating, 13, carried by the ring 5; or it may cause the extension to stand free within the ring and out of contact with any portion thereof.

The extension 6, may terminate in circular form, as shown in cross-section in Fig. 3, or in an electrode of Y-shape, as shown in Fig. 4, or in an electrode having other suitable configuration.

In Fig. 2 I have shown a modification illustrating the invention as applied to a multiphase electric circuit. The source, 30, is here shown as a three-phase generator, which may be either a transformer or any other suitable source of three-phase currents. It is not necessary that the multiphase circuit should be a three-phase circuit, it being readily possible to adapt the invention to circuits carrying any desired number of phases. The neutral point, 31, of the generator is joined by a wire, 9^a, with the leading-in wire 3. The terminals of the generator are connected by wires, 10^a, 10^b, and 10^c, respectively, with positive electrodes 15^a, 15^b, and 15^c, within the container 1. The magnet 11—12 is here included in the conductor 9^a, and a switch, 20, is provided for controlling the circuit. A work circuit is shown at 21. The electrode 5 is ring shaped as before and surrounds the open end of the extension 8. The latter simply rests within the mercury electrode, 2, without being mechanically linked to the leading-in wire. For energizing the magnet 11—12 and initiating the flow of current, I may use a suitable source, 14, of continuous electric currents and I may provide its circuit with a switch, 33, by means of which the said source may be cut into and out of circuit. This circuit may be independent of the work circuit. Assuming that the said switch is closed, the closure of the switch 20 will then complete a circuit from the source 14 through the leading-in wire 7, the extension 6, the electrode 5, the extension 8, the electrode 2, the leading-in wire 3, and the conductor 9^a. This will cause the extension 8 to be lifted out of contact with the ring electrode 5, and it will be held out of contact so long as the circuit to the source 14 remains closed. As to the operation of the device under the influence of multiphase currents, it may be said that successive phases pass through the device to the electrode 2 from the electrodes 15^a, 15^b and 15^c, and inasmuch as current from one of these electrodes begins before that through another ceases, the apparatus will be kept in operative condition.

In Fig. 5, I have shown a modification in the arrangement of the apparatus in which the negative electrode is put at the upper end of the device in the bottom of a bent-over extension and hangs downward through the tube and passing through the ring 5 at the lower end. The magnet 11 may be so placed as to swing the extension into contact with the electrode when it is desired to make contact therewith and it will be released when the circuit of the magnet 11 is broken, or it may be made to operate in the same manner as described with reference to Fig. 1. The magnet 11, in this instance, is shown as being connected in a separate circuit provided with a switch of any suitable character for temporarily closing its connection.

The present application is a continuation of applicant's case Serial Number 204,179, filed April 21st, 1904.

I claim as my invention:—

1. In a system of electrical distribution, the combination with an alternating cur-

rent source, a rectifier therefor comprising a completely exhausted container and electrodes therein including a plurality of anodes and a vaporizable reconstructing cathode and connections between said anodes and terminals of the source and a connection between the cathode and an intermediate point of said source, of a separate direct current source connected between the intermediate point of the alternating source and a separate anode within the container, means for connecting and disconnecting said additional anode to and from said cathode within the container and automatic means responsive to the rectified current from said alternating source for operating said means, together with non-automatic means for controlling the direct current source.

2. In a system of electrical distribution, the combination with an alternating current source, a rectifier therefor comprising a completely exhausted container and electrodes therein, including a plurality of anodes and a vaporizable reconstructing cathode and connections between said anodes and the terminals of the source and a connection between the cathode and an intermediate point of said source, of a separate direct current source connected between the intermediate point of the alternating source and a separate anode within the container, means for connecting and disconnecting said additional anode to and from said cathode within the container, a magnet coil located in the said first named connection to the intermediate point of the alternating source for operating said means, together with non-automatic means for controlling the direct current source.

Signed at New York, in the county of New York, and State of New York, this 19th day of March A. D. 1908.

PETER COOPER HEWITT.

Witnesses:
Wm. H. Capel,
George H. Stockbridge.

DEFENDANT'S EXHIBIT No. 45.

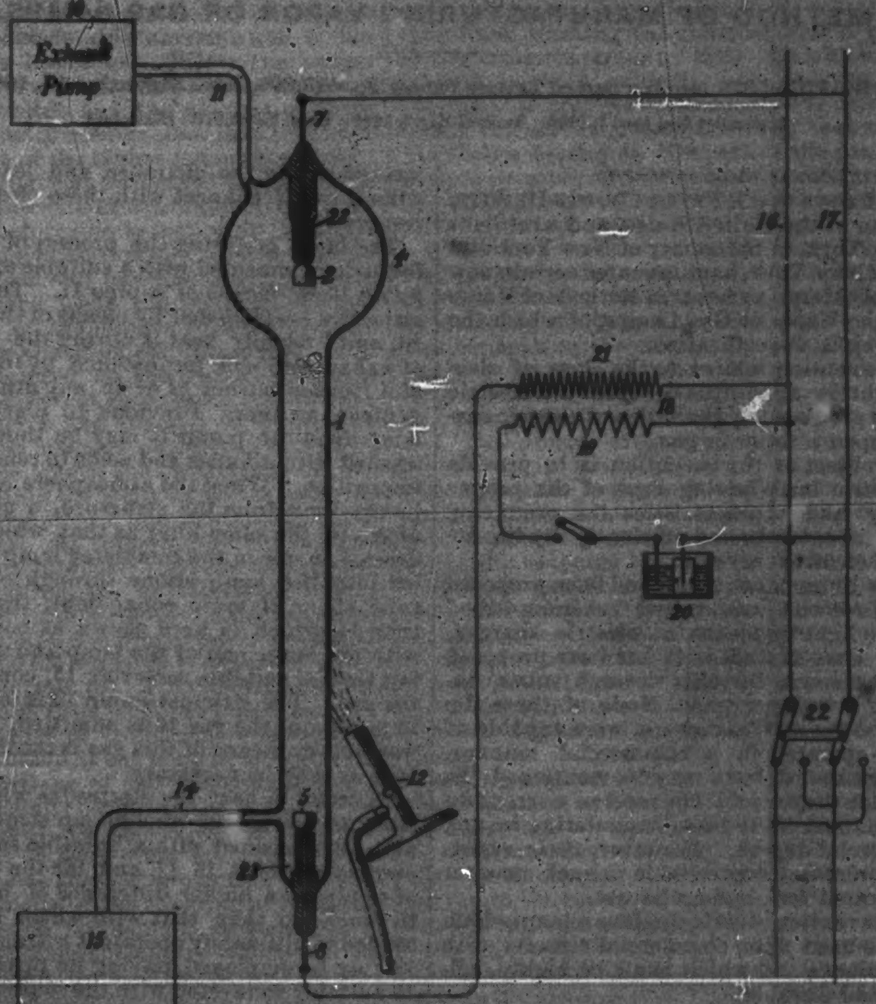
No. 682,690. Patented Sept. 17, 1901.

P. C. HEWITT.

METHOD OF MANUFACTURING VAPOR OR GAS LAMPS.

(Application filed Apr. 5, 1900. Renewed May 8, 1901.)

(No Model.)


10
Exhaust Pump
11
7
22
2
4
1
14
5
23
3
12
15
16
17
21
18
19
20
22

Witnesses

Raphaël Netter

Wm. H. Capel

Inventor

Peter Cooper Hewitt

by Charles A. Terry Atty.

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR TO PETER COOPER HEWITT, TRUSTEE, OF SAME PLACE.

METHOD OF MANUFACTURING VAPOR OR GAS LAMPS.

SPECIFICATION forming part of Letters Patent No. 682,699, dated September 17, 1901.

Application filed April 5, 1900. Renewed May 2, 1901. Serial No. 58,510. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Manufacturing Vapor or Gas Lamps, of which the following is a specification.

My invention relates to the class of electric-lighting apparatus in which an electric light is produced by the action of electric currents upon a vapor or gas.

The object of the invention is to provide an electric lamp having a gas of the proper density and characteristics for producing light conveniently and efficiently by the action of electric currents.

Prior to my invention it had been proposed to produce within a so-called "vacuum-tube" electric light by means of electric charges, and in some instances it has been proposed to pass electric currents through tubes containing a vapor or gas. None of these devices, so far as I am aware, were capable of being operated in a commercial manner. Among other defects may be mentioned the fact that they would not receive current in such manner as to be self-regulating in any commercial degree. Moreover, their resistances were not controllable in such manner as required for commercial use.

My invention aims to produce a lamp which may be used upon commercial circuits with convenience and which shall be highly efficient and durable.

In the manufacture of my lamp it is essential that the containing-chamber shall be freed from deleterious gases and substances and caused when finished to have a suitable quantity of gas or gases at the proper densities. These results I accomplish by manufacturing the lamp in a manner which will be more particularly described in connection with the accompanying drawing, which illustrates diagrammatically the lamp and the circuits and apparatus for manufacturing it.

Referring to the drawing, 1 represents the lamp-chamber, consisting in this instance of a tube which may, if desired, contain a slight enlargement 4 at one end. It is provided with two electrodes 2 and 5, suitably located within the chamber, and leading-in wires 7 and 8 connect with these electrodes, respectively

The lamp is during the process of manufacturing connected with a suitable exhaust-pump 10 by means of a pipe 11. The lamp structure is exhausted by means of the pump 10, and I usually heat it during the process of exhaustion—as, for instance, by the flame of a Bunsen burner 12 or in any other convenient manner. Previous to placing the lamp upon the pump it may be thoroughly washed with alkalies and acids to remove the impurities. When the atmosphere has been pumped out from the structure, a quantity of gas of the same kind as that which it is desired to use in the completed lamp may be let into the lamp either through exhaust-tube 11, or, if more convenient, through a tube 14, which is here shown as connected with the lower end of the lamp and as leading from a suitable reservoir 15, containing the gas. The exhaust-pump 10 is operated to pump out the gas thus admitted, and the washing by means of this gas is continued as long as may be necessary.

In order to heat the electrodes within the lamp as well as the whole lamp structure, it may be connected with a suitable source of electric currents 16 17, and for the purpose of applying a higher difference of potential to the lamp than that with which it is intended to ultimately operate it a transformer 18 may be employed, having its primary coil 19 suitably connected with the source 16 and 17, and, if desired, through an interrupter 20 of any convenient character, while the secondary coil 21 is connected in the circuit leading to the lamp. The higher difference of potential thus impressed upon the terminals of the lamp acts upon the vapor within the lamp, at first causing it to be slightly luminous. By means of a reversing-switch 22 the connections of the circuits may be reversed, so as to render the electrodes 2 and 5 alternately cathodes and anodes. I have found that the cathode will become highly heated by the action of these currents, and thus throw off occluded gases and be subjected to such chemical reactions and changes as might otherwise occur in the lamp after it is completed. By thus treating the lamp the impurities and such materials as would exercise a deleterious effect upon the lamp may be removed. When the lamp has thus been sufficiently treated, an excess of the gas with which it is to be operated is admitted to the chamber or created in it, and while the terminals of the lamp are subjected to the currents of higher electromotive force and also of the electromotive force with which it is designed to be operated, the excess of gas is pumped out until a point is reached where the gas becomes sufficiently conductive to receive considerable currents and to become highly luminous. When the proper conditions are reached, the action of the lamp is very noticeable and the amount of light yielded is vastly greater than that produced by the action of the higher-potential current. In some cases it may be desired to operate the lamp with currents of considerable quantity repeatedly before finally sealing off the lamp. By noting the operation of the lamp and the quantity of current received it may be readily determined when the lamp is charged with a gas of the proper density, and the lamp is then sealed off and completed. The densities required on the part of the gases differ with different gases used, and the electromotive force and quantity of current received by the lamp are dependent in a measure upon the length and cross-section of the gas path within the lamp, as well as upon the kind of gas employed, and also upon the kind of electrodes. By following the instructions herein given, however, the rules for governing each different gas, as well as the dimensions of the lamp structure, may be readily determined, and the proper point of time at which to seal off the lamp is indicated in the manner referred to. I have obtained excellent results from such gases as nitrogen.

The tendency of the electric current during the operation of the lamp is to pass to the farthest portions of the electrodes, and I therefore usually construct the lamps so that the portions of the electrodes 2 and 5 which are nearest to each other are the only exposed portions thereof, protecting the more remote portions by the covering of insulated material—such, for instance, as sleeves 23, of porcelain or other substance—which will not be acted upon by electric current, fitting tightly over the leading-in wires. The shapes of the electrodes may be variously modified. I have found, for instance, that a somewhat conical face serves well for the anode and a concave face for the cathode; but these shapes may be variously modified. The electrodes are made of suitable material—such, for instance, as iron, platinum, &c.

It will of course be understood that instead of admitting an excess of gas and then withdrawing it for the purpose of producing the required density a higher degree of exhaustion may be obtained and then the gas admitted gradually until the proper condition is reached.

In certain other applications filed by me April 5, 1900, Serial Nos. 11,605, 11,606, and 11,607, I have described a lamp of the general character of that described and claimed herein and its method of operation and process of manufacture.

The invention claimed is—

1. The hereinbefore-described process of manufacturing lamps having a gas path, which consists in heating the containing-chamber, exhausting the gaseous contents therefrom, washing the chamber with a gas of the same character as that with which it is to be provided, subjecting the interior of the chamber and the electrodes to the action of electric currents, creating within the chamber such a density as will permit the gas to receive currents of considerable quantity under the influence of moderate electromotive force, and then sealing off the lamp.

2. In the process of manufacturing lamps having gas or vapor serving as a path for the current between the electrodes, the method of cleansing the lamp which consists in electrically heating the electrodes and washing the lamp by a gas or vapor of the same character as that which is to constitute the gas or vapor path when the lamp is complete.

3. The process of producing within a gas electric lamp the required density of gas which consists in first thoroughly cleansing the lamp from deleterious materials and then providing within the lamp an excess of the gas, gradually reducing the density of the same, and applying an electromotive force of moderate potential and superposing alternating or intermittent currents of higher potential to the terminals of the lamp until such a density is attained that currents having the lower potential will traverse the lamp, and thereafter sealing off the inclosing chamber of the lamp.

4. The method of producing within a gas electric lamp the density of the gas required for operating the lamp under the influence of moderate electromotive force, which consists in thoroughly cleansing the lamp, applying to the terminals of the lamp an electromotive force of higher voltage than that with which the lamp is intended to operate and applying a difference of potential approximately the same as that with which the lamp is designed to operate, gradually changing the density of the gas within the containing-chamber until currents traverse the lamp under the influence of the lower electromotive force, substantially as described.

Signed at New York, in the county of New York and State of New York, this 27th day of March, A. D. 1900.

PETER COOPER HEWITT.

Witnesses:
WM. H. CAPEL,
CHARLES B. HILL.

DEFENDANT'S EXHIBIT No. 46.

No. 682,692. Patented Sept. 17, 1901.

P. C. HEWITT.

METHOD OF MANUFACTURING ELECTRIC LAMPS.

(Application filed Apr. 5, 1900.)

(No Model.)

Fig. 1.

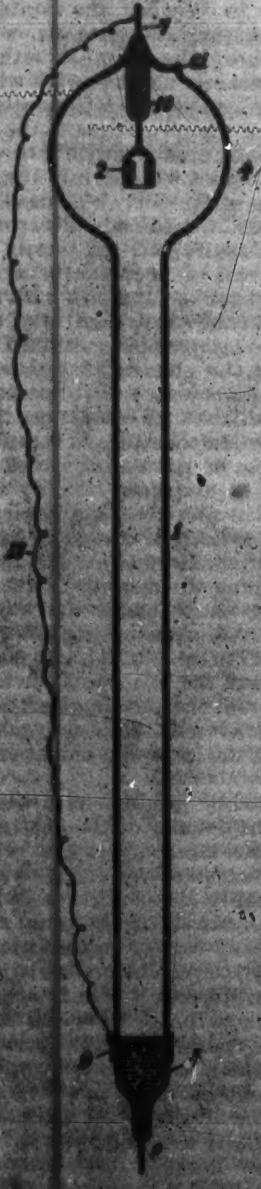
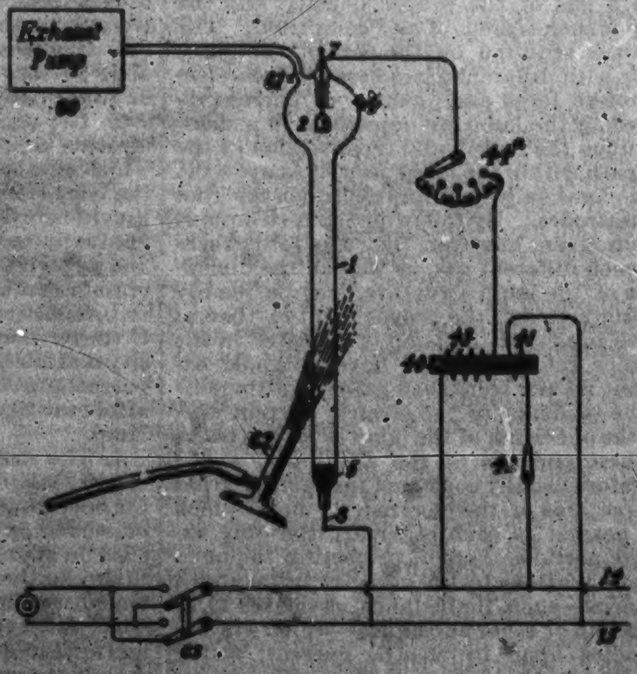


Fig. 2


Exhaust Pump
7
2
1
6
5
12
13

Witnesses:
Raphael Netter

Peter Cooper Hewitt Inventor

by Charles A. Terry Atty

UNITED STATES PATENT OFFICE.

PETER COOPER HEWITT, OF NEW YORK, N. Y., ASSIGNOR TO PETER COOPER HEWITT, TRUSTEE, OF SAME PLACE.

METHOD OF MANUFACTURING ELECTRIC LAMPS.

SPECIFICATION forming part of Letters Patent No. 682,692, dated September 17, 1901.

Application filed April 5, 1900. Serial No. 11,807. (No model.)

To all whom it may concern:

Be it known that I, PETER COOPER HEWITT, a citizen of the United States, and a resident of New York, in the county of New York and State of New York, have invented certain new and useful Improvements in Methods of Manufacturing Electric Lamps, of which the following is a specification.

My invention relates to methods of manufacturing a novel class of electric-lighting apparatus.

The general purpose of the invention is to produce an electric-lighting device capable of converting electric energy into light through the agency of vapors or gases as efficiently as possible and with simple and durable apparatus.

In the ordinary conversion of electric energy into light a large amount of the energy is wasted in heat, and while the development of heat is usually, if not always, attendant upon the development of commercial light, yet from theoretical considerations it may be assumed that the efficiency of a light-producing device, other things being equal, would be increased in approximate proportion as the development of heat is suppressed.

My invention aims to produce a device capable of yielding light by the conversion of electrical energy, with the coincident production of as moderate amount of heat as practicable. Gases or vapors produce this property in a greater degree than matter in any other state, and therefore they offer a field of operation in which the highest efficiencies can be obtained if proper means are devised for rendering the gases or vapors light-emitting under the influence of electricity.

It has been proposed to obtain light by the passage of alternating or intermitted electric currents of very high frequency through a more or less rarefied gas contained within hermetically-closed tubes, such gas being so acted upon by the currents as to become luminous. This class of apparatus, commonly known as "Geissler-tubes," has been found for various causes to have no commercial utility as a means of illumination. It has also been proposed in some instances to pass electric currents through two electrodes consisting of bodies of mercury contained in hermetically-closed tubes and to obtain light from the electric arc between the two mercury electrodes; but prior to my invention no such devices, so far as I am aware, have been produced which are suitable for commercial use. They have usually been started by bringing the two bodies of mercury constituting the electrodes into actual contact with each other and then separating them, the electric current then being caused to arc across from one electrode to the other. Such method of starting has been found impracticable for any extended use and requires the presence of a considerable outside resistance to prevent an excessive current-flow when the bodies of mercury are in contact, and even when started they have been incapable of commercial operation with efficiency or for any considerable period of time. These and other difficulties have rendered such devices impracticable for use upon circuits in which the electromotive force is liable to vary, as in the ordinary commercial systems of electric lighting or even in connection with other circuits, such as those supplied by storage batteries, and they have little or no value, except, perhaps, for special scientific or laboratory experiments. These devices, so far as I am aware, have not been capable of operation for any considerable period, if at all, by the conduction of current from one electrode to the other, but have been essentially arc-lamps.

The exact distinctions between an arc and conduction not involving an arc are somewhat difficult to define, although not difficult to detect in practical operation. It is noticeable, however, that in the case of an arc there is intense heating of both the positive and negative electrodes, but particularly of the positive electrode, and the current passes from the electrodes into the conducting-vapor at definite points or positions, whereas in the other form of conduction the effect is to produce a halo around the electrode, except that a dark space appears at or around the electrode. This space and its appearance seem to differ with different vapors used; but there is always a marked and well-defined difference between it and an arc, and when in the process of manufacture the last trace of arc disappears it is plainly noticeable. In the other form of conduction little or no heat is developed at the points where the current passes from the electrode into the vapor. Moreover, in the case of the arc there appears to be a narrowing at or near an electrode, whereas in the other form of conduction the body of light is of practically the same dimensions throughout the space between the electrodes or between points in close proximity to the electrodes. An arc, moreover, is striated, a condition which does not appear to be present in the other form of conduction. Again, the temperature established by the arc in any one place with a given flow of electric energy appears to be far in excess of that produced by a flow of the same amount of energy in the other form of conduction.

The lamps which I have produced do not operate upon the arc principle, but possess the characteristics of this special form of conduction. It is, moreover, essential that the proper adjustment of the resistance of the vapor path should be obtained, and I have found that this result can be secured in the case of vapors conducting in this manner, so that the electromotive force with which the lamp is adapted to be operated can be predetermined with as great a degree of accuracy as is usual in the manufacture of the ordinary incandescent lamps having carbon filaments, and the manner in which the resistance shall vary can be controlled in vapor-lamps with a much wider range of controllable resistance than is the case with a carbon filament, as the resistance of the carbon is a fixed factor, while the vapor resistance may be selected to vary at will within wide limits.

It does not appear to have been appreciated prior to my invention that such a control of resistance on the part of a vapor was possible or practicable, and, as a matter of fact, in the forms of lamp hereinbefore referred to, where an arc is established between bodies of mercury, such control has not been obtained.

Under proper conditions certain vapors and also certain materials which normally exist in the form of gases may be caused to remain in such condition as to convey electric currents under the influence of moderate electromotive forces after a current-flow has once been established. By properly correlating the resistances between the respective electrodes and the vapor or gas and the resistance of the vapor or gas path itself and providing a proper heat-radiating capacity a lamp may be produced which will take considerable currents at moderate electromotive forces and be self-regulating to such a degree as to permit of its use upon commercial circuits even though their electromotive forces may fluctuate through wide limits.

To render the lamp as stable and self-regulating as possible upon the circuit, it should have the resistance between the respective electrodes and the gas or vapor path reduced as much as possible, so that these resistances relative to the resistance of the gas column shall be small. The gas or vapor path then constitutes the principal portion of the resistance of the lamp, and as the electromotive force at its terminals increases the total opposition to the passage of current may be made to increase also. This may be due in a measure at least to the fact that the greater amount of current flowing under the increasing pressure tends to develop a higher current, which in turn tends to increase the resistance of the lamp, so that a balance can be effected, rendering the lamp self-regulating. I do not, however, desire to be understood as advancing this theory of its regulation as the only one or as being necessary, but merely one which may be advanced from the results obtained.

Some materials when in a gaseous or vaporized state possess the capacity of emitting light under the influence of electric currents in a much higher degree than others. The vapor of mercury is efficient as a light-yielding material, and owing to its molecular weight and its low boiling or vaporizing point it is well suited to the purposes of my invention. Moreover, it readily serves under the influence of the current to transfer the heat generated in the lamp to convenient points for radiation. Some of the materials normally existing in the form of gases may, however, be used—such, for instance, as nitrogen. The amount of light, however, which may be obtained from nitrogen per unit of length appears to be less than that which can be obtained from mercury vapors, other things being equal. The spectrum is also a matter to be considered in determining the material to be used. Mercury gives a light which is clear and white, but wanting in red rays, so that while useful for many purposes it may be undesirable for others. Lithium and similar materials yield spectra with red and other colors. Nitrogen and other gases develop red rays in abundance, and when combined with the mercury rays a beautiful result is obtained. The selection of the material for the vapor or gas must be determined by the conditions and requirements. The invention will be more particularly described with reference to mercury vapor as a matter of convenience and clearness, being among the most convenient to practice the art.

The lamp should be constructed to utilize as far as possible all the resistance of the lamp in the conversion of the electrical energy into light; but as there may be more or less heat developed the structure should be such as will radiate the heat at a suitable rate. Usually it is advantageous to employ a cooling-chamber at some portion of the device outside the path of the current. In the case of mercury, for instance, an enlargement of the tube may project a distance beyond one of the electrodes, so that the excess of heat will be radiated. In some instances it is practicable to cause the radiation to take place through the walls of the tube surrounding the gas column at a sufficient rate to meet the requirements. If the temperature of the lamp is allowed to become too high, the lamp is liable to extinguish itself. When a fixed gas is used or vapors under such conditions that their densities cannot be unduly increased by heat in the tube, then the cooling-chamber may be dispensed with. The lamp may be made of such a size as to render a special cooling-chamber unnecessary.

The ability to start the lamp readily is of the utmost importance, gases appearing to present a greater resistance to the passage of the current before the current is passing than after, and I have found that certain materials added to the lamp before or while in the process of manufacture produce a condition which makes it possible to start a current under a moderate increase of electric pressure, and thereupon the continuous or an alternating current of low pressure readily traverses the lamp, producing an intense enduring light. I have obtained excellent results by the use of an independent substance for effecting the starting of the lamp which produces a preliminary condition favoring the passage of current. One of the substances which I have used is sulfur or its compounds—for example, a small quantity of the sulfid of mercury introduced at the same time as the mercury when mercury is employed for forming the vapor. The tube containing these materials is then heated by any suitable means, the air, moisture, and foreign gases being pumped out by a suitable air-pump. I have found it advantageous during the process of exhaustion to heat the tube by convenient means until a vacuum is formed and to then subject the contents of the tube to the action of an electric current of high voltage. I am able to thus produce more or less heat throughout the length of the tube and produce such chemical reactions as may occur under the influence of the current and drive out foreign or deleterious gases and substances, leaving fairly pure mercury and a resultant sulfur compound, the exact nature of which I am not prepared to state with definiteness, although from such tests as I have been able to apply it would seem probable that it is a compound of mercury and sulfur containing a less proportion of sulfur than exists in the form of sulfid of mercury. Its effects seem quite different from that produced by pure red or black sulfids of mercury such as I have been able to make or procure in the markets. With this material present in the tube it is possible at starting cool to transmit an alternating or intermittent current from one end of the tube to the other with a much lower electromotive force than is required if the sulfur compound or its equivalent were not present. It seems also desirable to free the tube as far as possible from certain foreign substances, and particularly from oxygen, and I sometimes treat the tube with a bath of heated hydrogen before placing on the pump and also when the lamp is being exhausted. I have found it sometimes advantageous to use interrupted currents of high voltage flowing in a given direction and to first constitute one of the electrodes the anode and the other the cathode and then to reverse the direction of the currents. I usually employ solid materials—such, for instance, as pure iron or other suitable substance—for one or both of the electrodes, and by thus constituting the respective electrodes alternately anodes and cathodes during the process of exhaustion I am enabled to heat each of them to a very high temperature, and thus drive out any occluded gases and foreign materials and produce any chemical reactions in them that might otherwise occur later on and ruin the efficiency of the tube. While the lamp is thus being treated and exhausted, I connect the electrodes through a variable resistance with a suitable source of current of moderate electromotive force—such, for instance, as one hundred and ten or two hundred and twenty volts—the application of the high potential being also continued. In practice I find that the lamp should be run on the pump with a current at least equal to or, better, in excess of the current it is intended to afterward operate with. As the lamp approaches completion it suddenly becomes intensely luminous by reason of the passage of a considerable current of moderate potential from this source. The high-voltage current may then be temporarily withdrawn and the lamp further treated by current of low potential. Usually, however, it is desirable to use the currents of interrupted high potential at intervals, as they are useful for heating the electrodes and effecting the chemical changes, as above referred to. When the lamp ceases to give off further foreign gases, it may be sealed off, and it is then in condition for operation.

When no starting material is present in the lamp, it is possible to start by heating it by any convenient means—such, for instance, as a Bunsen burner or an electric heating-coil of any convenient construction—and simultaneously applying to the terminals a difference of potential substantially equivalent to that upon which the lamp is designed to operate and at the same time a boosted electromotive force to enable the regular current to pass; but in the case of fixed gases, owing to the electric phenomena the exact nature of which I am not as yet able to state, the lamp lights up and when once lighted will continue in operation as long as required. When, however, the starting material is used, the lamp may be started without preliminary heating by means of electric currents of the proper electromotive force, usually higher than that upon which the lamp is normally intended to run. This may be conveniently done by placing in the circuit leading to the lamp the secondary coil of a transformer the primary of which is connected with the supply-circuit through a suitable circuit-interrupter, or an alternating current from a suitable transformer may be used, the purpose being to first cause a current to pass through the space between the electrodes, which then appears to afford a path for the operating-currents of moderate potential. The readiness with which currents of lower electromotive force are caused to flow when a lamp provided with the starting material has been subjected for an extremely short period to a higher electromotive force would indicate that the starting is not in this case due to the heat development of the current, but to some other electrolytic or electrochemical action, the exact nature of which it is difficult to determine. For the purpose of constructing the lamp it is not essential that the theory of the action should be determined.

I have found that other materials than sulfur and mercury may be used to produce the starting material in the lamp. For instance, I have employed selenium and mercury with good results, and also phosphorus and mercury and other materials. After the lamp is started it is probable that the starting material does not continue to act as a current-carrier, but that it is forced out of the path of the current or undergoes a change, but when the lamp is again cooled it resumes the proper relation and condition to be availed of for again starting. I have found it advantageous when the lamp is to be started without heating and by means of moderately high voltage currents to surround the glass or wall in the neighborhood of one of the electrodes, or in the case of an alternating-current lamp each of the electrodes by a band of conducting or semiconducting material—such, for instance, as foil—which in turn is placed in electrical connection with the other electrode or grounded by means of a small conductor. This device appears to lessen or neutralize, to a certain extent at least, the surface tension or static charge which gathers about the electrode during the application of the starting-current, and it reduces the effective starting resistance of the lamp. A lamp which could be started only by extremely high potential currents, if at all, without this band, may be started without difficulty when it is present. When the lamp is once in operation under the influence of alternating or continuous currents of low pressures, the presence of the conducting-band seems to no longer exercise its function to the same degree, although it may remain without interfering with the operation of the lamp, as it is insulated from the neighboring terminal of the lamp.

In the accompanying drawings, illustrating my invention, Figure 1 represents one form of a complete lamp. Fig. 2 illustrates, partly in diagram, an organization of apparatus for exhausting and treating the lamp during exhaustion.

Referring to the figures, 1 represents a glass tube of such dimensions as may be required—say, for example, a tube of three-quarters of an inch in diameter and two or three feet in length and having a wall of such thickness as not to be fragile. The particular dimensions of the tube to be chosen are determined by the electromotive force and the current with which it is to be operated and other considerations which will be hereinafter pointed out. This tube is provided with two electrodes, (indicated at 2 and 5, respectively.) If the lamp is to be run by continuous current, the electrode 2 is usually the anode and the electrode 5 the cathode. In the drawings I have shown the electrode 2 as being of an inverted-cup shape; but other forms may be employed—such, for instance, as a closed spherical, oval, cylindrical, and other shapes. I have obtained excellent results by using a pure iron for this electrode; but other metals may be substituted. It is suspended within or near the neck of an enlargement or chamber 4, which I usually employ, this chamber serving to increase the heat-radiating capacity of the lamp and to retain impurities. The electrode 2 is suspended by leading-in conductor 7, of platinum or other suitable material, extending through the glass wall, and I usually provide a long seal 10 for protecting more or less of the leading-in conductor within the lamp. The electrode 5 is shown in this instance as being a small quantity of mercury. A leading-in conductor 8 connects with this electrode. Surrounding the lower end of the tube adjacent to and usually projecting a slight distance—say one-eighth of an inch—above the level of the lower electrode there is placed a thin band 9 of conducting material—such, for instance, as foil—and this is electrically connected by a conductor 13 with the leading-in wire 7. When the lamp is to be operated by alternating electric currents, it may be useful to place a conducting-band in similar relation to the other electrode and connect it with the leading-in conductor 8.

As already stated, the condensing and impurity-containing chamber 4 or its equivalent performs an important function in the operation of the lamp. As the lamp commences to operate heat accumulates and the increasing temperature appears to soon result in increased resistance on the part of the vapor-path. If the heat is not conducted away after the lamp has reached its proper working condition with the same rapidity that it is generated, the lamp may extinguish itself. The chamber 4 is therefore constructed with sufficient radiating-surface to get rid of the excess heat and keep the lamp in the proper condition. The chamber 4 need not, however, necessarily surround the electrode 2; but it may be located elsewhere and be of other form, provided it is out of the vapor path. The tube, properly shaped and prepared, is first thoroughly cleansed with acids, alkalies, and water. I have found it convenient to first dilute the tube with hydrofluoric acid and then wash with distilled water, and thereafter, if desired, it may be further washed by a bath of hot hydrogen. In case mercury is to be used for providing the conducting-vapor a small quantity of it is placed within the tube, and if the sulfid of mercury is to be used for forming the starting material a small quantity of that substance is added. Pure sulfur may be introduced instead of sulfid of mercury; but I have found that it is usually more difficult to secure the desired results with it than with the sulfid of mercury. The lamp is then sealed onto a suitable exhaust-pump 60, of any suitable character, through an exhausting-tube 61, and the process of exhaustion is commenced. Meanwhile artificial heat is applied to the tube—as, for instance, by a Bunsen burner 62, or an electric heater, or in some other convenient manner. After the free gases and air have been exhausted an electric current of higher potential is applied to the terminals of the lamp—as, for instance, by a system of circuits and apparatus—as shown diagrammatically in Fig. 2 and consisting of a transformer 40, the primary coil 41 of which is connected between the main conductors 14 and 15 and through any suitable form of circuit-interrupter 42. The secondary coil 43 has one terminal connected with the main conductor 14 and the other terminal through a suitable adjustable resistance 44ᵃ with the leading-in wire 7. In this manner induced high-potential currents may be applied to the terminals of the lamp, and the passage of this current through the lamp produces an effect somewhat similar to that noticeable in Geissler tubes. The operation of the exhaust-pump is continued, and a difference of potential approximately equal to that under which the lamp is intended to be operated is applied to the terminals of the lamp. As the lamp approaches completion it suddenly becomes intensely luminous by reason of the passage of a current of considerable quantity. If the higher-potential current employed is an interrupted current, it is desirable to reverse the terminals of the lamp with reference to that current one or more times, for the cathode is thereby readily heated to a very high temperature, which aids in driving off any occluded gases and impurities. A circuit-reverser 63 may be employed for that purpose.

The process of exhausting the lamp does not appear to remove the starting material, although apparently a different chemical compound is formed, and it is possible that some of the sulfur is thrown off or formed into some other combination and withdrawn from the tube. In any event sufficient of the starting material remains in the tube to permit the ready starting of the lamp when it is completed. The amount of sulfid of mercury to be introduced may be varied within wide limits. I have used in a lamp of approximately the dimensions hereinbefore referred to a quantity as small as may be taken upon the point of a pocket-knife and be plainly visible. Too much does not seem to exercise any very bad effect except retarding the process of exhaustion and possibly to blacken or coat the glass somewhat. In practice I usually find that after a time, notwithstanding the successive applications of high-potential currents and the running of the lamp with the low or moderate potential currents, little or no vapor is withdrawn from the lamp. The lamp may be continued on the pump for a greater or less time after this; but usually when the gases or vapors other than those employed in the operation of the lamp have been withdrawn therefrom the lamp is in condition to be sealed off.

While I have described the lamp more particularly with reference to mercury vapors, I desire it to be distinctly understood that I do not limit myself to those vapors nor to materials which at ordinary temperatures exist in the forms of solids or liquids, for permanent gases may be employed—such, for instance, as nitrogen. A convenient method to employ when gases are used is to first treat the lamp in the manner described with mercury vapors or any convenient vapor and then exhaust the mercury, and afterward introduce the gas or gases in the required amounts.

In certain other applications filed by me—for instance, Serial Nos. 11,605 and 11,606, filed April 5, 1900, and Serial Nos. 44,647, 44,648, and 44,649, filed January 25, 1901—claims are made upon certain of the subject-matters disclosed herein.

The invention claimed is—

1. The hereinbefore-described method of manufacturing electric lamps in which light is produced by the action of electric currents upon a vapor or gas which consists in heating the containing-chamber of the lamp by applied heat, exhausting the air and deleterious gases therefrom, heating the electrodes within the lamps by electric currents, introducing or forming the vapor or gas designed to constitute the light-emitting body and causing electric currents to traverse it and then closing the chamber substantially as described.

2. The method of manufacturing electric lamps in which light is produced by the action of electric currents upon a vapor or gas, which consists in introducing or forming into a containing-chamber the desired conducting vapor or gas and an additional substance yielding a starting material, heating the tube and exhausting air and vapor therefrom, causing a relatively high potential electric current to traverse the tube during a portion of the process of exhausting and then causing a current of considerable quantity and moderate electromotive force to traverse the

tube while continuing the process of exhaustion and thereafter sealing off the tube.

3. The process of manufacturing lamps adapted to produce light by the action of electric currents which consists in placing within an inclosing chamber a quantity of material adapted to afford a vapor which becomes light-emitting under the influence of electric currents of moderate potential and considerable quantity, adding thereto a quantity of material capable of imparting to the device the capacity of being traversed by electric currents, exhausting the atmosphere and impurities from the lamp and simultaneously heating the lamp by external heat and thereafter by the passage of electric currents.

4. The method of manufacturing lamps in which light is produced by electric energy acting upon a vapor or gas path, which consists in heating the elements of the lamp, exhausting the foreign substances therefrom, applying a sufficient difference of potential to the electrodes of the lamp during the process of exhaustion to cause the open space between the electrodes to be traversed by currents, varying the resistance of the lamp until currents of considerable quantity traverse the lamp at a moderate electromotive force, and thereafter sealing off the lamp.

5. In the process of manufacturing lamps having a vapor or gas path, the method of treating the electrodes during the process of exhaustion which consists in heating the electrodes by electric arcs formed at the junction of the gas or vapor with the electrodes.

6. The method of driving off occluded gases and foreign substances and producing chemical reactions within a lamp having a vapor or gas path, during the process of manufacturing the same, which consists in heating the electrodes within the lamp during the process of exhaustion by means of electric currents so applied as to render the electrode to be heated for the time being a cathode.

7. The method of manufacturing lamps, which consists in varying the density of the gas or vapor in the lamp while it is subject to the action of an electromotive force substantially the same as that with which the lamp is intended to operate, and also temporarily to a higher electromotive force, continuing such operation until the gas or vapor attains a standard luminosity and thereafter sealing off the lamp.

8. The method of manufacturing lamps having a vapor or gas path, which consists in applying a high alternating or interrupted difference of potential to its electrodes and gradually varying the resistance of the lamp by varying the density of pressure of the gas-path until a current of desired quantity traverses the lamp under the influence of the lower electromotive force with which the lamp is designed to operate.

Signed at New York, in the county of New York and State of New York, this 21st day of March, A. D. 1900.

PETER COOPER HEWITT.

Witnesses:
HENRY NOEL POTTER,
WM. H. CAPEL.

DEFENDANT'S EXHIBIT No. 47.

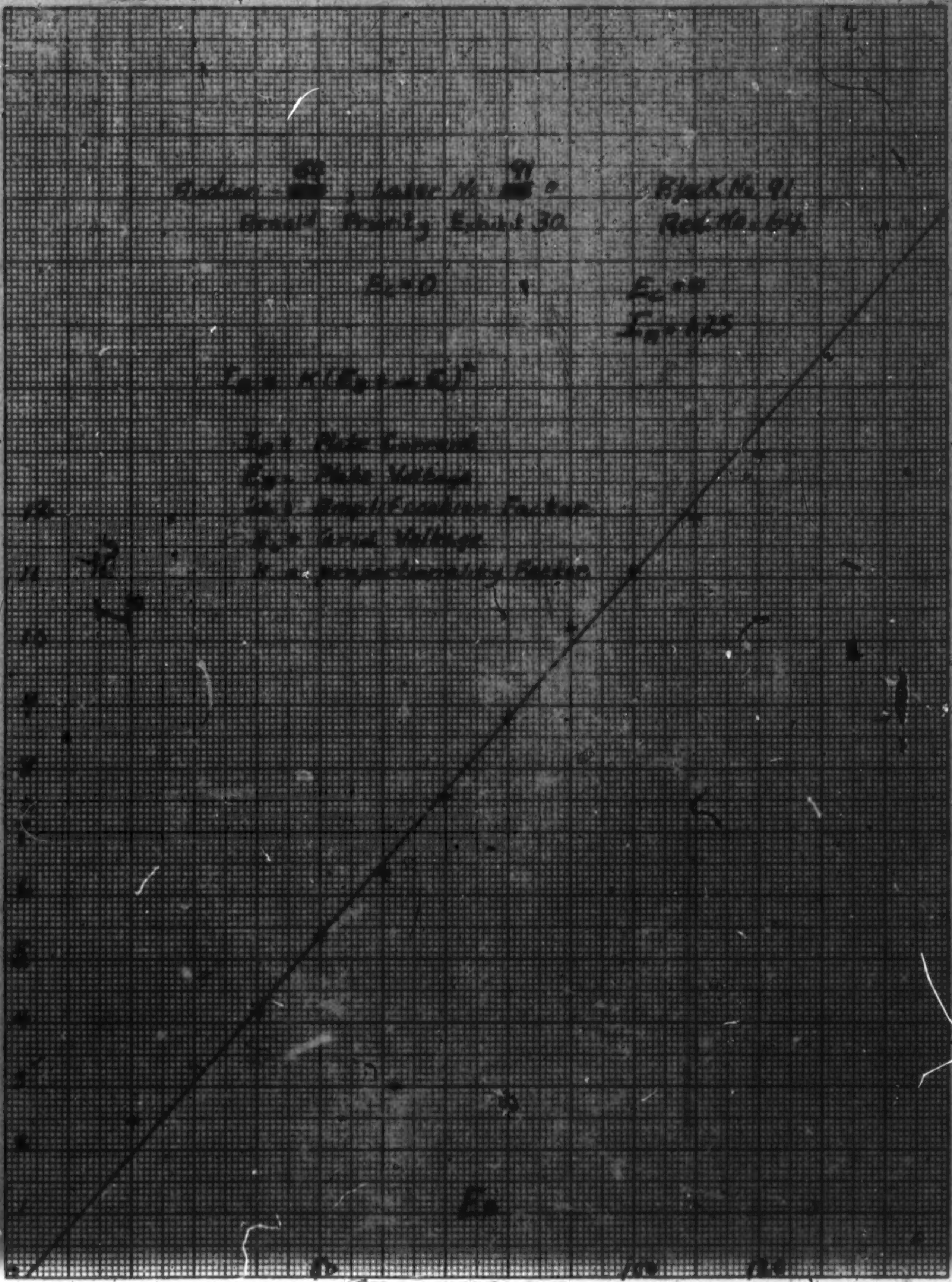
Kelly's Approximate Duplicate Tube of Arnold Priority Record Exhibit No. 30.

DEFENDANT'S EXHIBIT No. 48.

Blueprint Kelly Diagram for Arnold Priority Exhibit No. 30.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES


Station - 62, Tube No. 91 Block No. 91
Arnold Priority Exhibit 30. Rack No. 64

$E_c = 0$. $E_c = 0$

$I_p = 1.25$

$I_p = K(E_p + \mu E_c)^n$

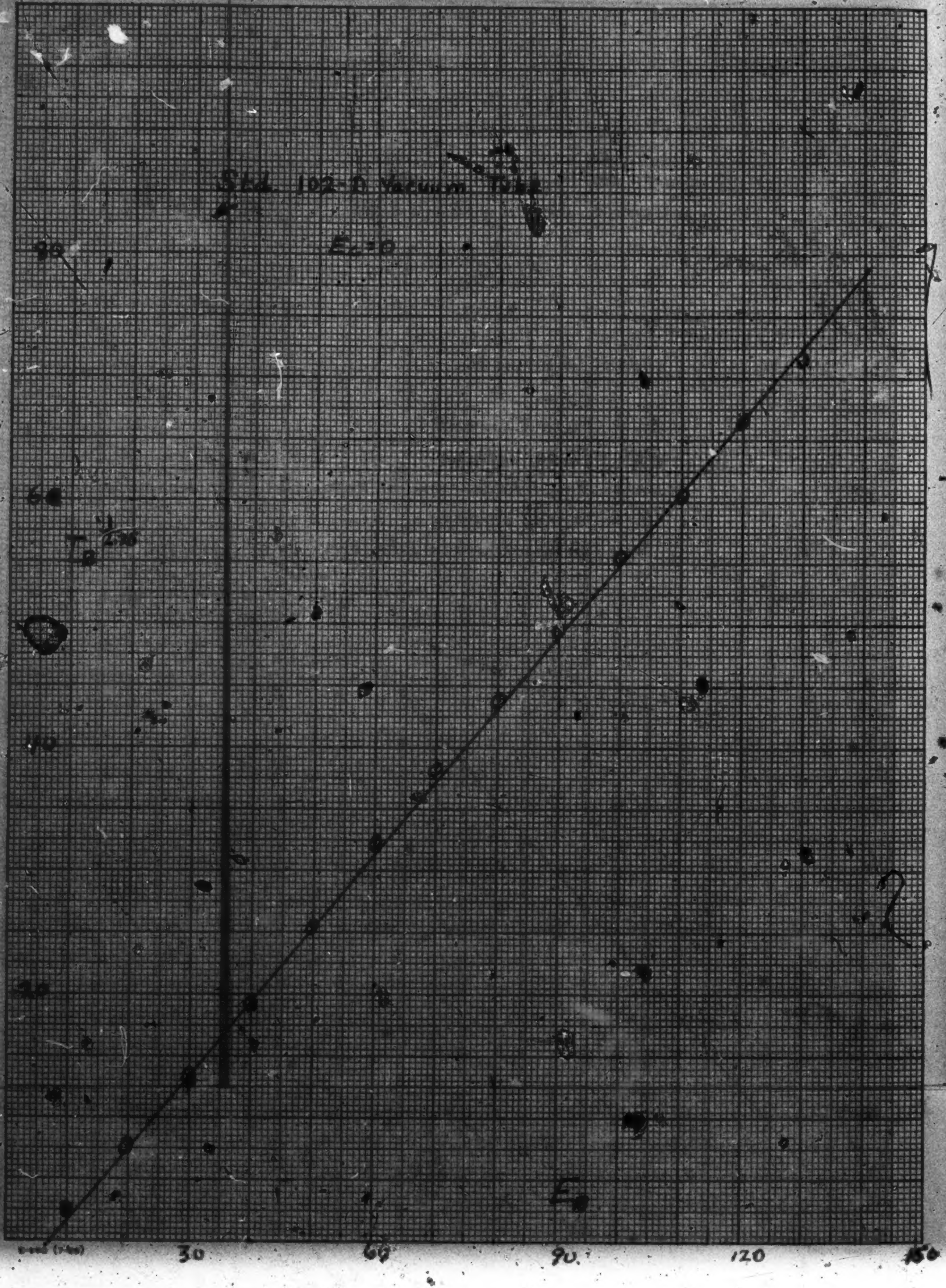
I_p = Plate Current
E_p = Plate Voltage
μ = Amplification Factor
E_c = Grid Voltage
K = proportionality factor

DEFENDANT'S EXHIBIT No. 49.

Kelly Diagram for Western Electric Standard 102-D Vacuum Tube.

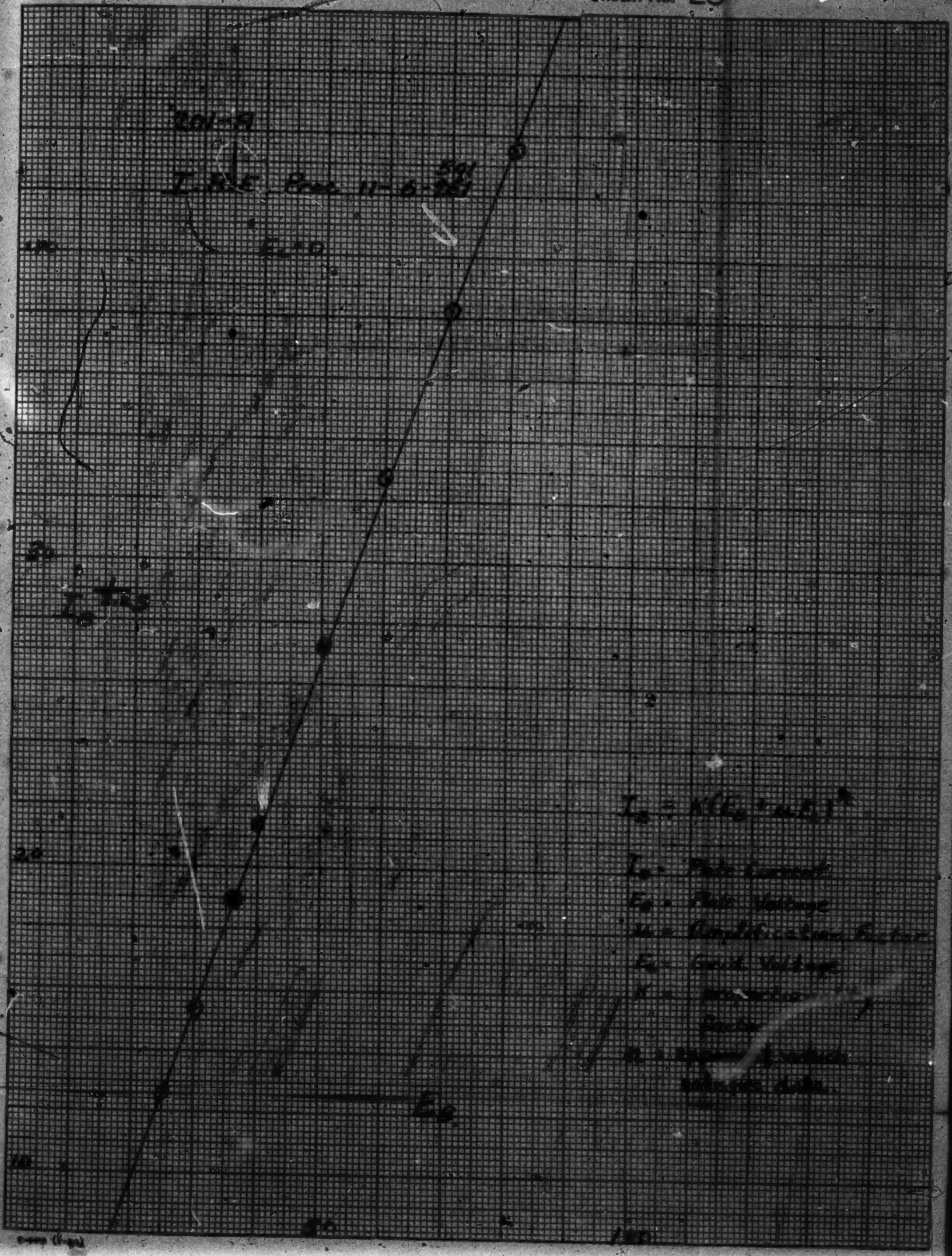
BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES



DEFENDANT'S EXHIBIT No. 50.

BELL TELEPHONE LABORATORIES INCORPORATED Kelly Diagram for Tube 201-A. Sketch No. ES



DEFENDANT'S EXHIBIT No. 51.

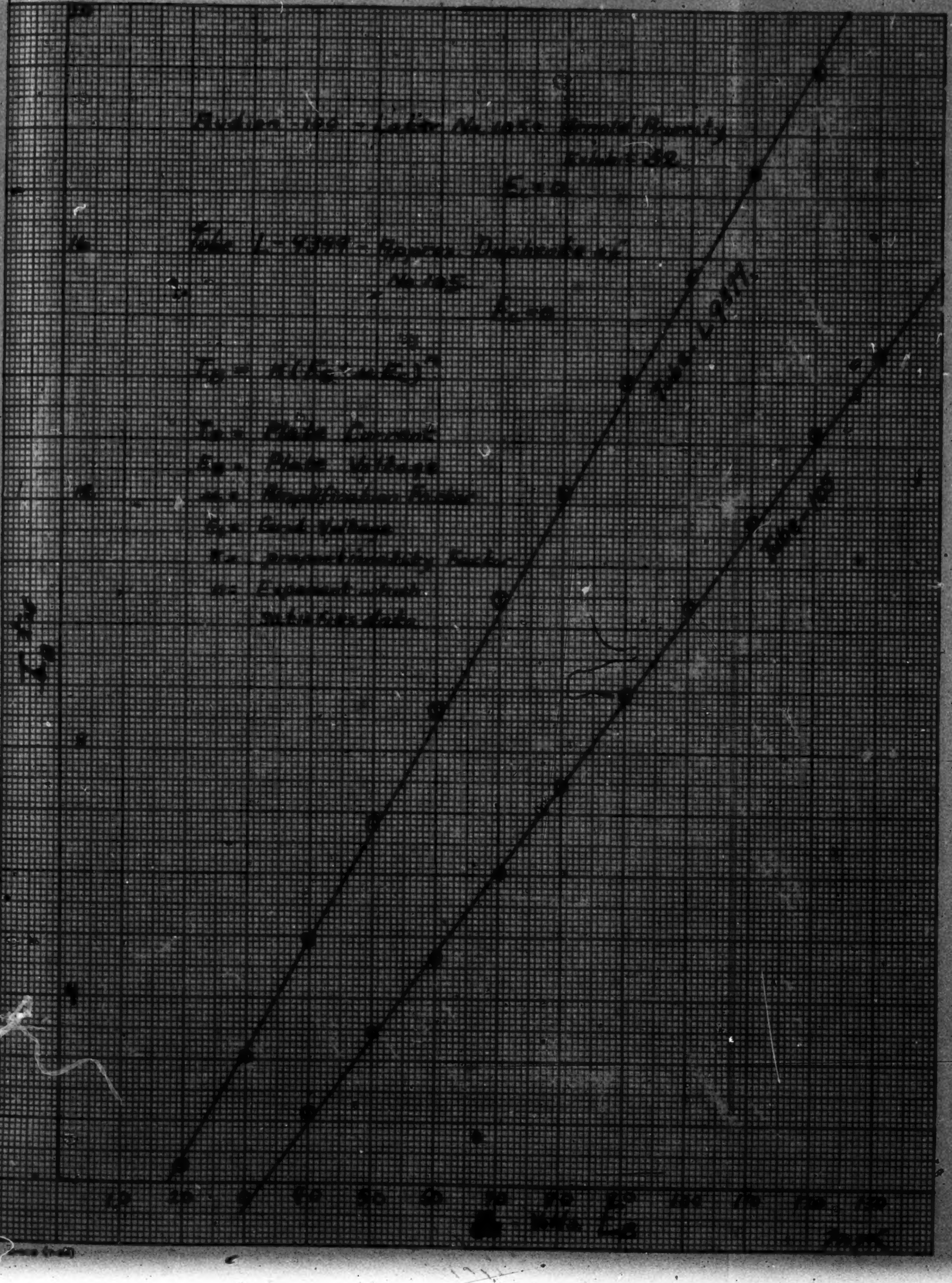
Kelly Approximate Duplicate Tube of Arnold Priority Exhibit No. 32.

DEFENDANT'S EXHIBIT No. 12

Kelly Diagram for Arnold Priority Exhibit No. 32 and Approximate Duplicate Tube.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES

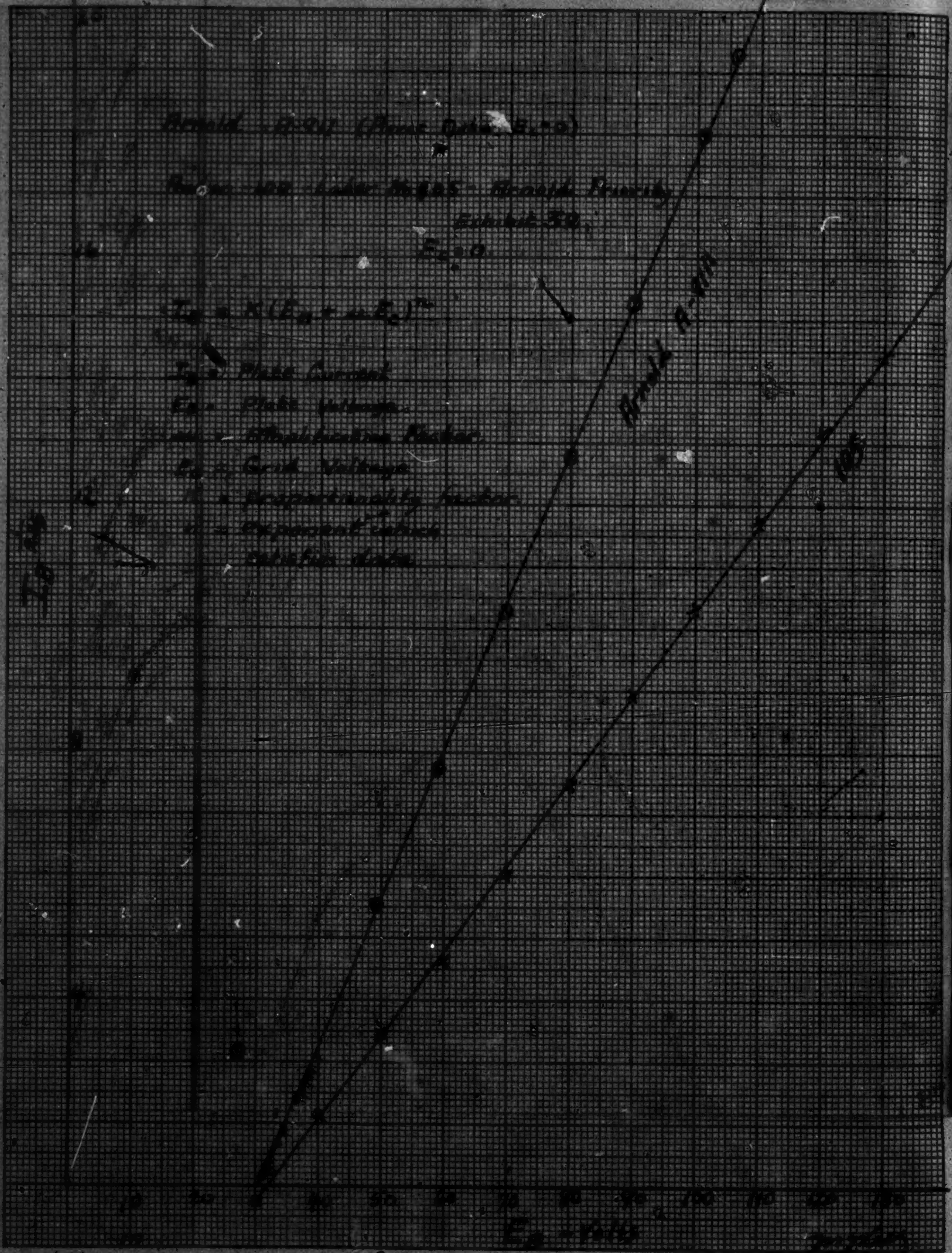


DEFENDANT'S EXHIBIT No. 53.

Kelly Diagram for Arnold Priority Exhibit No. 32 and Arnold Audion 9.111.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES



136

Pat.

65.867
S.b.

Vol. VI

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DEFOREST RADIO COMPANY, PETITIONER,

vs.

GENERAL ELECTRIC COMPANY

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT
COURT OF APPEALS FOR THE THIRD CIRCUIT

PETITION FOR CERTIORARI FILED JANUARY 8, 1931

CERTIORARI GRANTED FEBRUARY 25, 1931

(35,552)

DEFENDANT'S EXHIBITS.

GENERAL INDEX.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
1.	Hogan Graph plotted between filament and plate currents (Pltff.'s Ex. 52, Hewlett v. A. T. & T. Co., S. D. of N. Y.)	I	145	V	1
2.	Nature, July 15, 1875, p. 217, "Charcoal Vacua," by James DeWar	I	196	V	3
3.	Physikalische Zeitschrift, Vol. 29, pp. 46-50, 1909, "Tests of the Methods Used for Producing High Vacua," by Scheel & Heuse	I	196	V	8
4.	Annalin der Physik, Vol. 12 (1881) pp. 425-445, "A New Construction of the Mercury Pump of Toepler and Describing Some Experiments Made Therewith," by Bessel-Hagen	I	196	V	16
5.	Edison U. S. Patent No. 411,019, Sept. 17, 1889	I	196	V	37
6.	Malignani U. S. Patent No. 537,693, April 16, 1895	I	196	V	40
7.	Dwyer U. S. Patent No. 596,654, Jan. 4, 1898	I	197	V	42
8.	American Electrician, Vol. VIII, No. 1, May, 1896, "Crookes Tubes and Experiments With Roentgen Rays," by Thomas Duncan	I	197	V	47
9.	Proceedings of the Royal Society, A, Vol. 64, pp. 231-238, "Liquid Hydrogen for the Production of High Vacua," by James DeWar	I	197	V	53
10.	Annalin der Physik, Vol. II (1900), pp. 359-374, "Production of Cathode Rays by Ultra-Violet Light," by P. Lenard	I	197	V	62
10-A.	Annalin der Physik, Vol. VIII, (1902), pp. 149-198, "Photoelectric Action," by P. Lenard	I	197	V	79
11.	Electrical World and Engineer, Vol. III, May 21, 1904, pp. 963-965, "A Resume of Incandescent Electric Lamps Exhausting," by S. E. Doane	I	197	V	122
12.	Recklinghausen U. S. Patent No. 946,068, Jan. 11, 1910	I	197	V	135
13.	Merritt U. S. Patent No. 909,811, Jan. 12, 1909	I	197	V	138

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
14.	Proceedings of the Royal Society, Vol. 74 (1905), pp. 476-487, "Conversion of Electric Oscillations into Continuous Currents by Means of a Vacuum Valve," by J. A. Fleming	I	197	V	142
15.	Fleming U. S. Patent No. 803,684, Nov. 7, 1905	I	197	V	157
16.	Scientific American Supplement, No. 1568, Jan. 20, 196, pp. 25129-25131, "On the Electric Conductivity of a Vacuum," by J. A. Fleming	I	197	V	165
17.	Soddy U. S. Patent No. 859,021, July 2, 1907	I	198	V	181
18.	Nature, Nov. 21, 1907, pp. 53-54, "The Wehnelt Kathode in a High Vacuum," by Frederick Soddy	I	198	V	190
18-A.	Proceedings of the Royal Society (1907), Vol. 78-A, pp. 429-458, "Calcium as an Absorbent of Gases for the Production of High Vacua and Spectroscopic Research," by Frederick Soddy	I	198	V	192
19.	Physikalische Zeitschrift, Vol. 9 (1908), p. 193, Reply to Soddy by Lilienfeld	I	198	V	222
20.	Proceedings of the American Academy of Arts and Sciences, Vol. XLV, No. 1, August, 1909, pp. 1-17, "Friction in Gases at Low Pressures," by J. L. Hogg	I	198	V	225
21.	Annalin der Physik, Vol. 31, (1910), pp. 169-304, "A Contribution to the Knowledge of the Inertia of Moving Electrons," by E. Hupka	I	198	V	241
22.	Physikalische Zeitschrift, Vol. 10, (1909), pp. 168-176, "Concerning Slow Cathode Rays," by O. V. Baeyer	I	198	V	281
23.	Thatcher U. S. Patent No. 1,028,636, June 4, 1912	I	198	V	305
24.	Friedrich U. S. Patent No. 1,083,677, Jan. 6, 1914	I	198	V	309
25.	Annalin der Physik, Vol. 32 (1910), pp. 673-738, "Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	315
25-A.	Leipsiger Berichte, Vol. 63, (1911), pp. 534-539, "The Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	388
26.	Verhandlunger der Deutschen Physikalischen Gesellschaft, Vol. 13, (1911), pp. 601-606, "On a Method of Producing Very Soft Roentgen Rays in the Highest Vacuum," by H. Dember	I	198	V	397

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
27.	Annalin der Physik, Vol. 36 (1911), pp. 995-1026, "Reflection and Secondary Radiation of Photoelectrically Liberated Cathode Rays," by A. Gehrts...	I	199	V	403
28.	Marshall U. S. Patent No. 205,002, Nov. 14, 1916....	I	199	V	433
29.	Physical Review, Vol. 32, (1911), pp. 492-511, "Discharge from Hot CAO," by C. D. Child.....	I	199	V	437
30.	Atti Della Raele Accademia Dei Lincei, Vol. XXI, (1912), pp. 235-239, "On Electromagnetic Wave Indicators Based on the principle of Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	457
30-A.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 274-277, "On a New Type of Indicator of Electromagnetic Waves Based Upon Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	465
31.	Fortschritte uf dem Gebiete der Rontgen Strahlen, Vol. 18 (1912), pp. 256-263, "An X-Ray Tube of an Optional and Instantaneously Attainable Degree of Hardness Independent of Vacuum," by J. E. Lilienfeld and W. J. Rosenthal	I	199	V	472
32.	Physikalische Zeitschrift, Vol. XIII (1912), pp. 594-595, "About the Distribution of Light During the Stratified Discharge in Vapors of Alkali Metals," by Kunz and Kemp	I	199	V	488
33.	American Institute of Electrical Engineers, Proceedings of, June 25, 1912, pp. 1207-1217, "Vacua," by W. R. Whitney	I	199	V	491
34.	Clark U. S. Patent No. 1,121,803, Dec. 22, 1914....	I	199	V	502
35.	Annalin der Physik, Vol. 41 (1913), pp. 1-26, "Concerning the Pressure of Cathode Rays," by Ernst V. Angerer	I	199	V	507
36.	Clough U. S. Patent No. 246,054, Nov. 13, 1917....	I	200	V	539
37.	Mackay U. S. Patent No. 1,208,597, Dec. 12, 1916..	I	200	V	542
38.	Coolidge U. S. Patent No. 1,082,933, Dec. 30, 1913..	I	382	V	545
39.	Langmuir New Zealand Patent No. 35,611, April 8, 1924	I	384	V	556

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
40.	General Electric Co. Australian Patent No. 14,677, Oct. 22, 1914	I	384	V	580
41.	British Thomson-Houston Co., Ltd., British Patent No. 15,788 of 1914	I	387	V	592
42.	White U. S. Patent No. 1,159,307, Nov. 2, 1915	I	387	V	604
43.	Arnold U. S. Patent No. 1,118,172, Nov. 24, 1914	I	494	V	610
44.	Hewitt U. S. Patent No. 1,025,464, May 7, 1912	I	583	V	614
45.	Hewitt U. S. Patent No. 682,699, Sept. 17, 1901	I	583	V	619
46.	Hewitt U. S. Patent No. 682,692, Sept. 17, 1901	I	583	V	622
47.	Kelly's approximate duplicate tube of Arnold priority record Exhibit No. 30	II	816	—	—
48.	Kelly diagram for Arnold Priority Exhibit No. 30	II	826	V	629
49.	Kelly diagram for Western Electric Standard 102-D Vacuum Tube	II	828	V	630
50.	Kelly diagram for tube 201-A	II	828	V	631
51.	Kelly approximate duplicate tube of Arnold Priority Exhibit No. 32	II	833	—	—
52.	Kelly diagram for Arnold Priority Exhibit No. 32 and approximate duplicate tube	II	834	V	633
53.	Kelly diagram for Arnold Priority Exhibit No. 32 and Arnold Audion 9.111	II	836	V	634
54.	Kelly diagram for data of Audion 9.111 in Arnold priority Exhibit No. 34	II	837	VI	635
54-A.	Kelly diagram showing correction of lowermost line of Exhibit No. 54	II	852	VI	636
55.	Circulars of General Electric tubes including tube UV-200	II	840	VI	637
56.	Kelly Helium filled tube	II	845	—	—
57.	Kelly diagram for Helium filled tube	II	845	VI	651
58.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	652
58-A.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	653
58-B.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	654
59.	Kelly diagram of two-way telephone repeater	II	849	VI	655

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
60.	Diagram of Page 591 of Warner Article, Proceedings of Radio Engineers, showing curves for tubes UV-199, 201 and 201-A	II	854	VI	656
61.	Kelly diagram for Arnold priority Exhibit No. 32 and approximate duplicate tube, plotted for exponent 3/2 or its inverse	II	856	VI	657
62.	File wrapper and contents, Langmuir U. S. Patent No. 1,558,436	II	912	VI	659
63.	File wrapper and contents Langmuir U. S. Patent No. 1,244,216	II	912	VI	786
64.	File wrapper and contents Langmuir U. S. Patent No. 1,244,217	II	912	VI	824
65.	File wrapper and contents Langmuir U. S. Patent No. 1,522,597	II	912	VI	852
66.	Physical Review, December, 1913, "A Powerful Roentgen Ray Tube With a Pure Electron Discharge," by W. D. Coolidge	II	913	VI	919
67.	File wrapper and contents Coolidge U. S. Patent No. 1,203,495	II	913	VI	941
68.	Drawing of pump used by Lamont	II	915	VI	1031
69.	Drawing of pump used by Lamont	II	916	VI	1033
70.	Photograph of Lamont preliminary pump	II	916	VI	1034
71.	Photograph of Lamont mercury pump	II	916	VI	1035
72.	Hewlett pump sketch	II	916	VI	1036
73.	Clark pump sketch	II	916	VI	1037
74.	Lamont account book (cash)	II	917	VI	1038
75.	Lamont account book (order)	II	917	VI	1048
76.	Shop card, amplifiers (3-stage)	II	918	VI	1054
77.	Shop card, amplifier tubes	II	918	VI	1055
78.	Letter, McCandless & Co. to Federal Telegraph Co., May 4, 1912	II	918	VI	1056
78-A.	Letter, McCandless & Co. to Federal Telegraph Co., June 9, 1912	II	918	VI	1057
78-B.	Letter, McCandless & Co. to Federal Telegraph Co., Dec. 23, 1912	II	918	VI	1058
78-C.	Letter, McCandless & Co. to Federal Telegraph Co., Jan. 8, 1913	II	918	VI	1059

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
79.	Letter, Federal Telegraph Co. to McCandless & Co., April 27, 1912	II	919	VI	1060
79-A.	Letter, Federal Telegraph Co. to McCandless & Co., July 26, 1912	II	919	VI	1061
79-B.	Letter, Federal Telegraph Co. to McCandless & Co., August 14, 1912	II	919	VI	1062
79-C.	Letter, Federal Telegraph Co. to G. E. Lamont, Oct. 16, 1912	II	919	VI	1063
80.	Watkin's photograph	II	919	VI	1064
81.	Drawing 88, Federal Telegraph Co.	II	919	VI	1065
82.	Drawing 229, Federal Telegraph Co.	II	919	VI	1067
83.	DeForest Audion structure, California depositions (Exhibit withdrawn)	II	920	—	—
84.	Jahnke Tube, California depositions (Exhibit withdrawn)	II	920	—	—
85.	Letter, Commissioner of Patents to Irving Langmuir, Sept. 8, 1916	II	923	VI	1069
86.	Telegram, Albert G. Davis to Edw. Williams, Sept. 15, 1916	II	923	VI	1070
87.	Supplemental petition of Irving Langmuir that claims be added, Interference No. 40,380	II	924	VI	1071
88.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1075
89.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1076
90.	Memorandum, Albert G. Davis on motion to dissolve and to add counts, Interference No. 40,380, Feb. 2, 1921	II	925	VI	1079
91.	Stipulation between attorneys for Langmuir and Arnold, Interference No. 40,380	II	925	VI	1081
92.	Communication, from Law Examiner, Stipulation to amend, Interference No. 40,380, March 18, 1921	II	925	VI	1083
93.	Langmuir U. S. Patent No. 1,280,769, Oct. 8, 1918	II	925	VI	1085
94.	Hull U. S. Patent No. 291,527, Jan. 14, 1919	II	925	VI	1090
95.	Payne U. S. Patent No. 313,112, Aug. 12, 1919	II	925	VI	1095
96.	Hull U. S. Patent No. 1,313,187, Aug. 12, 1919	II	925	VI	1099
97.	Hull U. S. Patent No. 313,188, Aug. 12, 1919	II	925	VI	1104

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
98.	Hull U. S. Patent No. 1,385,873, July 26, 1921	II	925	VI	1108
99.	Hull, U. S. Patent No. 387,984, Aug. 16, 1921	II	925	VI	1117
	[Nos. 100 to 278, incl., Arnold Exhibits in Interference Record and not reprinted. *See Separate Index.*]	II	927	—	—
79.	(No Exhibit.)				
80.	Dushman U. S. Patent No. 172,961, Feb. 22, 1916	II	948	VI	1126
81.	Hawkins U. S. Patent No. 1,172,990, Feb. 22, 1916	II	948	VI	1130
82.	Meikle U. S. Patent No. 1,182,290, May 9, 1916	II	948	VI	1133
83.	Meikle U. S. Patent No. 266,517, May 14, 1918	II	948	VI	1137
84.	Langmuir U. S. Patent No. 1,273,628, July 23, 1918	II	949	VI	1141
85.	Langmuir re-issued Patent No. 15,278, Jan. 31, 1922	II	949	VI	1144
86.	Berg U. S. Patent No. 1,352,242, Sept. 7, 1920	II	949	VI	1150
87.	White U. S. Patent No. 1,365,576, Jan. 11, 1921	II	949	VI	1153
88.	Pratt U. S. Patent No. 1,374,679, April 12, 1921	II	949	VI	1157
89.	Alexanderson U. S. Patent No. 1,477,413, Dec. 11, 1923	II	949	VI	1160
90.	White U. S. Patent No. 1,506,468, Aug. 26, 1924	II	949	VI	1163
91.	Hull U. S. Patent No. 1,523,776, Jan. 20, 1925	II	949	VI	1168
92.	Alexanderson U. S. Patent No. 1,535,082, April 21, 1925	II	949	VI	1178
93.	Alexanderson U. S. Patent No. 1,549,737, Aug. 18, 1925	II	950	VI	1181
94.	Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	II	950	VI	1194
95.	Becker diagram for low current values of Sweetser, August, 1912, notes	III	1799	VI	1202
96.	Becker approximate duplicate Sweetser tube, August 1912	III	1804	—	—
97.	Becker diagram for current pressure relation in tube, Defendant's Exhibit No. 296	III	1804	VI	1204
98.	Becker current temperature diagrams for hydrogen Sweetser notes for Nov. and Dec., 1912	III	1809	VI	1205
99	Becker diagram for current pressure data of Defendant's Exhibit No. 298 reduced to common voltage	III	1813	VI	1206

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
300.	Petition, specification, oath and drawings, Langmuir U. S. Patent No. 558,437, Oct. 20, 1925	III	1851	VI	1207
301.	Amendment B to application, Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1851	VI	1228
302.	Alexanderson U. S. Patent No. 1,102,628, July 7, 1914	III	1821	VI	1233
303.	White U. S. Patent No. 1,195,632, Aug. 22, 1916	III	1821	VI	1241
304.	Langmuir U. S. Patent No. 1,273,627, July 23, 1918	III	1821	VI	1246
305.	White U. S. Patent No. 1,298,613, March 25, 1919	III	1821	VI	1251
306.	Langmuir U. S. Patent No. 1,301,279, April 22, 1919	III	1821	VI	1257
307.	Alexanderson U. S. Patent No. 313,042, Aug. 12, 1919	III	1821	VI	1263
308.	Langmuir re-issued U. S. Patent No. 15,495, Nov. 21, 1922	III	1822	VI	1267
309.	Goldsmith U. S. Patent No. 1,323,759, Dec. 2, 1919	III	1822	VI	1271
310.	Goldsmith and Weinberger U. S. Patent No. 1,334,087, March 16, 1920	III	1822	VI	1276
311.	Alexanderson U. S. Patent No. 1,340,101, May 11, 1920	III	1822	VI	1280
312.	Alexanderson U. S. Patent No. 1,373,931, April 5, 1921	III	1822	VI	1285
313.	Payne U. S. Patent No. 1,400,235, Dec. 13, 1921	III	1822	VI	1289
314.	Bradbury U. S. Patent No. 1,430,883, Oct. 3, 1922	III	1822	VI	1293
315.	Beverage U. S. Patent No. 1,434,984, Nov. 7, 1922	III	1822	VI	1297
316.	Beverage U. S. Patent No. 1,434,985, Nov. 7, 1922	III	1823	VI	1303
317.	Bradbury U. S. Patent No. 1,443,209, Jan. 23, 1923	III	1823	VI	1314
318.	Becker U. S. Patent No. 1,455,099, May 15, 1923	III	1823	VI	1317
319.	Alexanderson U. S. Patent No. 1,466,263, Aug. 28, 1923	III	1823	VI	1321
320.	Traver U. S. Patent No. 1,470,582, Oct. 9, 1923	III	1823	VI	1325
321.	Alexanderson U. S. Patent No. 1,491,372, April 22, 1924	III	1823	VI	1331
322.	White U. S. Patent No. 1,544,202, June 30, 1925	III	1823	VI	1337
323.	Hull U. S. Patent No. 1,547,153, July 21, 1925	III	1823	VI	1341
324.	Letter, Charles Neave to H. B. Thayer, Oct. 10, 1913, with Memorandum "Cooper-Hewitt Matters" annexed	III	1853	VI	1349

DEFENDANT'S EXHIBITS—GENERAL INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
325.	Letter, C. E. Scribner to D. C. Tanner, Feb. 10, 1915 with Memorandum from H. D. Arnold to E. H. Colpitts annexed	III	1859	VI	1358
326.	Physical Review, Vol. II, No. 5, Oct, 18, 1913, Abstract of Langmuir paper "The Effect of Space Charge and Residual Gases on the Thermionic Current in High Vacuum"	III	1886	VI	1361
327.	Logarithmic plot of Volt-Ampere characteristics of Type U pliotron (Plaintiff's Exhibit No. 60 with additions)	III	1886	VI	1363
328.	Data sheets furnished to plaintiff by defendant's witness Kelly	III	1887	VI	1364
329.	Tube used by Arnold in demonstration in Court of Blue Glow	III	1893	—	—
330.	DeForest tube as placed on pump	III	1901	—	—
331.	DeForest tube sealed off from pump	III	1901	—	—
332.	DeForest tube prior to volatilization of magnesium	III	1902	—	—
333.	DeForest tube in completed commercial form	III	1903	—	—

DEFENDANT'S EXHIBITS.

CLASSIFIED INDEX.

Diagrams, Drawings and Photographs.

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
295.	Becker diagram for low current values of Sweetser August, 1912, notes	III	1799	VI	1202
297.	Becker diagram for current pressure relation in tube, Defendant's Exhibit No. 296	III	1804	VI	1204
298.	Becker current temperature diagrams for hydrogen Sweetser notes for Nov. and Dec., 1912	III	1809	VI	1205
299.	Becker diagram for current pressure data of Defendant's Exhibit No. 298 reduced to common voltage	III	1813	VI	1206
73.	Clark pump sketch	II	916	VI	1037
81.	Federal Telegraph Co., Drawing 88	II	919	VI	1065
82.	Federal Telegraph Co., Drawing 229	II	919	VI	1067
72.	Hewlett pump sketch	II	916	VI	1036
1.	Hogan graph plotted between filament and plate currents (Pltff.'s Ex. 52, Hewlett v. A. T. & T. Co., S. D. of N. Y.)	I	145	V	1
48.	Kelly diagram for Arnold Priority Exhibit No. 30	II	826	V	629
49.	Kelly diagram for Western Electric Standard 102-D Vacuum Tube	II	828	V	630
50.	Kelly diagram for tube 201-A	II	828	V	631
52.	Kelly diagram for Arnold Priority Exhibit No. 32 and approximate duplicate tube	II	834	V	633
53.	Kelly diagram for Arnold Priority Exhibit No. 32 and Arnold Audion 9.111,	II	836	V	634
54.	Kelly diagram for data of Audion 9.111 in Arnold priority Exhibit No. 34	II	837	VI	635
54-A.	Kelly diagram showing correction of lowermost line of Exhibit No. 54	II	852	VI	636
57.	Kelly diagram for Helium filled tube	II	845	VI	651
58.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	652
58-A.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	653

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
58-B.	Kelly diagram for Nitrogen filled tube at different pressures	II	846	VI	654
59.	Kelly diagram of two-way telephone repeater	II	849	VI	655
61.	Kelly diagram for Arnold priority Exhibit No. 32 and approximate duplicate tube, plotted for exponent 3/2 or its inverse	II	856	VI	657
68.	Lamont, Drawing of pump used by	II	915	VI	1031
69.	Lamont, Drawing of pump used by	II	916	VI	1033
70.	Lamont preliminary pump, Photograph of	II	916	VI	1034
71.	Lamont mercury pump, Photograph of	II	916	VI	1035
327.	Logarithmic plot of Volt-Ampere characteristics of Type U pliotron (Plaintiff's Exhibit No. 60 with additions)	III	1886	VI	1363
60.	Warner Article, Diagram on Page 591 of, Proceedings of Radio Engineers, showing curves for tubes UV-199, 201 and 201-A	II	854	VI	656
80.	Watkin's photograph	II	919	VI	1064

Documentary, Miscellaneous.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
301.	Amendment B to application, Langmuir U. S. Patent No. 1,558,437, Oct. 20, 1925	III	1851	VI	1228
55.	Circulars of General Electric tubes including tube UV-200	II	840	VI	637
92.	Communication from Law Examiner, Stipulation to amend, Interference No. 40,380, March 18, 1921	II	925	VI	1083
328.	Data sheets furnished to plaintiff by defendant's witness Kelly	III	1887	VI	1364
74.	Lamont account book (cash)	II	917	VI	1038
75.	Lamont account book (order)	II	917	VI	1048
78.	Letter, McCandless & Co. to Federal Telegraph Co., May 4, 1912	II	918	VI	1056
78-A.	Letter, McCandless & Co. to Federal Telegraph Co., June 9, 1912	II	918	VI	1057
78-B.	Letter, McCandless & Co. to Federal Telegraph Co., Dec. 23, 1912	II	918	VI	1058
78-C.	Letter, McCandless & Co. to Federal Telegraph Co., Jan. 8, 1913	II	918	VI	1059

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
79.	Letter, Federal Telegraph Co. to McCandless & Co., April 27, 1912	II	919	VI	1060
79-A.	Letter, Federal Telegraph Co. to McCandless & Co., July 26, 1912	II	919	VI	1061
79-B.	Letter, Federal Telegraph Co. to McCandless & Co., August 14, 1912	II	919	VI	1062
79-C.	Letter, Federal Telegraph Co., to G. E. Lamont, Oct. 16, 1912	II	919	VI	1063
85.	Letter, Commissioner of Patents to Irving Langmuir, Sept. 8, 1916	II	923	VI	1069
88.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1075
89.	Letter, G. E. Folk to Commissioner of Patents, October 14, 1920	II	924	VI	1076
324.	Letter, Charles Neave to H. B. Thayer, Oct. 10, 1913, with Memorandum "Cooper-Hewitt Matters" annexed	III	1853	VI	1349
325.	Letter, C. E. Scribner to D. C. Tanner, Feb. 10, 1915 with Memorandum from H. D. Arnold to E. H. Colpitts annexed	III	1859	VI	1358
90	Memorandum, Albert G. Davis on motion to dissolve and to add counts, Interference No. 40,380, Feb. 2, 1921	II	925	VI	1079
76.	Shop card, amplifiers (3-stage)	II	918	VI	1054
77.	Shop card, amplifier tubes	II	918	VI	1055
91.	Stipulation between attorneys for Langmuir and Arnold, Interference No. 40,380	II	925	VI	1081
87.	Supplemental petition of Irving Langmuir that claims be added, Interference No. 40,380	II	924	VI	1071
86.	Telegram, Albert G. Davis to Edw. Williams, Sept. 15, 1916	II	923	VI	1070

File Wrappers and Contents.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
67.	File wrapper and contents Coolidge U. S. Patent No. 1,203,495	II	913	VI	941
62.	File wraper and contents, Langmuir U. S. Patent No. 1,558,436	II	912	VI	659

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
63.	File wrapper and contents Langmuir U. S. Patent No. 1,244,216	II	912	VI	786
64.	File wrapper and contents Langmuir U. S. Patent No. 1,244,217	II	912	VI	824
65.	File wrapper and contents Langmuir U. S. Patent No. 1,522,597	II	912	VI	852
300.	Petition, specification, oath and drawing, Langmuir U. S. Patent No. 558,437, Oct. 20, 1925	III	1851	VI	1207
	Patent, Australian.				
40.	General Electric Co., No. 14,677, Oct. 22, 1914	I	384	V	580
	Patent, British.				
41.	Thomson-Houston Co., Ltd., British, No. 15,788 of 1914	[illegible]	387	V	592
	Patent, New Zealand.				
39.	Langmuir, No. 35,611, April 8, 1924	I	384	V	556
	Patents, United States.				
289.	Alexanderson, No. 1,477,413, Dec. 11, 1923	II	949	VI	1160
292.	Alexanderson, No. 1,535,082, April 21, 1925	II	949	VI	1178
293.	Alexanderson, No. 1,549,737, Aug. 18, 1925	II	950	VI	1181
302.	Alexanderson, No. 1,102,628, July 7, 1914	III	1821	VI	1233
307.	Alexanderson, No. 313,042, Aug. 12, 1919	III	1821	VI	1263
311.	Alexanderson, No. 1,340,101, May 11, 1920	III	1822	VI	1280
312.	Alexanderson, No. 1,373,931, April 5, 1921	III	1822	VI	1285
319.	Alexanderson, No. 1,466,263, Aug. 28, 1923	III	1823	VI	1321
321.	Alexanderson, No. 1,491,372, April 22, 1924	III	1823	VI	1331
43.	Arnold, No. 1,118,172, Nov. 24, 1914	I	494	V	610
318.	Becker, No. 1,455,099, May 15, 1923	III	1823	VI	1317
286.	Berg, No. 352,242, Sept. 7, 1920	II	949	VI	1150
315.	Beverage, No. 1,434,984, Nov. 7, 1922	III	1822	VI	1297
316.	Beverage, No. 1,434,985, Nov. 7, 1922	III	1823	VI	1303
314.	Bradbury, No. 1,430,883, Oct. 3, 1922	III	1822	VI	1293
317.	Bradbury, No. 1,443,209, Jan. 23, 1923	III	1823	VI	1314

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

34.	Clark, No. 1,121,803, Dec. 22, 1914	I	199	V	502
36.	Clough, No. 246,054, Nov. 13, 1917	I	200	V	539
38.	Coolidge, No. 1,082,933, Dec. 30, 1913	I	382	V	545
280.	Dushman, [illegible] 172,961, Feb. 22, 1916	II	948	VI	1126
7.	Dwyer, No. 596,654, Jan. 4, 1898	I	197	V	42
5.	Edison, No. 411,019, Sept. 17, 1889	I	196	V	37
15.	Fleming, No. 803,684, Nov. 7, 1905	I	197	V	157
24.	Friedrich, No. 1,083,677, Jan. 6, 1914	I	198	V	309
309.	Goldsmith, No. 1,323,759, Dec. 2, 1919	III	1822	VI	1271
310.	Goldsmith and Weinberger, No. 1,334,087, March 16, 1920	III	1822	VI	1276
281.	Hawkins, No. 1,172,990, Feb. 22, 1916	II	948	VI	1130
44.	Hewitt, No. 1,025,464, May 7, 1912	I	583	V	614
45.	Hewitt, No. 682,699, Sept. 17, 1901	I	583	V	619
46.	Hewitt, No. 682,692, Sept. 17, 1901	I	583	V	622
94.	Hull, No. 291,527, Jan. 14, 1919	II	925	VI	1090
96.	Hull, No. 1,313,187, Aug. 12, 1919	II	925	VI	1099
97.	Hull, No. 313,188, Aug. 12, 1919	II	925	VI	1104
98.	Hull, No. 1,385,873, July 26, 1921	II	925	VI	1108
99.	Hull, No. 387,984, Aug. 16, 1921	II	925	VI	1117
291.	Hull, No. 1,523,776, Jan. 20, 1925	II	949	VI	1168
323.	Hull, No. 1,547,153, July 21, 1925	III	1823	VI	1341
93.	Langmuir, No. 1,280,769, Oct. 8, 1918	II	925	VI	1085
284.	Langmuir, No. 1,273,628, July 23, 1918	II	949	VI	1141
285.	Langmuir, Re-issue, No. 15,278, Jan. 31, 1922	II	949	VI	1144
294.	Langmuir, No. 1,558,437, Oct. 20, 1925	II	950	VI	1194
304.	Langmuir, No. 1,273,627, July 23, 1918	III	1821	VI	1246
306.	Langmuir, No. 1,301,279, April 22, 1919	III	1821	VI	1257
308.	Langmuir, Re-issue, No. 15,495, Nov. 21, 1922	III	1822	VI	1267
37.	Mackay, No. 1,208,597, Dec. 12, 1916	I	200	V	542
6.	Malignani, No. 537,693, April 16, 1895	I	196	V	40
28.	Marshall, No. 205,002, Nov. 14, 1916	I	199	V	433
282.	Meikle, No. 1,182,290, May 9, 1916	II	948	VI	1133
283.	Meikle, No. 266,517, May 14, 1918	II	948	VI	1137
13.	Merritt, No. 909,811, Jan. 12, 1909	I	197	V	138
95.	Payne, No. 313,112, Aug. 12, 1919	II	925	VI	1095
313.	Payne, No. 1,400,235, Dec. 13, 1921	III	1822	VI	1289
288.	Pratt, No. 1,374,679, April 12, 1921	II	949	VI	1157

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
12.	Recklinghausen, No. 946,068, Jan. 11, 1910	I	197	V	135
17.	Soddy, No. 859,021, July 2, 1907	I	198	V	181
23.	Thatcher, No. 1,028,636, June 4, 1912	I	198	V	305
320.	Traver, No. 1,470,582, Oct. 9, 1923	III	1823	VI	1325
42.	White, No. 1,159,307, Nov. 2, 1915	I	387	V	604
287.	White, No. 1,365,576, Jan. 11, 1921	II	949	VI	1153
290.	White, No. 1,506,468, Aug. 26, 1924	II	949	VI	1163
303.	White, No. 1,195,632, Aug. 22, 1916	III	1821	VI	1241
305.	White, No. 1,298,613, March 25, 1919	III	1821	VI	1251
322.	White, No. 1,544,202, June 30, 1925	III	1823	VI	1337

Publications.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
20.	American Academy of Arts and Sciences, Proceedings of the, Vol. XIV, No. 1, August, 1909, pp. 1-17, "Friction in Gases at Low Pressures," by J. L. Hogg	I	198	V	225
8.	American Electrician, Vol. VIII, No. 1, May, 1896, "Crookes Tubes and Experiments with Roentgen Rays," by Thomas Duncan	I	197	V	47
33.	American Institute of Electrical Engineers, Proceedings of, June 25, 1912, pp. 1207-1217, "Vacua," by by W. R. Whitney	I	199	V	491
4.	Annalin der Physik, Vol. 12 (1881), pp. 425-445, "A New Construction of the Mercury Pump of Toepler and Describing Some Experiments Made Therewith," by Bessel-Hagen	I	196	V	16
10.	Annalin der Physik, Vol. II, (1900), pp. 359-374, "Production of Cathode Rays by Ultra-Violet Light," by P. Lenard	I	197	V	62
10-A.	Annalin der Physik, Vol. VIII, (1902), pp. 149-198, "Photoelectric Action," by P. Lenard	I	197	V	79
21.	Annalin der Physik, Vol. 31, (1910), pp. 169-304, "A Contribution to the Knowledge of the Inertia of Moving Electrons," by E. Hupka	I	198	V	241
25.	Annalin der Physik, Vol. 32 (1910), pp. 673-738, "Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	315

Ex. No.		Admitted		Printed	
		Vol.	Page	Vol.	Page
27.	Annalin der Physik, Vol. 36 (1911), pp. 995-1026, "Reflection and Secondary Radiation of Photo-electrically Liberated Cathode Rays," by A. Gehrts	I	199	V	408
35.	Annalin der Physik, Vol. 41, (1913), pp. 1-26, "Concerning the Pressure of Cathode Rays," by Ernst V. Angerer	I	199	V	507
30.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 235-239, "On Electromagnetic Wave Indicators Based on the Principle of Electronic Emissions from Incandescent Wires," by Quirino Majorana	I	199	V	457
30-A.	Atti Della Reale Accademia Dei Lincei, Vol. XXI (1912), pp. 274-277, "On a New Type of Indicator of Electromagnetic Waves Based Upon Electronic Emissions From Incandescent Wires," by Quirino Majorana	I	199	V	465
11.	Electrical World and Engineer, Vol. III, May 21, 1904, pp. 963-965, "A Resume of Incandescent Electric Lamps Exhausting," by S. E. Doane	I	197	V	122
31.	Fortschritte uf dem Gebiete der Rontgen Strahlen, Vol. 18 (1912), pp. 256-263, "An X-Ray Tube of An Optional and Instantaneously Attainable Degree of Hardness Independent of Vacuum," by J. E. Lilienfeld and W. J. Rosenthal	I	199	V	472
25-A.	Leipsiger Berichte, Vol. 63, (1911), pp. 534-539, "The Conduction of Electricity in Extreme Vacuum," by J. E. Lilienfeld	I	198	V	388
2.	Nature, July 15, 1875, p. 217, "Charcoal Vacua," by James DeWar	I	196	V	3
18.	Nature, Nov. 21, 1907, pp. 53-54, "The Wehnelt Kathode in a High Vacuum," by Frederick Soddy..	I	198	V	190
29.	Physical Review, Vol. 32, (1911), pp. 492-511, "Discharge from Hot CAO," by C. D. Child	I	199	V	437
66.	Physical Review, December, 1913, "A Powerful Roentger Ray Tube With a Pure Electron Discharge," by W. D. Coolidge	II	913	VI	919

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
326.	Physical Review, Vol. II, No. 5, Oct. 18, 1913, Abstract of Langmuir paper "The Effect of Space Charge and Residual Gases on the Thermionic Current in High Vacuum"	III	1886	VI	1361
3.	Physikalische Zeitschrift, Vol. 29, pp. 46-50, 1909, "Tests of the Methods Used for Producing High Vacua," by Scheel & Heuse	I	196	V	8
19.	Physikalische Zeitschrift, Vol. 9 (1908), p. 193, Reply to Soddy by Lilienfeld	I	198	V	222
22.	Physikalische Zeitschrift, Vol. 10 (1909), pp. 168-176, "Concerning Slow Cathode Rays," by O. v. Baeyer	I	198	V	281
32.	Physikalische Zeitschrift, Vol. XIII (1912), pp. 594-595, "About the Distribution of Light During the Stratified Discharge in Vapors of Alkali Metals," by Kunz and Kemp	I	199	V	488
9.	Royal Society, Proceedings of the, A, Vol. 64, pp. 231-238, "Liquid Hydrogen for the Production of High Vacua," by James DeWar	I	197	V	53
14.	Royal Society, Proceedings of the, Vol. 74 (1905), pp. 476-487, "Conversion of Electric Oscillations Into Continuous Currents by Means of a Vacuum Valve," by J. A. Fleming	I	197	V	142
18-A.	Royal Society, Proceedings of the, (1907), Vol. 78-A, pp. 429-458, "Calcium as an Absorbent of Gases for the Production of High Vacua and Spectroscopic Research," by Frederick Soddy	I	198	V	192
16.	Scientific American Supplement, No. 1568, Jan. 20 1906, pp. 25129-25131, "On the Electric Conductivity of a Vacuum," by J. A. Fleming	I	197	V	165
26.	Verhandlunger der Deutschen Physikalischen Gesellschaft, Vol. 13, (1911), pp. 601-606, "On a Method of Producing Very Soft Roentgen Rays in the Highest Vacuum," by H. Dember	I	198	V	397

Physical Exhibits

Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
329.	Arnold, tube used by, in demonstration in Court of Blue Glow	III	1893	—	—

DEFENDANT'S EXHIBITS—CLASSIFIED INDEX—Continued.

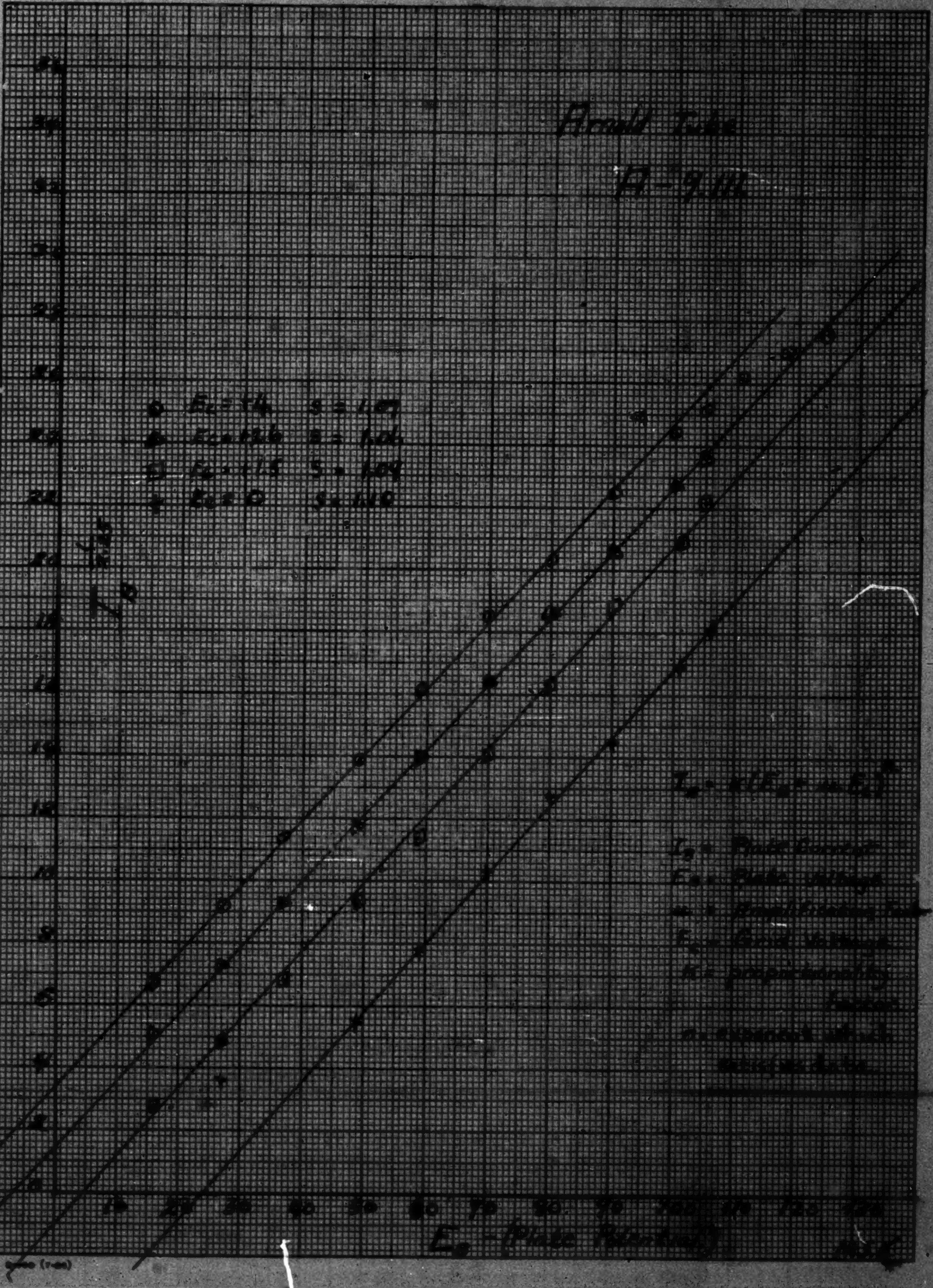
Ex. No.		Admitted Vol.	Admitted Page	Printed Vol.	Printed Page
296.	Becker approximate duplicate Sweetser tube, August, 1912	III	1804	—	—
83.	DeForest Audion structure, (California depositions) [Exhibit withdrawn]	II	920	—	—
330.	DeForest tube as placed on pump	III	1901	—	—
331.	DeForest tube sealed off from pump	III	1901	—	—
332.	DeForest tube prior to volatilization of magnesium	III	1902	—	—
333.	DeForest tube in completed commercial form	III	1903	—	—
84.	Jahnke Tube, (California depositions) [Exhibit withdrawn]	II	920	—	—
47.	Kelly's approximate duplicate tube of Arnold priority record Exhibit No. 30	II	816	—	—
51.	Kelly's approximate duplicate tube of Arnold Priority Exhibit No. 32	II	833	—	—
56.	Kelly Helium filled tube	II	845	—	—

DEFENDANT'S EXHIBIT No. 54.

Kelly Diagram for Data of Audion 9.111 in Arnold Priority Exhibit No. 34.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES



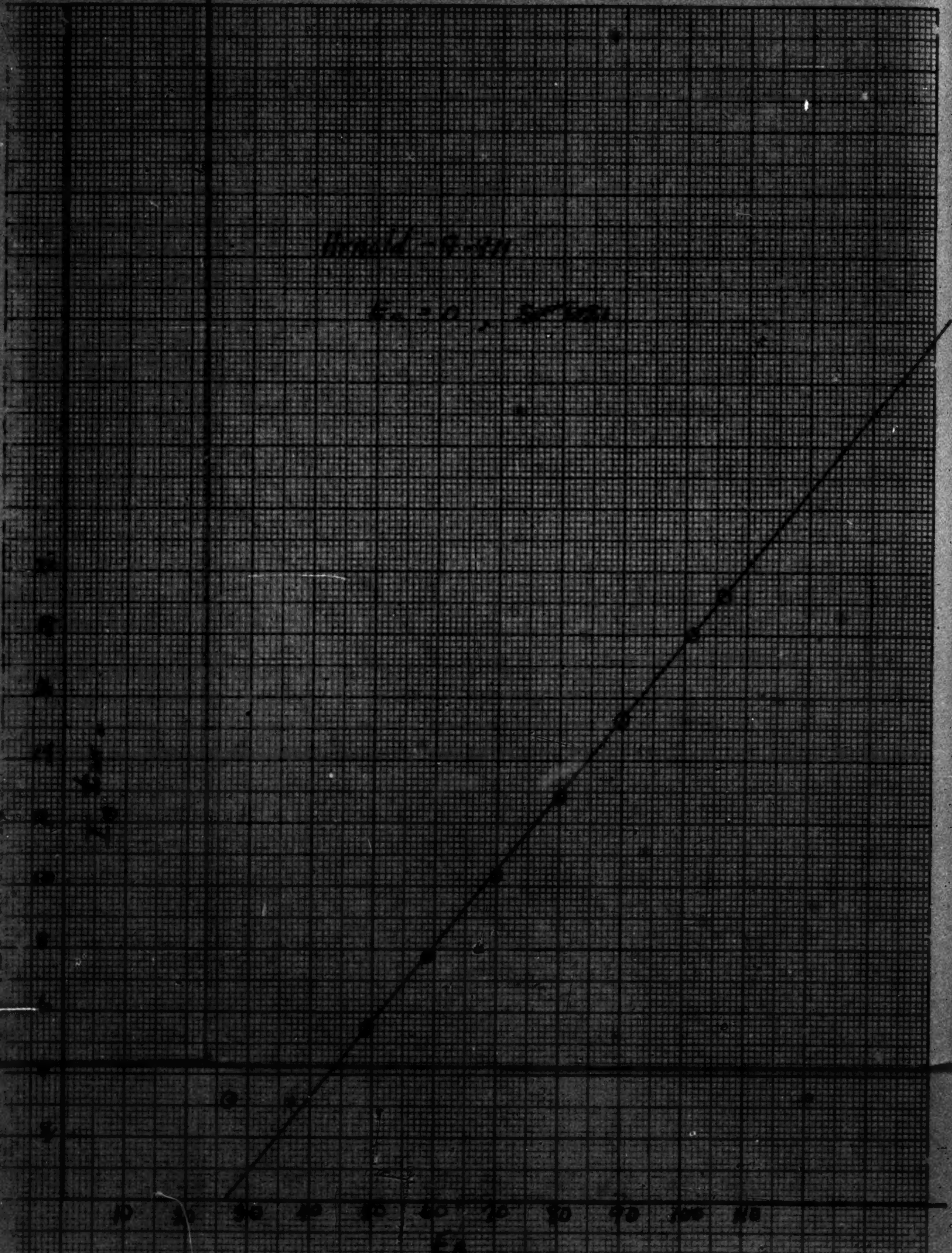
54-A

DEFENDANT'S EXHIBIT No. 54-A.

Kelly Diagram Showing Correction of Lowermost Line of Exhibit No. 54.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES



DEFENDANT'S EXHIBIT No. 55.

Circulars of General Electric Tubes Including Tube UV-200.

RADIO CORPORATION of AMERICA

RADIOTRON U. V. 200

NEW VACUUM TUBE DETECTOR AND CASCADE AMPLIFIER

FOR

AMATEUR AND EXPERIMENTAL WIRELESS STATIONS

IN presenting **RADIOTRON U. V. 200** to the Amateur and Experimental field, the **RADIO CORPORATION OF AMERICA** offers a vacuum tube in which **QUALITY** is the predominating factor. U. V. 200 was designed specifically for the Amateur. It is a product of the great **RESEARCH LABORATORIES** of the General Electric Company. For the first time the Experimenter has at his disposal a supersensitive detector tube which will operate from one Standard Plate Battery. This tends towards economy and eliminates one of the objections to former types of tubes, some of which required from three to five standard plate batteries to furnish the requisite plate voltage.

RADIOTRON U. V. 200 is not only the best detector or "spark receptor" designed to date, but it is also an excellent *tone frequency amplifier* for magnification of the telephone currents in vacuum tube receiving circuits. It gives *unusual* results in standard amateur regenerative circuits.

A particularly good combination for radio-telegraphic and radio-telephonic reception is the use of **ONE U. V. 200** as a **DETECTOR** and two additional U. V. 200's as **TONE FREQUENCY AMPLIFIERS.** Such a combination can be worked from a *single 22½-volt plate battery.* Cascade tone frequency circuits (for radio-telegraphic reception), using one or two Model U. V. 200 tubes, are remarkably free from tube noises and from "singing" so characteristic of former gas content tubes when operated in this manner.

For extreme amplifications some experimenters prefer from three to six stages of tone frequency amplification. In such cases the combination of one Radiotron U. V. 200 as a *detector* and several stages of the Radio Corporation's Amplifier of the **PLIOTRON TYPE RADIOTRON U. V. 201**—give the best results.

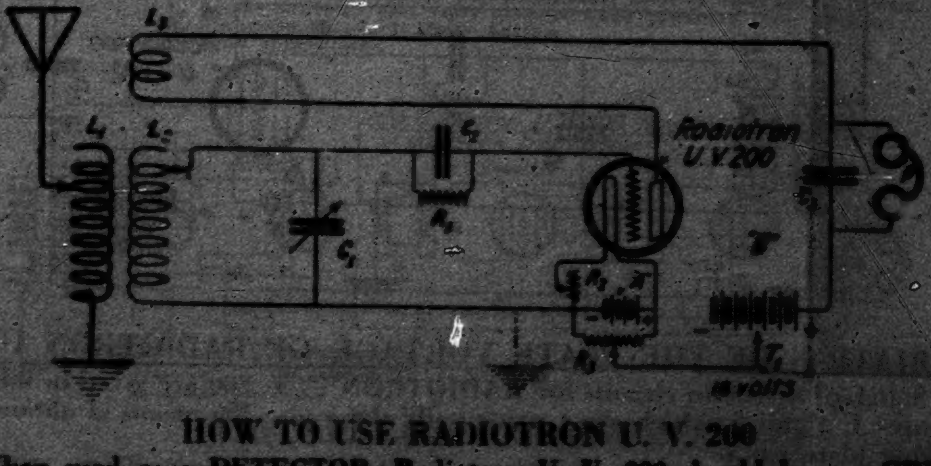


Fig. 1

HOW TO USE RADIOTRON U. V. 200

When used as a **DETECTOR**, Radiotron U. V. 200 should have a **GRID CONDENSER** of .00025 mfds., or thereabouts, connected in series with the grid. Many experimenters prefer a variable grid condenser which is of undoubted advantage in Regenerative circuits. In addition to the grid condenser one of the **RADIO CORPORATION'S** standard **GRID LEAKS** should be connected across the grid condenser, as shown in Figure 1.

To put Radiotron U. V. 200 into action, insert the tube in the **RADIO CORPORATION'S** Standard Vacuum Tube Socket.

Connect the "high potential" terminal of the tuner secondary to the grid (with a grid condenser in series).

Connect the other terminal of the tuner secondary to the negative terminal of the tube filament.

Connect the filament terminals to a 6-VOLT STORAGE BATTERY with a standard filament RHEOSTAT (of 6 to 10 ohms) in series. Make sure that all of the resistance of the rheostat is in the circuit before closing the circuit to the battery.

Connect the *Positive* terminal of a standard 22½-volt PLATE BATTERY to the "plate" of the tube, and the *Negative* terminal of the plate battery to the Positive or Negative terminal of the filament battery (with a telephone in series), according to the circuit used.

The voltage of the plate battery should now be capable of variation, either by means of an "A" *battery-potentiometer* (as in Fig. 1), or by means of taps brought from individual cells of a plate battery.

Set the plate battery tap at about 18 volts, and gradually increase the filament temperature by reducing the resistance at the filament rheostat, until signals from a distant radio station or from a locally excited oscillator circuit are clearly audible in the telephones.

Now *vary* the *plate voltage* and also the *filament temperature* until the maximum signal audibility is obtained.

NOTE that the *normal* filament current of RADIOTRON U. V. 200 is approximately 1 ampere, the maximum allowable current being about 1.1 ampere.

VOLTAGES IN EXCESS of 28 to 30 should not be applied to the plate circuit of RADIOTRON U. V. 200.

GRID LEAKS

Although tests indicate that in most cases the proper "leak resistance" for use with RADIOTRON U. V. 200 is approximately ½ megohm, this is not necessarily the correct value for all circuits. There are a number of factors in standard receiving circuits which govern the proper value of resistance, not the least of which is leakage through the insulation of the receiving apparatus. (Note R_1 in the accompanying diagrams.)

Resistance values of 500,000 ohms to 3 and even 6 megohms have been found to be of advantage. To get the best results with any vacuum tube detector the amateur should have at his disposal a small assortment of GRID LEAKS covering from ½ to 3 megohms for experimentation. The use of these leaks gives stability to tube circuits and often increases the signal audibility several times. The Radio Corporation's standard grid leaks are the most reliable yet put on the market.

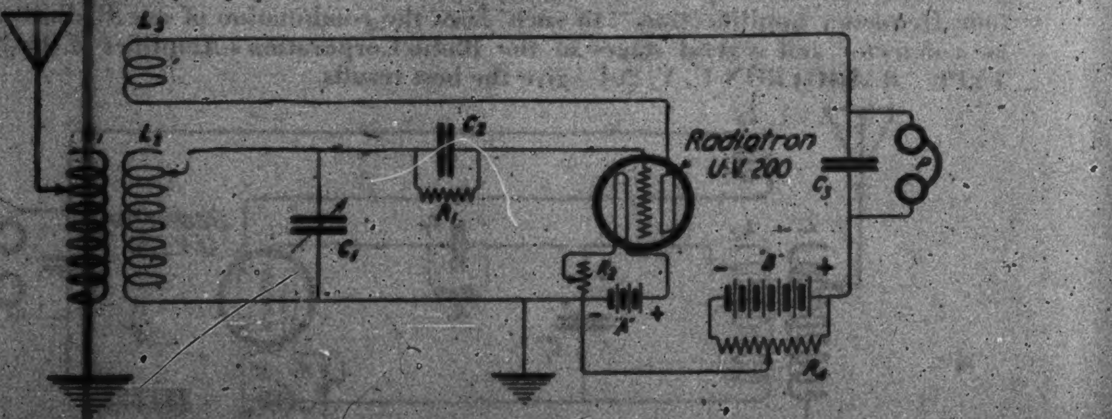


Fig. 2

VARIATION OF THE PLATE VOLTAGE OF RADIOTRON U. V. 200

Standard detection circuits for RADIOTRON U. V. 200 are given in the accompanying figures 1, 2 and 3, which show principally three possible means of obtaining a closely adjustable plate e.m.f.

In Figure 1, a standard 22½-volt "B" battery is tapped at the 12th cell giving approximately 18 volts. R-3 is the RADIO CORPORATION'S special "A" BATTERY POTENTIOMETER (which will be placed upon the market shortly) of approximately 200 ohms resistance. Through the voltage variation afforded by running the contact on R-3 along this resistance a very close adjustment of the plate e.m.f. can be obtained. When the "B" cell becomes partially exhausted the tap can be moved to the negative terminal of the last cell. The voltage thus supplied by the "B" cell, plus the additional voltage supplied by the resistance drop across the filament battery, gives the requisite variation of the plate potential for maximum signals.

Figure 2 differs from Figure 1 only in the method of varying the plate voltage. In this case, a "B" battery potentiometer R-4 of about 2000 ohms is connected across the "B" battery. This provides a very close adjustment of the plate e.m.f.

Fig. 3

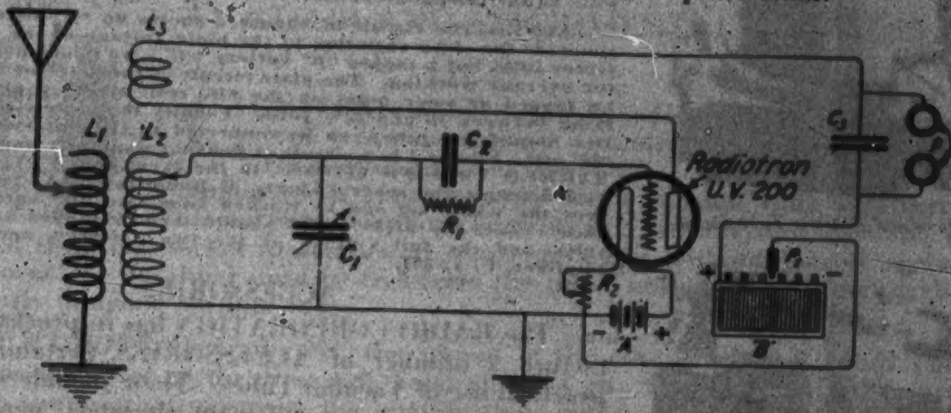


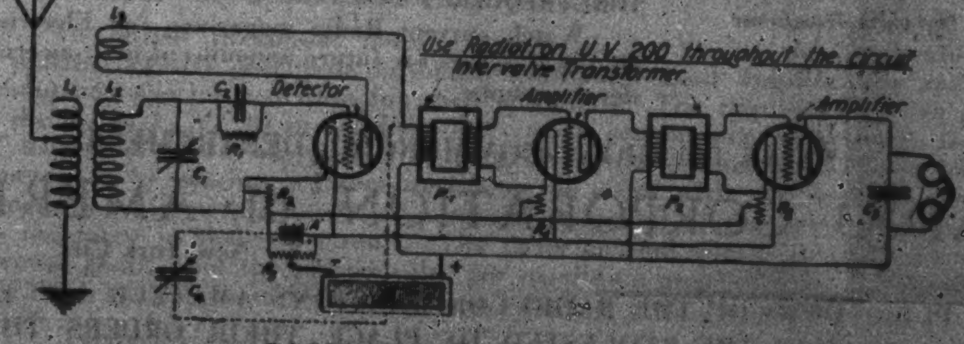
Figure 3 shows the same detection circuit with a tapped "B" battery, giving voltage variations by single cells through the tap P-1. Such batteries are now obtainable on the market. For most purposes a single cell variation of the plate voltage is satisfactory, but for extreme sensitiveness or maximum signal audibility, particularly when U. V. 200 is used as a detector, the Radio Corporation's "A" battery potentiometer is recommended.

INTERPRETATION OF THE CIRCUIT DIAGRAMS

For those not familiar with radio-telegraphic circuits, interpretations of the notations on the diagrams, Figures 1, 2 and 3, are given below:

L-1. primary coil of tuning transformer.
L-2. secondary coil-tuning transformer.
L-3. "tickler" coil for regenerative amplification.
C-1. secondary variable condenser.
C-2. grid condenser (fixed or variable).
C-3. telephone condenser (fixed).
R-1. Radio Corporation's standard grid leak.
R-2. Standard filament rheostat (to carry at maximum 1.2 ampere).
R-3. Radio Corporation's special "A" battery potentiometer.
R-4. Standard "B" battery potentiometer, 2000 to 4000 ohms. (Fig. 2.)
A. 6-volt storage cell (any ampere-hour capacity from 40 up).
B. Standard 22½-volt plate battery.
P. head telephones.

Fig. 4



CASCADE AMPLIFICATION

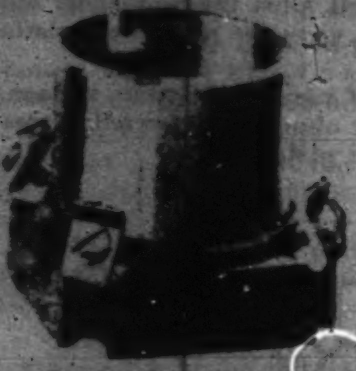
Amateurs and Experimenters are becoming accustomed more and more to use a detector tube with a 2-stage amplifier, for general communication. Such amplification is particularly desirable in radio telephony. It is in fact positively essential to secure satisfactory working ranges.

It is in this type of circuit that RADIOTRON U. V. 200 gives such marked results.

Figure 4 illustrates a detector-regenerative circuit with two stages of tone-frequency amplification. The notations on the diagram are explained below:

C-2. Radio Corporation's grid condenser of approximately .00025 mfds.
R-1. Radio Corporation's grid leak—½ to 3 megohms.
R-2. R-4, R-3, standard filament rheostats (6 to 10 ohms).
R-3. special "A" battery potentiometer (30 to 200 ohms).
A. 6-volt storage battery.
B. 22½-volt plate battery.
P-1. P-2, tone-frequency intervalve transformers.
C-4. bridging condenser (not necessary at short wave lengths).
P. telephones.
C-3. shunt telephone condenser (fixed or variable).

NOTE:—The circuit of Figure 4 shows an "A" battery potentiometer for close variation of the plate voltage of the first or detector tube, but a tapped "B" battery will give good enough results for average working. The plate circuit of the detector tube should be tapped at some point on the "B" cell, giving a plate voltage lying between 16 and 22½ volts. Usually the plate circuits of the two amplifying tubes can be connected to the full voltage of the "B" cell. Figure 4 is a circuit of unusual simplicity and one giving MARKED AMPLIFICATIONS. In the event that U. V. 200 is used as a detector and several stages of Radiotron U. V. 201 as amplifiers the whole set can be worked from two "B" batteries. The plate connection of U. V. 200 should then be tapped at 16 to 22½ volts, and the full voltage of the two batteries applied to the amplifier, U. V. 201.


Standard Vacuum Tube Socket

Standard Grid Leak

Intervalve Transformer

ACCESSORIES

The RADIO CORPORATION has in process of manufacture a number of ACCESSORIES pertaining to the practical use of Vacuum Tubes. These include special "A" battery potentiometers, filament rheostats, new forms of vacuum tube sockets, grid condensers of novel design, and many other devices which for obvious reasons cannot be announced at this time.

High grade workmanship characterizes the accessories. They are built for those who want the best at moderate cost.

New Amplifying Transformers for Radiotrons are in manufacture. These incorporate unusual features of design and give amplification markedly above that obtainable with existing types. We have some surprises in store for Experimenters.

LIST PRICES

RADIOTRON U. V. 200, gas content detector	$5.00
RADIOTRON U. V. 201, Pliotron amplifier	6.50
R. C. STANDARD VACUUM TUBE SOCKET	1.50
R. C. STANDARD GRID LEAKS, 30 values (from ½ to 6 megohms) each mounted	1.25
R. C. GRID LEAK UNIT only	.75
R. C. GRID LEAK MOUNTING	.50
TONE-FREQUENCY INTERVALVE TRANSFORMER	7.50

Watch current Radio magazines and Electrical Merchandise papers for future announcements concerning new developments.

SALES DIVISION—COMMERCIAL DEPARTMENT

RADIO CORPORATION of AMERICA

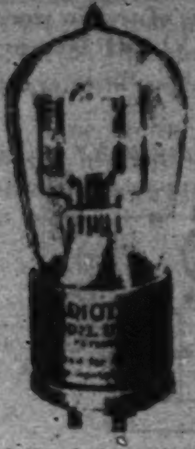
233 Broadway New York City

PURCHASERS OF THE RADIO CORPORATION'S AMATEUR AND EXPERIMENTAL DEVICES ARE REQUESTED TO PLACE THEIR ORDERS THROUGH THEIR LOCAL DEALERS. IN THE EVENT THAT THERE IS NO DEALER IN YOUR LOCALITY, WE WILL PUT YOU IN TOUCH WITH THE NEAREST ONE.

If you have not already seen our special bulletin for *Radiotron U. V. 201*, the Pliotron Amplifier, ask your Dealer for it or write us direct.

ON SALE BY

RADIO CORPORATION of AMERICA



RADIOTRON U. V. 201

A NEW AMPLIFIER OF THE PLIOTRON TYPE
FOR
AMATEUR AND EXPERIMENTAL WIRELESS STATIONS

COMPLEX amplifying circuits for the magnification of radio and tone frequency currents require an amplifying Vacuum Tube of *rigid* operating characteristics. There is an increasing demand among radio experimenters for a vacuum tube amplifier which will magnify the telephone currents in a radio receiving set and which can be shifted from one socket to another in a cascade outfit without loss of signal audibility. Moreover, the amplifier must be free from the tube "noises" accompanying the use of improperly designed vacuum tubes.

RADIOTRON U. V. 201, the second of the new series of Vacuum Tubes designed by the engineers of the Research Laboratory of the General Electric Company for the Radio Corporation, possesses the qualifications outlined above and it should be a part of every experimental radio receiving station. U. V. 201 may be used as a *detector*, or as a *tone frequency* or *radio frequency amplifier*.

In cascade radio frequency amplifying circuits, U. V. 201 can be adjusted to magnify without distortion. The use of such circuits is on the increase in amateur stations, particularly where long distance communication is desired on short wave lengths (200 meters or less).

As a *detector* the best results are secured from *Radiotron U. V. 201* with a *grid condenser* of approximately .0001 mfd. capacity and with a shunt GRID LEAK of ½ to 2 megohms, according to the type of circuit employed.

The normal plate voltage of Radiotron U. V. 201 is 40 volts, although increasing amplifications can be obtained at plate voltages up to 100. At 40 volts on the plate, the amplification constant varies from 6.5 to 8; at 100 volts on the plate, from 8 to 10. The output impedance varies from 15,000 ohms to 25,000 ohms at 40 volts on the plate, and from 10,000 to 15,000 with 100 volts on the plate.

The normal *filament current* for RADIOTRON U. V. 201 is approximately 1 ampere. The filament is designed for connection to the terminals of a 6-volt storage battery with a standard filament rheostat in series.

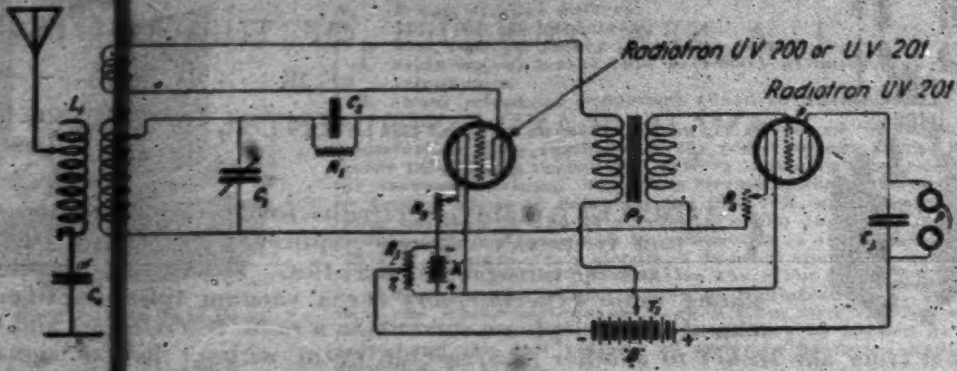
To obtain maximum amplification with U. V. 201 means should be supplied for placing negative potentials on the grid, although good amplification may be secured without any special provision for such potentials. The requisite negative grid potential for the use of U. V. 201 in *amplification circuits* can be secured by connecting a standard "C" battery of two or three volts in the grid circuit, shunted by a 200 to 400 ohm potentiometer, or by placing a 2 ohm resistance in series with the negative terminal of the filament and connecting the "low" potential" terminal of the tuner secondary to include this resistance in the grid circuit. The latter method usually provides the requisite grid potential results, but the proper value for maximum amplification is generally best found by trial and experiment, with a variable source of e.m.f. supplied locally.

IMPORTANT FACTS CONCERNING RADIOTRON U. V. 201

The Radio Corporation's gas content detector and amplifier tube, RADIOTRON U. V. 200, is in itself an excellent tone frequency amplifier, but it does not give the "power" amplifications obtainable from the Corporation's SPECIAL AMPLIFIER TUBE RADIOTRON U. V. 201. Thus, for devices requiring a considerable amount of energy for their operation, such as loud speaking telephones, Radiotron U. V. 201 should be used rather than RADIOTRON U. V. 200.

RADIOTRON U. V. 201 is, of course, applicable to all types of radio receiving circuits now in use among amateurs. Certain circuits in which U. V. 201 is especially desirable are depicted in Figures 1, 2, 3 and 4.

Fig. 1



DETECTOR AND ONE-STAGE AMPLIFIER CIRCUIT

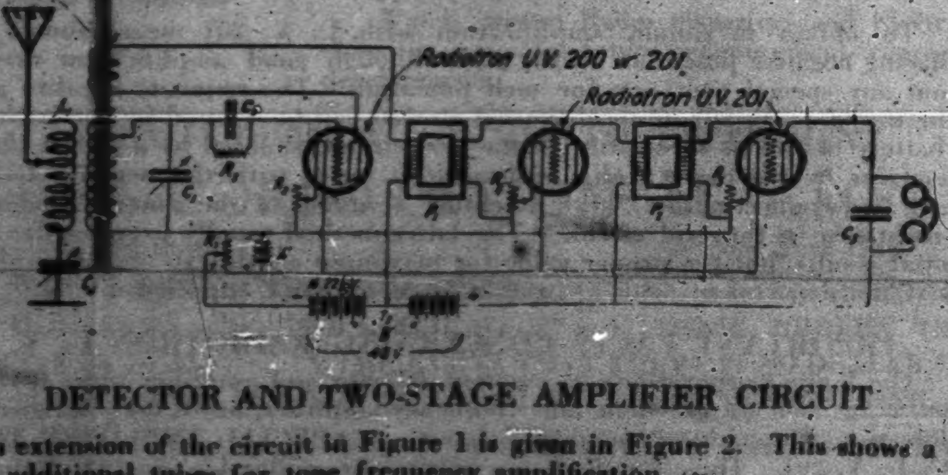
Figure 1 represents a detector and one stage amplifier circuit in which *one U. V. 200* or *one U. V. 201* tube is used for *detection* and one U. V. 201 as a *tone frequency amplifier.* Many experimenters prefer U. V. 200 as the detector, as it gives somewhat greater sensitiveness than U. V. 201 when used for the same purpose, but U. V. 200 requires a closer adjustment of the filament current and plate voltage than U. V. 201 for maximum signal audibility.

An explanation of the notations on the diagram follows:

-1, primary coil of tuning transformer.
-2, secondary coil-tuning transformer.
-3, tickler coil for regenerative amplification.
-1, secondary variable condenser.
-2, grid condenser (.00025 mfd. for U. V. 200 and .0001 mfd. for U. V. 201).
-3, telephone condenser (variable preferably).
-4, antenna series condenser.
-1, Radio Corporation's standard grid leak from ½ to 2 megohms).
-2, R-4, filament rheostats (6 to 10 ohms).
-3, Radio Corporation's special "A" battery potentiometer (300 to 200 ohms).
-1, tone frequency amplifying transformer.
P, head telephones.
A, 6-volt storage battery.
B, two standard plate batteries giving 40 volts.
-2, tap on the plate battery for applying from 16 to 22½ volts on the plate circuit for U. V. 200, if used.

NOTE:—If RADIOTRON U. V. 201 is used as the detector, the tap T-2 should be set to impress the full voltage of the plate battery on the plate circuit of the detector tube. For the use of U. V. 200 as a detector, the tap T-2 should be set at approximately 18 volts and the contact on the "A" battery potentiometer set at the position giving the loudest signals. If single cell variations of the plate voltage are obtainable, good results can be obtained without the "A" battery potentiometer. This potentiometer is not necessary when U. V. 200 is used as a detector.

Fig. 2



DETECTOR AND TWO-STAGE AMPLIFIER CIRCUIT

An extension of the circuit in Figure 1 is given in Figure 2. This shows a detector and two additional tubes for tone frequency amplification.

If RADIOTRON U. V. 201 is used throughout the circuit of Figure 2, the plate circuits of all three tubes may be energized at voltages from 40 to 100 volts. If RADIOTRON U. V. 200 is used as the detector, the tap T-2 should be set at approximately 18 volts. The "A" battery potentiometer R-3 may be dispensed with when RADIOTRON U. V. 201 is used as a detector as well as an amplifier, as mentioned above.

Tone frequency amplifying transformers are indicated at P-1 and P-2. Separate filament rheostats are shown for each tube, but if U. V. 201 is used for detection and for amplification, many amateurs will operate the filaments of all tubes through a single filament rheostat of the proper current carrying capacity.

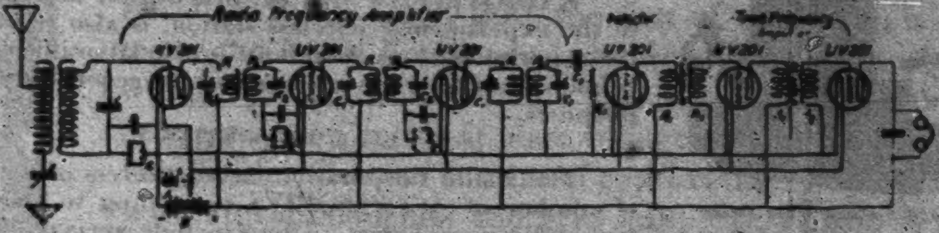


Fig. 3

CIRCUIT FOR RADIO AND TONE FREQUENCY AMPLIFICATION AND DETECTION

Figure 3 indicates a complex detection and amplification circuit in which U. V. 201 will be found desirable. This circuit is made up first of three stages of radio frequency amplification, followed by one detector tube and two stages of tone frequency amplification.

In the radio frequency group, P-1, C-1 constitute the tuned primaries of radio frequency transformers, and P-2, C-2, the tuned secondaries, through which amplified radio frequency currents are impressed upon the grids of successive tubes. Negative grid potentials for distortionless amplification are obtained by the use of a "C" battery of 1 to 10 volts, shunted by a suitable potentiometer. The radio frequency currents in the grid circuit are by-passed around the potentiometer by a shunt condenser.

The grid condenser C-3 in series with the grid of the fourth tube (assisted by the GRID LEAK R-2) rectifies the amplified incoming radio frequency currents, and the output currents of the fourth or detector tube are further amplified by two stages of tone frequency amplification.

RADIOTRON U. V. 201 should be used throughout the circuit of Figure 3.

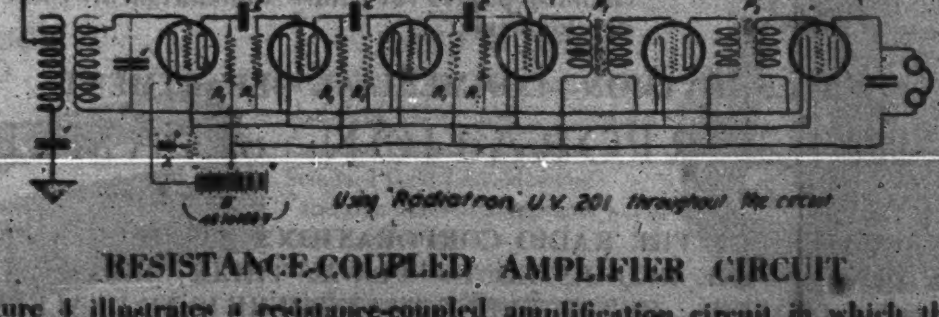

Radio Frequency Amplifier
Detector
Tone Frequency Amplifier
B Battery
Using "Radiotron" U.V. 201 throughout the circuit

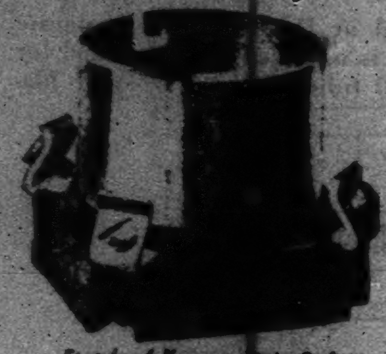
Fig. 4

RESISTANCE-COUPLED AMPLIFIER CIRCUIT

Figure 4 illustrates a resistance-coupled amplification circuit in which there are three stages of radio frequency amplification, the fourth tube being used as a detector. The tone frequency output of the detector tube is in turn amplified by two additional tubes in cascade.

For radio frequency amplification R-1 represents a coupling resistance of ½ megohm (The Radio Corporation's standard grid leak resistance may be used for this purpose.) R-2 indicates a GRID LEAK of approximately 2 megohms. P-1 and P-2 are suitable intervalve tone frequency transformers. A is a 6-volt storage battery of suitable current output, and B a plate battery providing from 40 to 100 volts for the plate. If a single filament rheostat such as R-4 is employed to control the filament current of all the tubes, the precaution should be taken to secure a rheostat of suitable current carrying capacity, allowing approximately 1 ampere for each tube.

There are numerous other circuits in which RADIOTRON U. V. 201 may be used with marked results.



Standard Vacuum Tube Socket

Standard Grid Leak

Intervalve Transformer

NOTE:—The Radio Corporation has in manufacture a new Amplifying Transformer designed specifically to fit the output circuit of RADIOTRON U. V. 201. The transformer incorporates certain novel features of construction and gives an over-all efficiency not yet approached by any other type. It is a device of superior workmanship and it is not to be confounded with intervalve transformers designed only to be sold at a cheap price. Delivery date will be announced later.

RADIOTRON U. V. 201, in addition to its usefulness to the experimental wireless station, is also recommended for experimental investigations in the laboratories of High Schools, Colleges, Universities and for general instructional purposes.

ACCESSORIES

The Radio Corporation has in process of manufacture a number of ACCESSORIES pertaining to the practical use of Vacuum Tubes. These include special "A" battery potentiometers, filament rheostats, new forms of vacuum tube sockets, grid condensers of novel design, and many other devices which for obvious reasons cannot be announced at this time.

High grade workmanship characterizes the accessories. They are built for those who want the best at moderate cost.

New Amplifying Transformers for tubes are in manufacture. These incorporate unusual features of design and give amplifications markedly above those obtained from existing types. We have some surprises in store for Experimenters.

LIST PRICES

RADIOTRON U. V. 201, Pliotron amplifier	$6.50
RADIOTRON U. V. 200, gas content dectector	5.00
R. C. STANDARD VACUUM TUBE SOCKET	1.50
R. C. STANDARD GRID LEAKS, 30 values (from ½ to 6 megohms) each mounted	1.25
R. C. GRID LEAK UNIT only	.75
R. C. GRID LEAK MOUNTING	.50
TONE-FREQUENCY INTERVALVE TRANSFORMER	7.50

Watch current Radio magazines and Electrical Merchandise papers for future announcements concerning new developments.

SALES DIVISION—COMMERCIAL DEPARTMENT

RADIO CORPORATION of AMERICA

233 Broadway New York City

PURCHASERS OF THE RADIO CORPORATION'S AMATEUR AND EXPERIMENTAL DEVICES ARE REQUESTED TO PLACE THEIR ORDERS THROUGH THEIR LOCAL DEALERS. IN THE EVENT THAT THERE IS NO DEALER IN YOUR LOCALITY, WE WILL PUT YOU IN TOUCH WITH THE NEAREST ONE.

If you have not already seen our special bulletin for *Radiotron U. V. 200*, the gas content detector, ask your Dealer for it or write us direct.

ON SALE BY ☞

RADIOTRONS VACUUM TUBES *for* Amateur or Experimental Use

THE facilities and resources of the world-famous RESEARCH LABORATORIES of the General Electric Company have been concentrated upon the development and design of a new series of VACUUM TUBES for Radio Detection and Amplification. The RADIO CORPORATION OF AMERICA now offers to the Wireless Experimenter two distinct types, each adapted to a particular field of usage.

LIST PRICE
$5.00

RADIOTRON U. V. 200, the first of the series, is a Detector and Audio Frequency Amplifier of unusual capabilities, which operates from a single standard plate battery. Best detector action occurs at plate voltages between 18 and 22½ volts, with a filament current of approximately 1 ampere, and with a grid condenser and grid leak. U. V. 200 is particularly adapted to amateur regenerative circuits. A trial in such circuits will be the most convincing.

NOTE—A special "A" or filament battery potentiometer for close adjustment of the plate voltage of U. V. 200 will shortly be placed on the market by the Radio Corporation.

LIST PRICE
$6.50

RADIOTRON U. V. 201, the second of the series, is an unexcelled Amplifier of the PLIOTRON type, which may be used for Detection and for Radio or Audio Frequency Amplification. Normal plate voltage, 40 (two standard "B" batteries). Voltages up to 100 may be used on the plate with increasing amplification. Amplification constant, 6.5 to 8 at 40 volts on the plate, 8 to 10 at 100 volts on the plate.

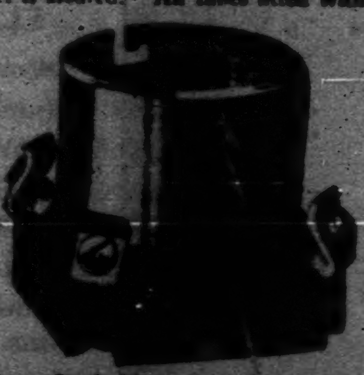
Note to Amateurs, Dealers and Jobbers

Radiotrons are manufactured by ultra-scientific methods laid down by America's foremost tube experts. No guess work—each tube bears the stamp of electrical manufacturers of world-wide reputation. A uniform product is assured. All tubes fitted with standard four-prong base. Filaments operate from 6 volt battery with rheostat.

Standard Grid Leak

LIST PRICES

Radiotron U. V. 200	$5.00
Radiotron U. V. 201	6.50
Standard Vacuum Tube Socket	1.50
Standard Grid Leak, Mounted 100,000 ohms to 6 megohms	1.25
Grid Leak Unit	.75
Grid Leak Mounting	.50
Audio Frequency Transformer	7.50


Standard Vacuum Tube Socket

A complete line of vacuum tube ACCESSORIES are now in manufacture and will shortly be available.

Dealers and Jobbers: We have an especially attractive proposition for you. Write us at once.

The Radio Corporation's tubes are covered by patents dated November 7th, 1905, January 15th, 1907, and February 18th, 1908, as well as by other patents issued and pending. Tubes licensed for amateur and experimental use only. Any other use will constitute an infringement.

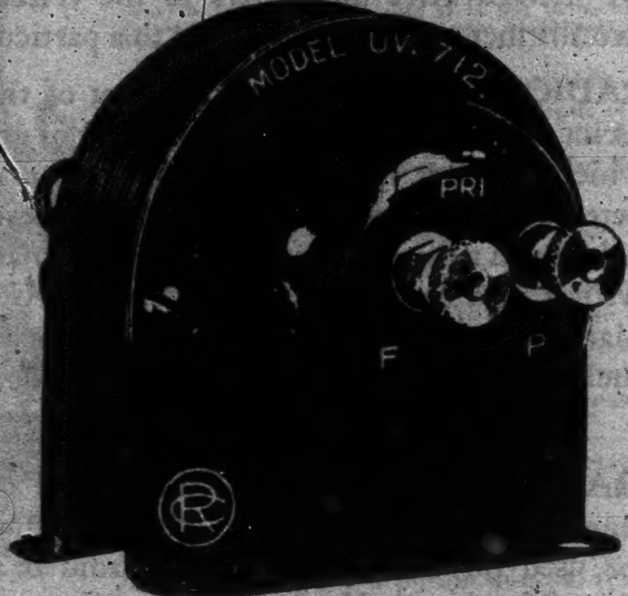
Address all orders and enquiries to
SALES DIVISION
COMMERCIAL DEPARTMENT, Radio Corporation of America

RADIO CORPORATION APPARATUS

For Amateur or Experimental Use Only

INTER-TUBE TONE FREQUENCY AMPLIFYING TRANSFORMERS

MODEL
U. V. 712
Price
$7.00



For Use With
Radiotrons
U. V. 200
and
U. V. 201

PHYSICAL CHARACTERISTICS

1. Totally enclosed.
2. Net weight 1 lb. 4½ oz.
3. Shipping Weight, 1 lb. 7 oz.
4. Overall length, 3⅞"
   Overall height 2¾"
5. Base area for mounting 2"x2¾"

ELECTRICAL CHARACTERISTICS

1. Ratio of Secondary to Primary Turns, 9/1.
2. Useful frequency range, 60/3000 cycles
3. Allowable current on each winding, 10 milliamperes.
4. Test voltage between windings and between core and windings, 300 volts at 60 cycles.
5. Terminal voltage limit of secondary winding, 300 volts.
6. D. C. resistance of windings: Primary 430 ohms, Secondary 5,100 ohms.
7. Impedance at 1000 cycles, (one milliampere);—

Primary with secondary open	19,000	ohms	(approximate)
Primary with secondary shorted	650	"	"
Secondary with primary open	1,100,000	"	"
Secondary with primary shorted	13,000	"	"

Model U. V. 712 is the only transformer designed specifically for use with Radiotrons.

GENERAL

It is a well known fact that for maximum amplification the characteristics of a tone frequency amplifying transformer must be such as to fit the output impedance of the preceding tube in a cascade amplifying set. There is an allowable variation of the constants of the transformer when loaded on the secondary by an amplifying tube, but nevertheless, the maximum signal is obtained from a transformer especially designed to *fit* the output impedances of the tubes with which it is used.

Prior to the introduction of the Radio Corporation's amplifying transformer, Model U. V. 712, amateur experimenters were compelled to employ intervalve transformers of various characteristics, none of which were designed specifically for the Radio Corporation's detector tube, Radiotron U. V. 200, and the amplifier tube, Radiotron U. V. 201. Transformer U. V. 712 not only has been designed to fit these vacuum tubes but special care has been taken to reduce the transformer losses to the lowest possible minimum.

The accompanying illustration shows the new amplifying transformer, Model U. V. 712, which in recent tests has proved most conclusively that it is superior to any on the market today. Transformer Model U. V. 712 has been designed and manufactured strictly on a quality basis. It is not to be compared with other types in which efficiency has been sacrificed to obtain compactness or to reduce manufacturing costs.

BRIEF OPERATING INSTRUCTIONS

In general a tone-frequency amplifier transformer should occupy the same position in the output circuit of a vacuum tube as the receiving telephone. The terminals P and F of transformer Model U. V. 712 may be connected to the binding posts which ordinarily are connected to the telephone receiver. The secondary terminals should connect to the grid and filament of the following tube of a multi-stage amplifier. Such a circuit using two stages of tone-frequency amplification is shown in Fig. 1. This circuit makes use of the detecting qualities of Radiotron U. V. 200 and the amplifying qualities of Radiotron U. V. 201.

In many receiving circuits, it is of advantage to connect a variable condenser from the plate of the detector tube to the negative side of filament, as shown by the dotted line at C_1. It is also frequently advisable to ground the point shown by the dotted lines at GND in order to obtain complete stability and eliminate inductive noises, although it is possible that noisy operation may be caused by rundown batteries, loose connections and faulty adjustment of the amplifier.

If the Radiotron amplifier U. V. 201 is used in the circuit of Figure 1, a plate potential of from 10 to 100 volts may be used, the resultant amplification increasing with the voltage. Forty volts, however, is sufficient for ordinary purposes. When

RECE

using 100 volts on Radiotron U. V. 201, the plate current is approximately 5 milliamperes and if this voltage is used, the polarity of connection to the telephone receivers should be such as to *increase* the magnetization of the permanent magnets rather than to decrease it. Using Radiotron U. V. 200, the Radio Corporation's [illegible] content bulb, as a detector, the plate voltage should be adjusted to some value between 18 and 22½ volts.

It is highly essential for the amateur to connect the transformer terminals as marked and as shown in Fig. 1. Transformer terminal marked G must always be connected to the grid of the next tube.

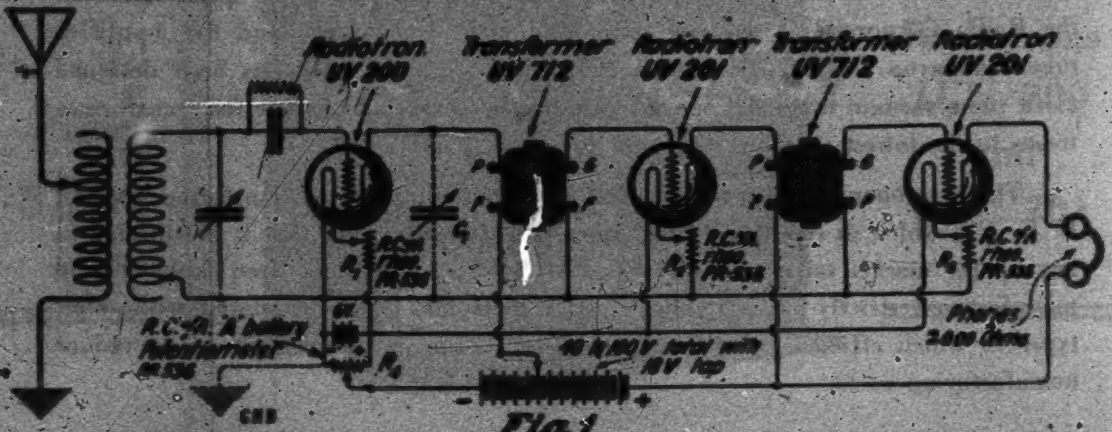


Fig. 1

In all radio amplifier circuits using Model U. V. 712 transformer, the insulation of all apparatus connected to the secondary must be as perfect as possible. Leakage from the grid to the filament of amplifier tubes through the socket, mounting, panel, wiring or otherwise, will decrease the amplification. The lead from terminal G should be kept reasonably short and in cascade amplifier sets adjacent transformers should not be mounted too close; a separation of at least 3 or 4 inches should be allowed.

R_1 R_2 R_3 are the filament control rheostats, P. R. 535, and R_4 is the special "A" battery potentiometer, P. R. 536, manufactured by the Radio Corporation.

The circuit diagram here given has the secondary F terminal connected to the filament rheostat on the side away from the filament. This puts a bias negative potential on the grid of Radiotron U. V. 201 which will have a value of approximately one volt providing a six-volt battery is used and the filament current is adjusted to the normal value of one ampere. Separate biasing batteries may be used if it is desired to get the absolute maximum of amplification. One or two dry cells may be connected in series with the grid circuit. These cells should be connected near to the low potential terminal of the secondary, that is next to one leg of the filament. The positive terminal of the battery should connect to one leg of the filament and the negative terminal to the tuner secondary.

NOTE: All Radio Corporation products are manufactured by the General Electric Company.

RADIO CORPORATION APPARATUS FOR EXPERIMENTAL USE

Radiotron Vacuum tubes and Accessories are manufactured exclusively for the Radio Corporation of America by the General Electric Company and are sold for amateur and experimental use only.

RADIOTRON U. V. 200, a "gas-content" detector designed specifically for amateur purposes	$5.00
RADIOTRON U. V. 201, an exceptional amplifier of the Pliotron type	$6.50
RADIOTRON U. V. 202, a 5—watt transmitter tube for C. W. transmission	$8.00
RADIOTRON U. V. 203, a 50—watt transmitter tube for C. W. transmission	$30.00
RADIOTRON U. V. 204, a 250—watt transmitter tube for special C. W. experimental work	$110.00
R. C. STANDARD RHEOSTAT, Model P. R. 535, for Radiotrons U. V. 200, U. V. 201, U. V. 202	$3.00
R. C. STANDARD "A" BATTERY POTENTIOMETER, Model P. R. 536, for Receiving circuits	$2.00
R. C. STANDARD RHEOSTAT, Model P. T. 537, for Radiotrons U. V. 203, U. V. 204	$10.00
20—WATT KENOTRON RECTIFIER VALVE—Model U. V. 216	$7.50
150—WATT KENOTRON RECTIFIER VALVE—Model U. V. 217	$26.50
R. C. STANDARD PORCELAIN SOCKET, Model U. R. 542, for Radiotrons U. V. 200, U. V. 201, U. V. 202	$1.00
R. C. STANDARD BAKELITE SOCKET for Radiotrons U. V. 200, U. V. 201 and U. V. 202	$1.50
R. C. SPECIAL BAKELITE SOCKET for Radiotron U. V. 203, the 50 watt transmitter tube	$4.25
R. C. STANDARD PORCELAIN SOCKET, Model U. T. 541, for Radiotron U. V. 203	$2.50
R. C. STANDARD END MOUNTINGS for Radiotron U. V. 204, (Model U. T. 501 for filament end; Model U. T. 502 for plate end.) per pair	$2.00
R. C. INTER-TUBE TONE FREQUENCY AMPLIFYING TRANSFORMER, Model U. V. 712, for use with Radiotrons U. V. 200 and U. V. 201	$7.00
R. C. STANDARD GRID LEAK, MOUNTING AND UNIT	$1.25
R. C. STANDARD GRID LEAK MOUNTING	$0.50
R. C. STANDARD GRID LEAK UNIT (24 values, ½ to 6 megohms)	$0.75
R. C. SPECIAL 5000 OHM, SIZE "M" GRID LEAK with midtap at 3500 ohms for use with 5 watt transmitter tube	$1.10
R. C. SPECIAL 5000 OHM, SIZE "B" GRID LEAK with midtap at 2500 ohms for use with 50 watt transmitter tubes	$1.65

Valuable instructional bulletins on Radiotron Vacuum Tubes and Accessories are now available.

DEALERS WRITE AT ONCE FOR OUR ATTRACTIVE SELLING PROPOSITION

Address all Inquiries and Orders to

Sales Division

Commercial Department

Radio Corporation of America

WORLD WIDE WIRELESS

233 BROADWAY — NEW YORK CITY

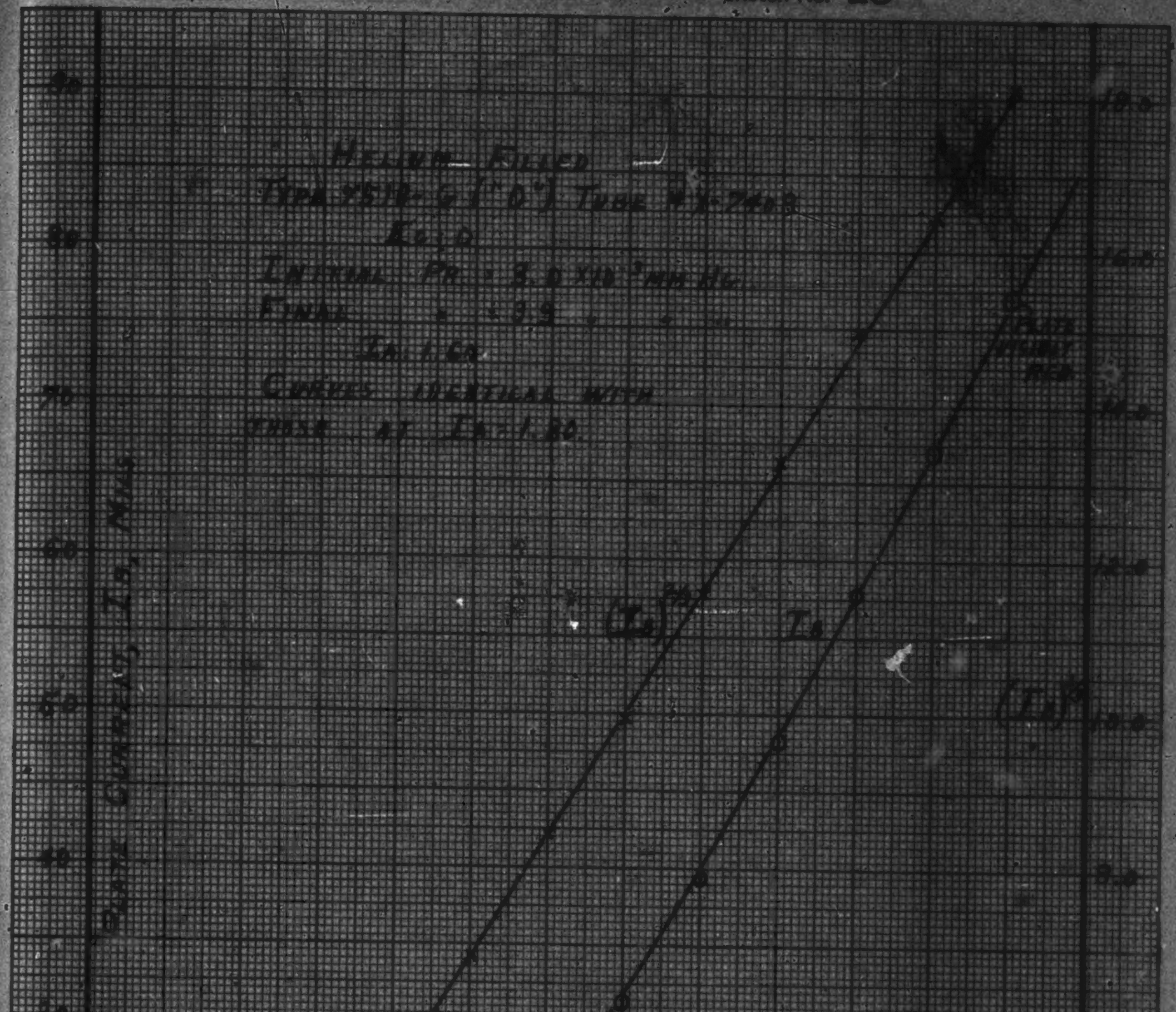
ON SALE BY

DEFENDANT'S EXHIBIT No. 56.
Kelly Helium-Filled Tube.

DEFENDANT'S EXHIBIT No. 57.
Kelly Diagram for Helium-Filled Tube.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES

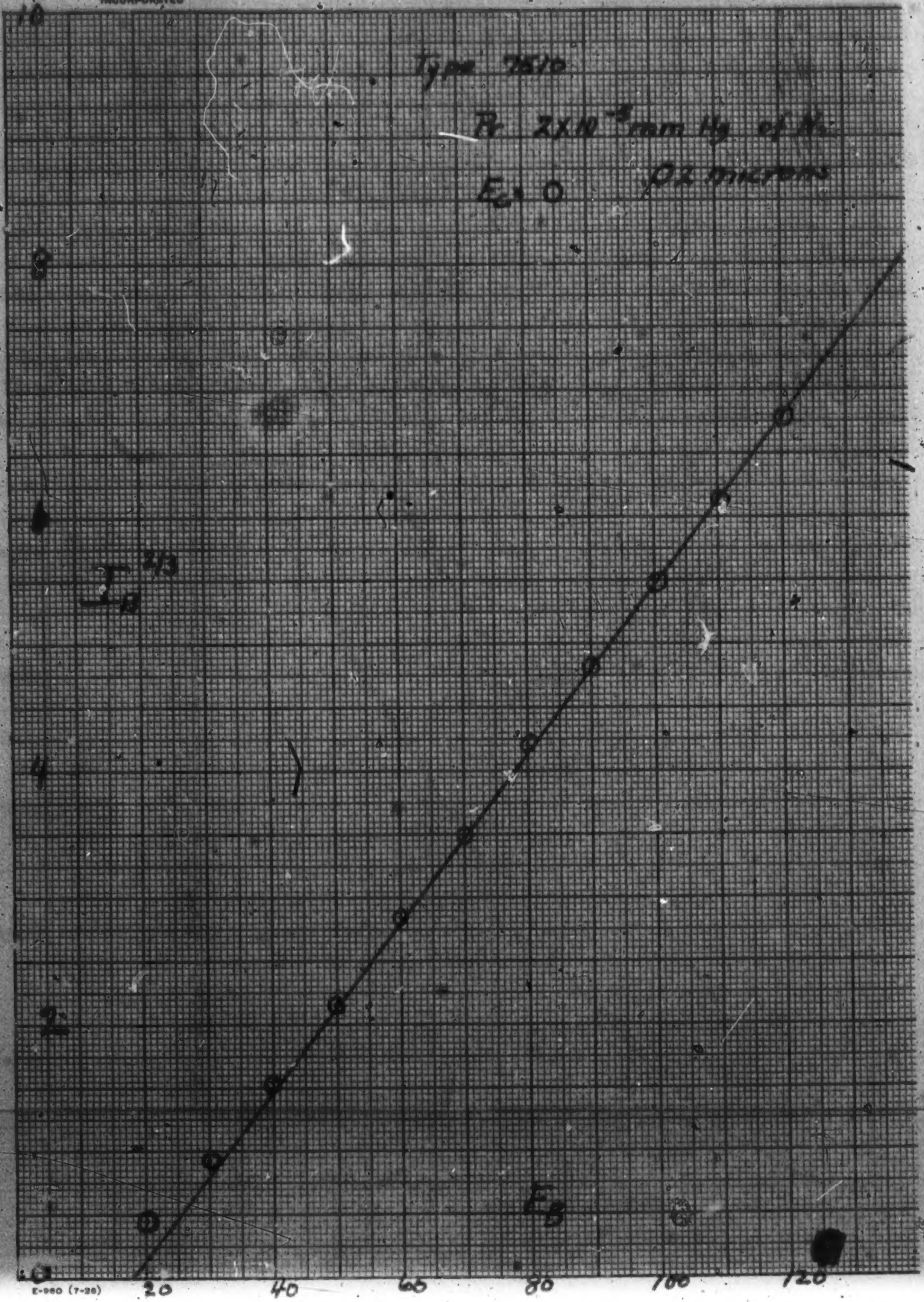


DEFENDANT'S EXHIBIT No. 58.

Kelly Diagram for Nitrogen-Filled Tube at Different Pressures.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES



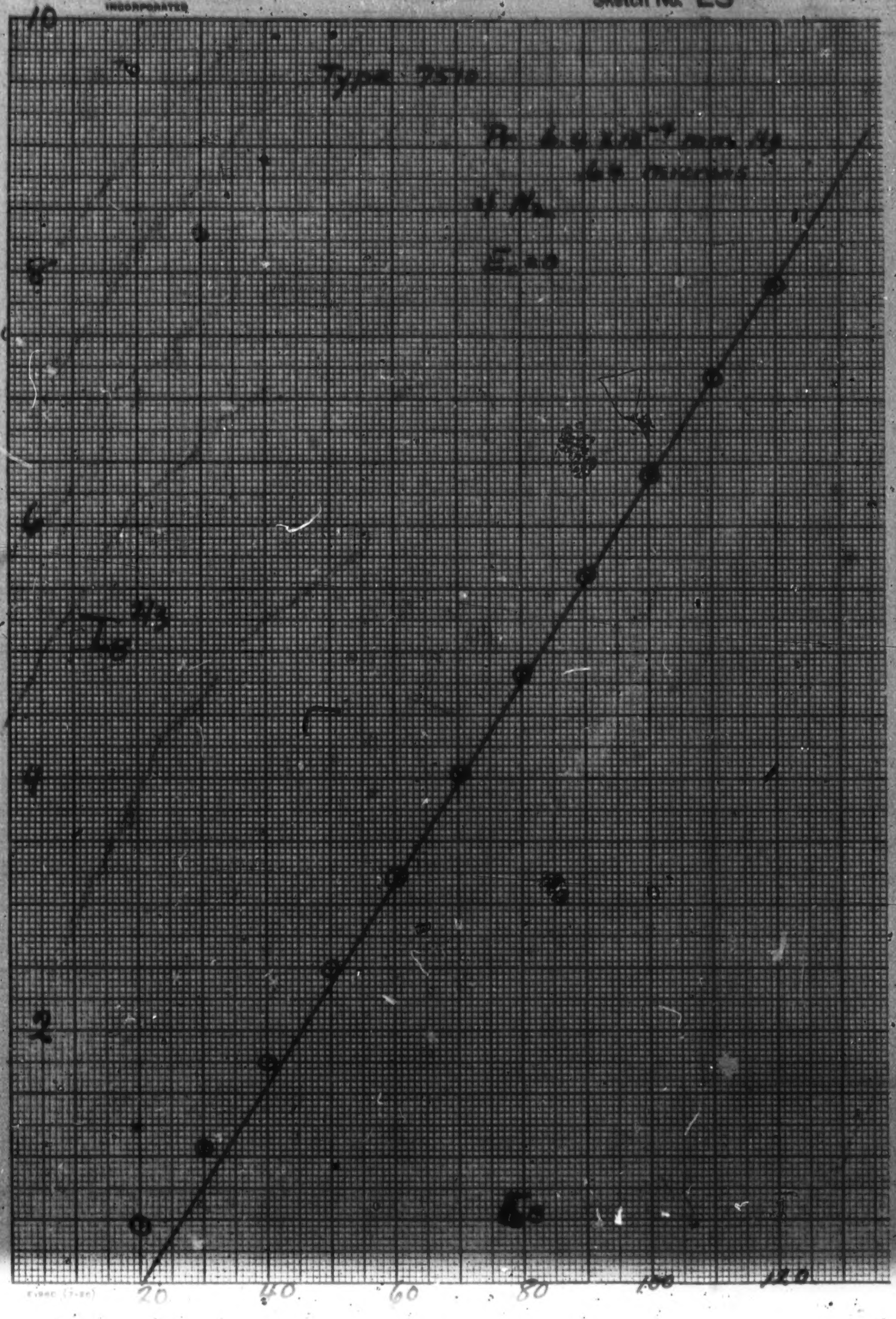
E-960 (7-26)

DEFENDANT'S EXHIBIT No. 58-A.

Kelly Diagram for Nitrogen-Filled Tube at Different Pressures.

Bell Telephone Laboratories
Incorporated

Sketch No. ES

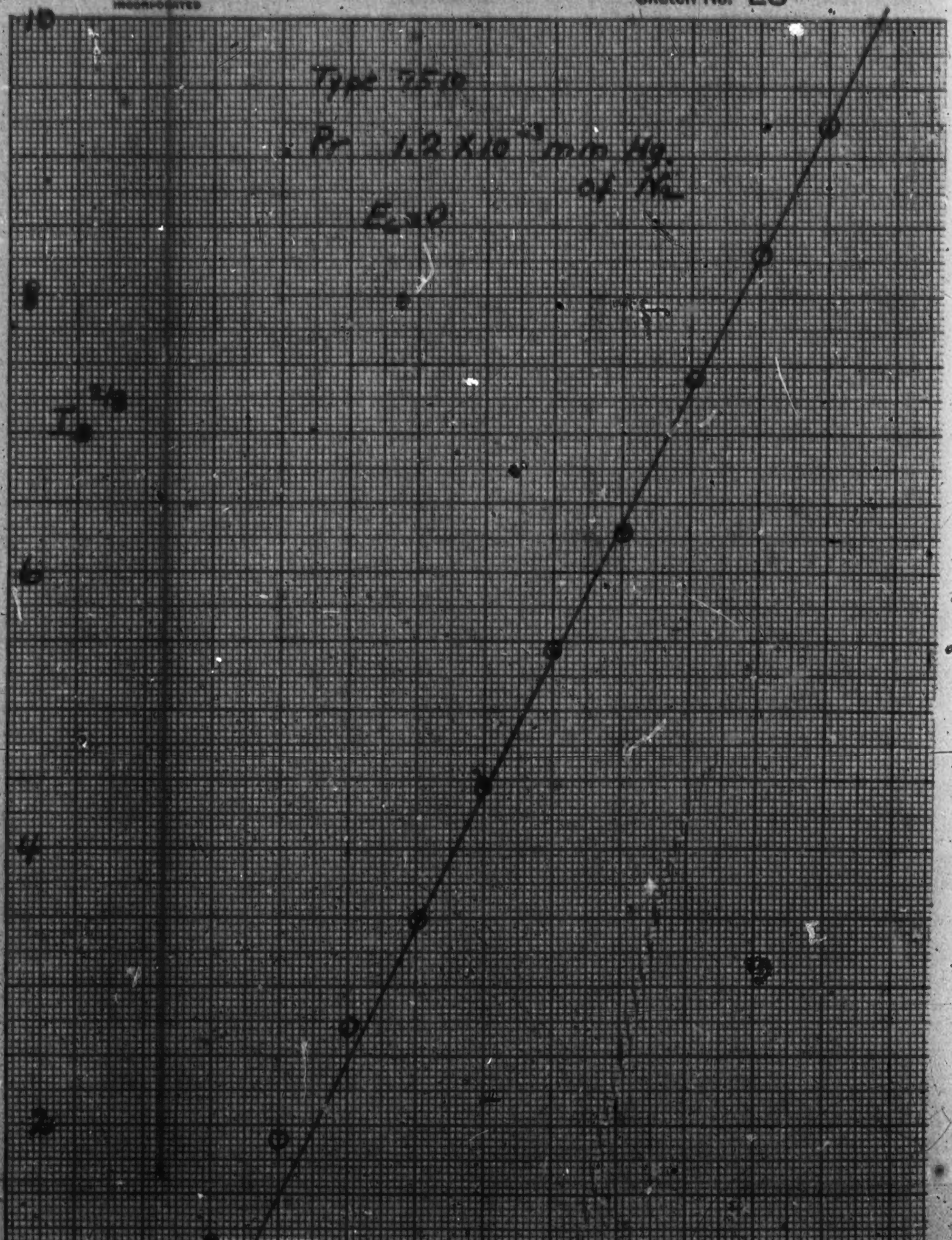


DEFENDANT'S EXHIBIT No. 58-B.

Kelly Diagram for Nitrogen-Filled Tube at Different Pressures.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES



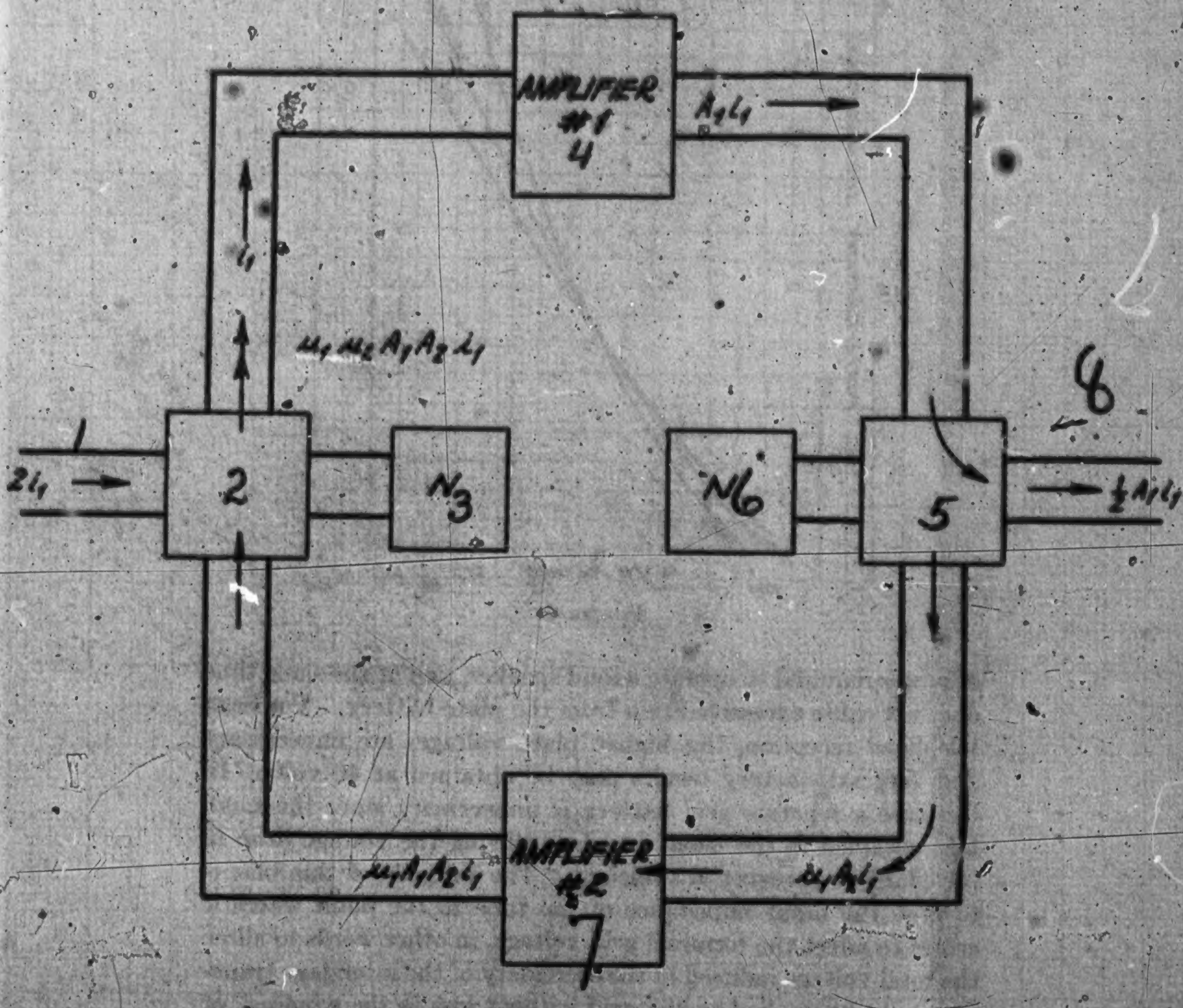
DEFENDANT'S EXHIBIT No. 59.

Kelly Diagram of 2-Way Telephone Repeater.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES

DIAGRAM OF 2-WAY TELEPHONE REPEATER


AMPLIFIER
#1
4
$A_1 i_1$
i_1
$\mu_1 \mu_2 A_1 A_2 i_1$
1
$2i_1$
2
N3
N6
5
8
$\frac{1}{2} A_1 i_1$
$\mu_1 A_1 A_2 i_1$
AMPLIFIER
#2
7
$\mu_1 A_1 i_1$

When $\mu_1 \mu_2 A_1 A_2 i_4 \geqq i_1$
or $\mu_1 \mu_2 A_1 A_2 \geqq 1$ repeater will sing.

DEFENDANT'S EXHIBIT No. 60.

Diagram on Page 591 of Warner Article, Proceedings, Radio Engineers, Showing Curves for Tubes UV-199, 201 and 201-A.

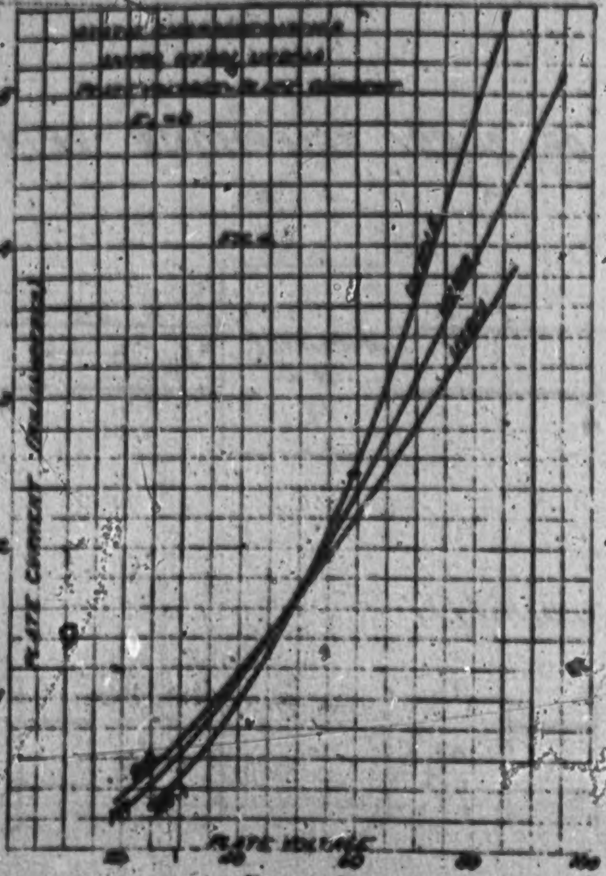


FIGURE 4

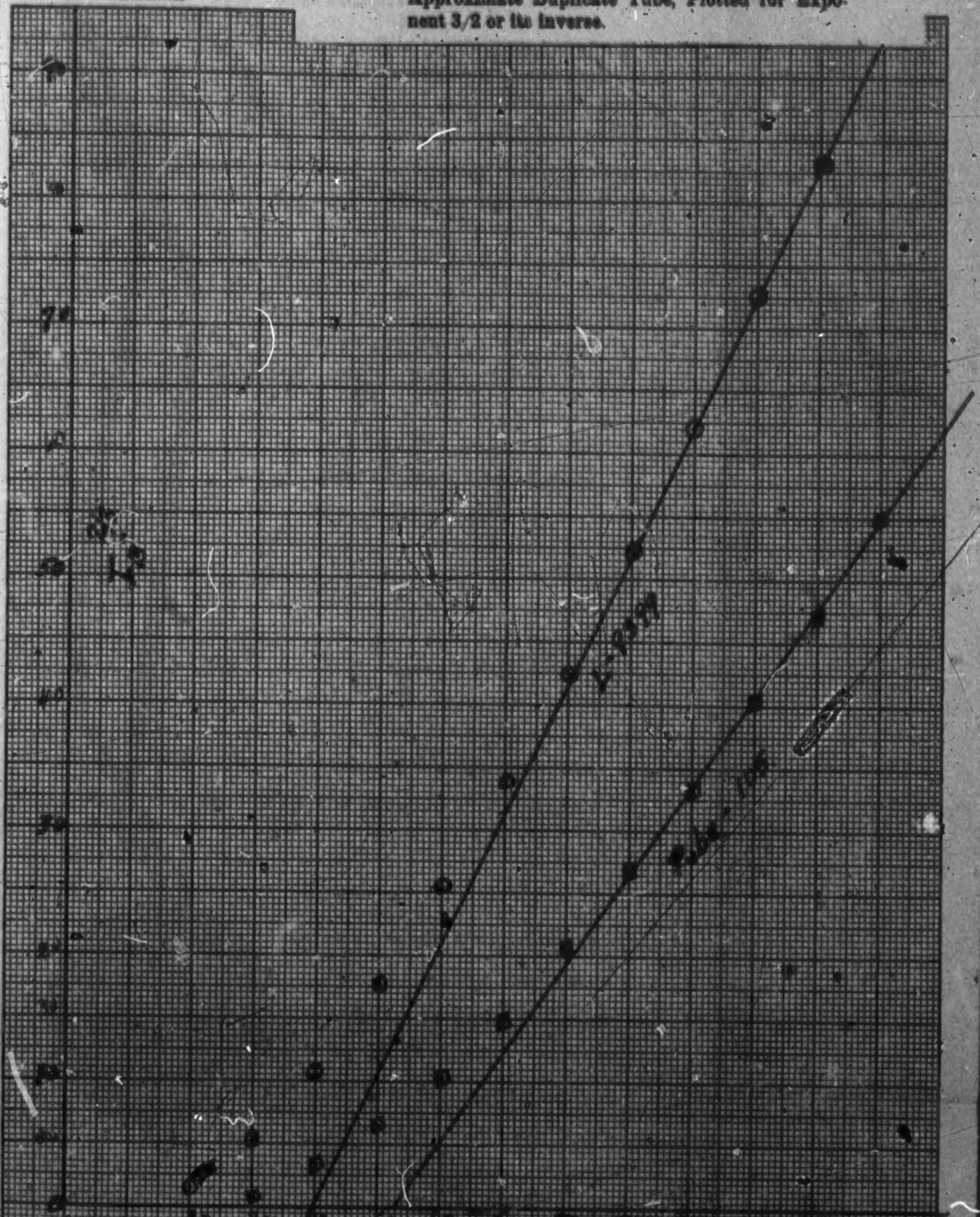
of power required to operate a loud speaker, and at the same time does not cause excessive drain from the plate battery. For head telephone reception, the higher plate voltages are unnecessary and very satisfactory results may be obtained at 40 volts. In this case a separate grid battery is unnecessary since the small bias obtained in the usual way by utilizing the voltage drop in the filament rheostat is sufficient. The purpose of this bias is to raise the input impedance of the tube to the point where it ceases to affect the terminal grid voltage, in other words to allow the total voltage induced in the secondary of the interstage transformer to be applied to the grid without loss in the windings of the transformer. A fraction of a volt is usually sufficient for this purpose.

The small elements and base of the UV-199 result in relatively low internal capacities, approximately 40 percent less than corresponding values for the UV-201. This feature is of particular

DEFENDANT'S EXHIBIT No. 61.

Kelly Diagram for Arnold Priority Exhibit No. 32 and Approximate Duplicate Tube, Plotted for Exponent 3/2 or its inverse.

BELL TELEPHONE LABORATORIES
INCORPORATED



DEFENDANT'S EXHIBIT No. [illegible]

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper and Contents, in the matter of the

Letters Patent of

Irving Langmuir, Assignor to
General Electric Company,

Number 1,558,436. Granted October 20, 1925,

for

Improvement in Electrical Discharge Apparatus and Processes of Producing and Using the Same.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-sixth day of October in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

ATTEST: Willis B. Magruder,
Chief of Division.

Thomas E. Robertson
Commissioner of Patents.

660

Renewal

~~NUMBER (Series of 1900)~~ Series of 1915
~~475,610~~ 84,242

1921

(EX'R'S BOOK) X-V-X
3-7-1 ~~19~~ 2-7

DIV. ~~16~~ 51

PATENT No. 1558436

Name Irving Langmuir
Assor to General Electric Company, a Corp of N. Y.

of Schenectady
County of
State of New York
Invention Electrical Discharge Apparatus and the Process of Preparing and Using the Same

	ORIGINAL		RENEWED	
Petition	Oct. 16	1913	Mar. 14	1926
Affidavit		1913		19
Specification		1913		19
Drawing		1913		19
Photo Copy	Nov. 12	1913		19
First Fee Cash	$15 Oct. 16	1913	$15 Mar. 14	1926
" " Cert.		19		19
Appl. filed complete	Oct. 16	1913	Mar. 14	1926
Examined and Passed for Issue	Feb. 18	1915	WITHDRAWN	
	Wm. A. Kinnan Exr. Div. 16		Wm. A. Kinnan Exr. Div. 7	
Notice of Allowance	Feb. 19	1915	WITHDRAWN	1926
Final Fee Cash		19	$70 Sept. 24	1926
" " Cert.		19		19

Parts of Application Filed

Division of Appl. No.

Patented 19

Attorney Albert G. Davis, c/o Genl. Electric Co., Schenectady, N. Y.

Associate Attorney Alexander D. Lunt
Schenectady

No. of Claims Allowed Print Claim 1 in O. G. (C1250-27)

Title as Allowed Electrical Discharge Apparatus and Process of Preparing ~~the Same~~ and Using the Same

15

Cm

PETITION

To the Honorable Commissioner of Patents:

436

Your petitioner Irving Langmuir,

a citizen of the United States, residing at Schenectady,

in the County of Schenectady State of New York

whose Post Office address is % General Electric Co., Schenectady, N. Y.

prays that Letters Patent may be granted him for the improvement in

ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS

OF PREPARING THE SAME (Docket No. 18,339)

set forth in the accompanying specification.

And he further prays that you will recognize Mr. Albert G. Davis, of Schenectady, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

Irving Langmuir

Cowgen

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN, that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, County of Schenectady, State of New York, have invented certain new and useful improvements in ELECTRICAL DISCHARGE APPARATUS, AND ~~AND~~ PROCESS OF PREPARING and Using THE SAME, of which the following is a specification.

N

The present invention relates to electrical vacuum discharge devices, and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization such as occurring, for example, in the ordinary Roentgen tube.

My present invention comprises improvements in electron-discharge apparatus which make possible ~~having~~ a high load capacity and operation ~~operable~~ with the highest voltages. N The novel features of my invention will be pointed out with greater particularity in the appended claims.

N

Insert N

Figs. 1 and 2 of the accompanying drawings, Fig. 2 being a partial view, illustrate two types of discharge devices embodying my invention; Fig. 3 is a fragmental view showing a cathode construction, and Figs. 4 and 5 are diagrams of electrical systems illustrating certain applications of my electron discharge tubes.

In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas. In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas a Roentgen ~~an [illegible]~~ X-ray tube ceases to operate and as this minimum is approa

N

the resistance of the tube steadily increases.

Sub. N. 2

1/3

Scientific research has shown that under certain very carefully controlled conditions with extremely low current values of the order of magnitude of .01 of one milliampere or lower and at low voltages, well below 200 volts, an electrical discharge current may take place in an evacuated space between a heated cathode and a cooperating anode without causing the residual gas to take part in the conduction of current. This effect also takes place in a vacuum when an unheated electrode consisting of certain materials, for example, potassium, is subjected to the influence of light, particularly, to ultraviolet rays. The discharge current is carried by negative charges called electrons, which pass through the vacuous space under the influence of the impressed voltage. In the presence of gas these electrons, when moving with proper velocity, collide with gas molecules and give rise to gas ionization which completely changes the phenomena accompanying the discharge. The gas molecules are split up into electrons and larger and more slowly moving positive ions. The positive ions take part in the conduction of current, giving at first erratic readings on measuring instruments connected in circuit. As gas ionization continues at higher voltages a blue glow may appear. The cathode under these conditions is ~~electrically~~ disintegrated, technically it is "sputtered", which causes its rapid destruction. The bombardment of the cathode by positive ions also causes heating of the cathode.

N

4 N 3

Insert N. 3

9

N

The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device with three electrodes known as the "Audion". This device has been used as a receiver for radio-telegraphy and depends in its operation upon the rapid change of the

N

discharge current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the Audion begins *to be important* somewhere between 20 and 30 volts. (9) N 5 ~~With the exception of the X-ray tube described in an application, Serial No. 366,540, filed May 2, 1913, no prior~~ *no prior hot cathode* devices are known to me operating with currents as great as about ~~6~~ milliamperes with voltages as high as about 200 volts. N 5 (6) N 6

Insert N 5

Per ...

Insert N 6

In devices made in accordance with my invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas.

The cathode is not heated by the discharge itself. ~~Blue glow~~ *glass fluorescence* and in fact all *readily* visible indications of a discharge are *ordinarily* absent. (8) N 7 ~~Glass fluorescence is absent in a device operating with a pure electron discharge. The discharge current passing through a given space with the cathode at a sufficiently high temperature varies directly with the 3/2 power of the impressed voltage. The discharge is independent of the vacuum, providing the pressure is below the minimum at which gas ionization by collision will take place.~~ As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterised by regularity and reproducibility with given conditions. (82) N 8 ~~and operating independently of positive ionization~~

Insert N 7

Insert N 8

Devices made in accordance with my invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents (7) N 9 with currents thousands of times greater than the ~~minute~~ currents at which the devices ~~above referred~~

Insert N 9

of the prior art ~~to~~ were operable without substantial positive ionization

~~The gas occluded in metals and driven out by the electrons impinging thereon appears to be especially liable to ionization, as it may be observed that gas eliminated from the anode even when below the pressure permissable for residual gas produces the effects accompanying gas ionization. In fact, gas thus eliminated from the anode may not even produce a difference in the reading of a McLeod vacuum gage and yet produce ionization effects.~~

~~The application filed by Wm. D. Coolidge describes a novel electron discharge apparatus adapted particularly for the production of X-rays which is operable with a high energy input during the evacuating process. I have found that deleterious gases may be removed by electron bombardment even at a low temperature, which is advantageous as the device may not be adapted to receive a high energy input, or current of sufficiently high voltage may not be available.~~

Before describing the method of preparing my new type of apparatus, I will describe the structure of the apparatus illustrated by Figs. 1 to 3.

As shown in Fig. 1 the various parts of the apparatus may be mounted in a tube, or envelope ~~globe~~ 1, upon a pedestal 2, similar to the mount used in incandescent lamps. The cathode 3 is centrally located and may consist of a short straight filament not shown in Fig. 1, but indicated by the position of terminals 5, 6, and shown plainly in Fig. 3. The cathode shown in Fig. 2 consists of a thin V-shaped conductor. Either form may be used, the particular form of cathode being ordinarily determined by convenience of construction. Preferably the cathode conductor is held taut by a spring 7 to avoid contact of the cathode conductor with the grid by sagging when the metal is expanded at a high temperature. The filament 3 is mounted between two oppositely disposed supports, 9, 9', in this case constituting a closed loop, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this frame-work is wound a ~~wire~~ discharge-varying conductor 10, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. By means of this grid 10 potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge.

The supporting framework for the cathode and grid is attached to a rod 11, mounted upon the stem of the tube. Adjacent to the cathode and grid is the anode 12 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 13 upon fork-shaped supports 14 and 15, but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 16 and 17. The grid is indicated in Fig. 1 as being attached to leading-in conductors 18 and 19 at opposite ends, although but one terminal is ordinarily necessary.

In some cases it is desirable to use a plate-shaped anode; Fig. 2 illustrates such an arrangement suitable particularly for rectifying alternating current. The tube itself and other extraneous parts have not been shown in Fig. 2, as they are similar to Fig. 1. The cathode construction has already been referred to and the anodes 20 and 21 also preferably consist of tungsten and may be connected electrically with each other. Current connections are made by conductors 22, 23, the supports 24, 25 being merely indicated. 15

Insert N 10 WH

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to ~~the melting point of tungsten.~~ brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. ~~In fact, the~~ The heating may take place in a suitable vacuum furnace, the temperature preferably being ~~close to the melting point of tungsten, or whatever refractory metal constitutes the anodes.~~ raised to 1800°C or even higher

I.L. WHH

I.L. WH Insert N 11

Subst N 12

~~However, heat alone will not remove all the gas liberated by the electron discharge, but this gas is driven out even at ordinary temperatures by the discharge itself. The discharge appears to affect especially the surface of the metal. Heating is a valuable aid in bringing gases from the interior of the metal body into the sphere of action of the discharge but may be omitted when the devices are not heated during normal operation.~~

The bombardment is carried out when the evacuation

Expunge

The bombardment is carried out when the evacuation has proceeded to a high degree by applying a potential between the cathode 3 and the anode 12, Fig. 1, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionization, and as already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon. The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50,000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating voltage. In the case of a plate-shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes. ~~In the case of a device in which the anode normally operates at low temperature bombardment without heating may suffice.~~ After the metal has been freed from occluded gas, reabsorption of gas will not readily take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated with less ~~without further~~ electron bombardment of the anode or anodes.

The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionization by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow, disintegration of the cathode, and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the per-~~[illegible]~~missible pressure is higher than when the cathode and anode are at some distance. It is also true that when the anode has been carefully freed from gas, residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated.

Electron discharge apparatus thus provided with a gas-free pretreated anode or anodes, may be constructed to handle currents at a very high voltage by proper mechanical design of the parts subjected to static strains, suitable proportioning of the parts and so forth as described, for example, in my ~~copending~~ application Serial No. 775,604 filed ~~concurrently~~ herewith ✓ N. 3

Insert N. 3

The ~~[illegible]~~ asymmetric conductivity existing between the heated and unheated electrodes of a device of the character described may be utilized for various technical purposes. Reference has already been made to the rectification of current. As shown in Fig. 4 an electron discharge tube may be used for detecting electromagnetic waves in radio-telegraphy. As shown in this Fig. 4 the grid g and heated cathode c of an electron discharge tube 24 are connected respectively to the terminals of the secondary of a transformer 27, the primary of which is included in the antenna circuit 28. The antenna is grounded through a condenser 29 in the usual manner. The cathode *c* is heated by a local source of energy, as battery *B*. A battery 30 in the grid circuit 31 has its negative terminal connected to the grid *g*. A condenser 32 shunts the secondary of the loosely coupled transformer 27. The inductance of the transformer and the capacity of the condenser are adjusted to make the receiving circuit resonant to the frequency of the oscillations to be received. The oscillations set up by the incoming signals are superimposed upon the negative grid potential and causes a variation of current transmitted between cathode *c* and anode *a* by a local source of energy such as a battery 33 included in the local or plate circuit 34,35, of the discharge tube. This circuit is connected to an ordinary telephone receiver 36, preferably shunted by means of a condenser 37, whereby the signals are detected.

Fig. 3 illustrates how an electron discharge tube may be used in a system for producing alternating current from direct current. The anode *a* and cathode *c* are connected respectively to conductors 38,39, one of which includes a local source of energy, such as a battery 40. The terminals of these conductors are connected to an inductive coil 41. The cathode and grid *g* are also connected respectively by conductors 39 and 42 to a second inductive coil 43 which may be in a variable inductive relation to the coil 41. As soon as a flow of current starts in the plate circuit 38,39, current is induced in the coil 43 of the grid circuit 39,42. When by reason of this current the grid becomes negatively electrified, the flow of current in the plate circuit is reduced, and as the plate current decreases the grid electrification changes to positive, which again allows the current in the plate circuit to increase. These changes take place with a frequency depending on the

electrical characteristics of the circuits. Across the grid circuit 39, 42, of the discharge tube, in some cases is connected a condenser 44, the capacity of which may be varied to control the frequency of the oscillations set up by the system. The oscillations may be transformed to higher or lower voltage by a transformer coil 45 to the terminals of which are connected transmitting conductors 46, 47. The system shown in Fig. 5 is described and claimed in a copending application, Serial No. 772 997. filed October 29, 1913.

Insert N 14

26

What I claim as new and desire to secure by Letters Patent of the United States, is:-

263

10 ~~1. The process of removing ionizable gas from an anode of an electron discharge device which consists in subjecting said anode to prolonged electron bombardment with an energy input below the value necessary to appreciably heat said anode and coincidentally removing the gas thereby disengaged.~~

Insert L

~~2. The method of preparing an electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence and a cooperating anode, which consists in removing gas as completely as possible from the envelope, impressing between the cathode while at incandescence and the anode a voltage adapted to produce an electron discharge but insufficient to produce appreciable gas ionization as indicated by a blue glow, continuing evacuation, progressively raising the discharge voltage as gas is removed, and sealing said envelope when the normal operating voltage has been exceeded.~~

11 ~~3. The method of preparing an electron discharge device comprising a gas-tight envelope, an electron emitting cathode and a cooperating tungsten anode while maintaining said anode substantially unheated which consists in evacuating said envelope to a high degree, impressing between cathode and anode a voltage adapted to produce an electron discharge but insufficient to produce a blue glow at the cathode, and step by step raising the discharge voltage and continuing the evacuation until the anode will no longer disengage ionizable gas at the normal working current and voltage of the device.~~

Per Fr

~~4. The method of preparing an electrical discharge device comprising an envelope, an electron-emitting cathode, and a coöperating anode which consists in carrying on the evacuation of said envelope while impressing between cathode and anode a voltage sufficiently high to produce an electron discharge but insufficient to produce a blue glow in the envelope, thereby removing gas from the anode, continuing the removal of gas and progressively raising the discharge voltage as gas is eliminated from the anode until the normal operating voltage of the device has been exceeded.~~

Per E

~~5. The process of removing gas from an anode of an electron discharge apparatus ionizable at the operating voltage of said device without heating said anode to incandescence which consists in subjecting said anode to an electron-discharge at an impressed voltage in excess of the operating voltage and coincidentally removing the gas driven out thereby.~~

IN WITNESS WHEREOF, I have hereunto set my hand this 15th day of October 1913.

WITNESSES:

Benjamin B. Hull

W. G. Gartner

Irving Langmuir

674

AFFIDAVIT

STATE OF New York } ss:
COUNTY OF Schenectady }

Irving Langmuir, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Schenectady in the County of Schenectady, State of New York, and that he verily believes himself to be the original, first, and sole inventor of the improvements in

ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME

described and claimed in the annexed specification; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any foreign country on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any foreign country."

Irving Langmuir

Sworn to and subscribed before me this 15th day of October, 1913

Benjamin B. Hull
Notary Public

Sent Appln as filed 3900

[illegible]

PAPER NO. 2 –

C/16

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 795,610, : ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME
Filed Oct. 16, 1913, :
Room No. ------- :

Honorable Commissioner of Patents,

Sir:-

It is requested that the following amendment be made in the above-entitled application:

Page 3, line 8, cancel "prior" and substitute - hot cathode -

Line 21, after "temperature" insert - so as to give a sufficient electron emission for a given voltage -

Add the following claims:

Sub. 15

~~6.~~ An electrical discharge device comprising a gas-tight envelope, an electron-emitting cathode, and a discharge ~~varying~~ conductor ~~and~~ a cooperating anode, the space in said envelope being evacuated to below the pressure at which deleterious gas ionization takes place constituting a device ~~in which~~ ~~as evidenced by the fact that~~ the current passed over ~~the normal~~ a working range of voltage and temperature varies with the 3/2 power of the impressed voltage for voltages above a minimum voltage depending on the electron emission of the cathode.

a'

~~7.~~ An electrical discharge device comprising a gas-tight envelope, an incandescent cathode, and a gas-free anode, the space in said envelope being evacuated to below the pressure at which deleterious gas ionization takes place, ~~as evidenced by the fact that~~ the current passed by said device

~~over the normal~~ a working range of voltage and temperature ~~varies with the 3/2 power of the impressed voltage for voltages above a minimum voltage depending on the temperature of the cathode.~~

11. ~~6.~~ A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and ~~and~~ an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the ~~impressed~~ voltage is as high as 200 volts. N¹⁶ follows

A. F₁ E ~~Insert~~ C

15 ~~8~~ ~~7.~~ ~~An electrical discharge ~~amplifying~~ device, comprising a gas-tight envelope, an electron-emitting cathode, an anode deprived of ionizable gas and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterised by the fact that the current varies with the 3/2 power of the impressed voltage when the electron emission of the cathode is above a minimum value for a given voltage.~~

E

Sub N¹⁶

--------o--------

The above claims are added to more completely protect applicant's invention.

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Schenectady, N. Y.,

December 26, 1913.

WCC/GAL

677

Div. 16 Room 109
Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

P.N.

Paper No. 3
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON Feb. 28, 1914.

Mr. Albert G. Davis.
C/o General Electric Co.,
Schenectady, New York.

Please find below a communication from the EXAMINER in charge of the application of

Irving Langmuir, S. No. 795,610, filed Oct. 16, 1913, Electrical Discharge Apparatus and the Process of Preparing the Same.

Thomas Ewing
Commissioner of Patents.

The amendment filed Dec. 29, 1913, has been made of record.

The following references are made of record:

Friedrich, 1,083,677, Jan. 7, 1914, 250 - 35,
Fleming, 803,684, Nov. 7, 1905, 250 - 8,
German patent 254,588 of 1912, (one sheet), 250 - 271
German patent 259,246 of 1913, (one sheet), 250 275, and the book
"Notes on X-Lights", by Rollins, Boston, 1903.

The reference to application No. 767,549, in lines 7 and 8, page 3, should be canceled unless filed by applicant. Line 10, page 4, should be corrected accordingly.

Page 8, lines 22 and 23, complete data for the application referred to should be supplied. Also see lines 8 and 9, page 10, in this connection.

Note 97, page 105, of Rollins describes a method of evacuating a tube in which a moderate current is sent through the tube for some hours during the pumping process. Claim 1 is rejected as being fully anticipated by the disclosure in Rollins.

Claims 2, 3, 4 and 5 are rejected on the same reference and ground as claim 1. The moderate voltage described in Rollins is "adapted to" perform the function recited in these claims. The reference also states that as the vacuum increases it is necessary to increase the operating potential, and this increase could be carried on to any point desired. Increasing the voltage to a point in excess of the operating voltage is a mere carrying forward of the method disclosed in Rollins. Furthermore, there is nothing to indicate that the process was not continued to such a point in Rollins. This method is also mentioned in the resume of known methods of evacuation found in Freidrich, cited.

Claims 6, 7 and 9 are rejected on Freidrich, cited, attention being particularly directed to lines 121 to 125, page 3 of this reference. It is noted that the matter beginning "as evidenced by" in no way distinguishes from the reference. If applicant's device is an improvement over the reference he should define the difference by structural limitations.

Claim 8 is rejected on either of the German patents cited, each of which discloses an incandescent cathode. There is no invention in reducing any discharge device having an incandescent cathode, as these German patents, for example, to any degree of vacuum in view of the Rollins note and Freidrich, cited.

The claims are each rejected.

Wm A Kinnan
Examiner, Division XVI.

IN THE UNITED STATES PATENT OFFICE.

In re application of :
Irving Langmuir, :
Serial No. 795,610, :
Filed Oct. 16, 1913. :
Div.16, Room 109. :

ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.

Schenectady, N.Y., April 30, 1914.

Hon. Commissioner of Patents,

Sir:-

In response to the Official Action of February 28, 1914, please amend as follows:

Page 3, lines 6 to 8, cancel "With the exception of the X-ray tube described in an application, Serial No. 766,549, filed May 8, 1912, no"

Line 8, before "not" insert - No prior -

Page 4, cancel the sentence beginning with "The application" line 10 and ending with "process" line 13.

Page 8, line 22, after "Serial No." insert - 795,609 -

Line 23, after "filed" insert - concurrently herewith -

Page 10, line 9, after "Serial No." insert - 797,987 -

Same line, after "filed" insert - October 29, 1913 -

Pen

Claim 1, line 5, after "anode" insert - ~~and an impressed voltage below the value at which considerable gas ionization occurs~~ -

Claim 6, lines 5 and 6, cancel "as evidenced by the fact that" and insert - constituting a device, in which -

Line 6, after "current" insert - passed -

Claim 7, line 5, after "place" insert a comma

Same line, cancel "as evidenced by the fact that"

Same line, after "current" insert - passes by said device -

Line 7, cancel "varies" and substitute- varying-

Add the following claim:

Pec N

Pec C

~~13.~~ 16 The process of removing ionisable gas from a conductive body which consists in producing an electron discharge substantially independent of gas ionization, directing said discharge upon said body in a vacuum, while maintaining the energy of said discharge below the value necessary to heat said body to incandescence and coincidentally removing the gas thereby ~~thereby~~ disengaged from said body.-

Pec D

Insert C³

Applicant's attorney fully realizes the difficulty the Examiner finds in distinguishing the boundaries of the present invention over disclosures of a highly exhausted X-ray tube. Such differences are present, however, in a very real sense. No matter what language may be used in describing the vacuum of devices such as shown in the Friedrich patent 1,083,677, the fact remains that the operation of theFriedrich tube must depend on the presence of gas. In fact, Friedrich says, (page1, lines 50 to 56) "The regulating device should not be on the outside of the tube but should be located within some near the center so that the gases absorbed by the regulator may be easily liberated for the purpose of forming a passage for the current" and again (page 4, lines 31 to 33) referring to the heating of the asbestos, that "gases are expelled for the purpose of establishing a passage for the high potential current between the electrodes". A vacuum discharge not provided with some such electron-emitting means, as an incandescent cathode, must depend on gas ionization to furnish current carriers. Hence, clean-up of gas by operating the device can never reduce the pressure below the point at which gas is ionizable and for this reason an X-ray tube of the nature described by Friedrich or Rollins cannot be used to practice the method claimed. For this reason the gas can not be removed from the anode by bombardment to the degree necessary for a device which operates without positive ionisation.

The difference between the pure electron discharge and a discharge in which positive ions are produced have already been discussed in the specification. A further discussion may not be out of order. The Examiner either does not consider the limitation "electron-emitting cathode" a structural limitation or considers the vacuum to differ merely in degree over German patents Nos. 254,588 and 259,246. These patents to be sure do disclose a hot cathode but evidently describe devices depending on gases for their operation (lines 42-44, patent 254,588 and lines 58-59, patent 259,246), in fact, the subject matter of the invention is the provision of a source of vapor for the operation of the device.

The Fleming patent 803,684, discloses a rectifying detector for wireless telegraphy, which contains a heated carbon filament. Fleming merely states that "a very high vacuum should be obtained" but gives little information as to the characteristics of the device. Applicant claims not merely to have improved on the Fleming device, or any other hot cathode device, but to have produced a fundamentally new device which operates independently of gas conduction or ionization. Prior investigators were unable to enter this region of low vacuum, in which the permissable pressures are one-thousandth as great as Rollins "millionth of an atmosphere". (Notes on X-Lights cited by the Office).

Nine years before the filing of his patent application Fleming published a paper in the Phil. Mag. Vol. 42 (1896), page 52, describing his hot cathode device. He gives a great many current readings. These readings never exceed a few milli-amperes, usually less than one milli-ampere. The voltages used necessarily were very low - from .34 to 26.8 volts. As pointed out in the specification, gas ionization at low voltage is very slight. Inasmuch as it was impossible to free carbon from gases under the conditions open to Fleming, higher voltages would inevitably produce blue glow and the various other phenomena accompanying positive ionization.

Richardson, a prominent worker in the field, describes in the Proc. Roy. Soc. LXXI. pp.415-418 (1903) widely variable results. He reports an electron emission-

For platinum from 10^{-10} to 10^{-3} amperes per sq.cm. of surface.
For carbon from 10^{-8} to 2 amperes per sq.cm. of surface.
For sodium from 10^{-11} to 2×10^{-2} amperes per sq.cm of surface.

Wilson Phil. Trans. (1904) p.243, or Proc.Roy.Soc. Vol. 72, p.272, found that pretreating the platinum the current was reduced to $\frac{1}{250,000}$ of the values assigned by Richardson. With carbon he confirms the results of Richardson. He concludes that "It is probable that a pure platinum wire heated in a perfect vacuum would not discharge any electricity at all, either positive or negative, to an extent appreciable on a galvanometer." Wilson's results lead him to believe that the "negative leak" as he called it, "is due to the presence of hydrogen or possibly some other substance in the wire".

Pring and Parker later [Phil. Mag. 23,192,(1912)] showed that by careful purification of the carbon and an improvement of the vacuum very much lower readings were produced. With a potential difference of 330 volts, at a cathode temperature of 1800° they got the low value of 1.5 x 10^{-9} (.000,000,001,5 amperes) per sq. cm. of cathode surface, and at 2000° with a voltage of 200, a current of 4 x 10^{-7} amperes. They observed that the current "increased only very slightly with the temperature above 1800°". From these figures they conclude.

> "These results clearly show that the large currents hitherto obtained with heated carbon cannot be ascribed to the emission of electrons from carbon itself, but they are probably due to some reaction at high temperatures between the carbon or contained impurities and the surrounding gases which involves the emission of electrons."

Pring and Parker conclude that the large currents found by Richardson must be erroneous as by the formula announced by him the emission at 2000° should be about 100,000 amperes instead of 4 x 10^{-7} as found by them.

The large currents noted by Pring and Parker when the vacuum is poor suggest a possible explanation of the results obtained by Richardson and Wilson using a carbon cathode. In this connection a later paper by Pring ~~and [illegible]~~ is of interest (Proc. Roy. Soc. 89,344) In the conclusion the following statements occur:-

> "It has been shown that a still further large reduction in the ion[illegible]ought about by eliminating further the absorbed gases from the carbon."

> "It is clear from these results that thermal ionisation ordinarily observed with carbon is to be attributed to chemical reaction between the carbon and the surrounding gas."

Applicant preferstungsten to carbon because tungstencan be rendered gas-free so much more completely.

Fredenhagen in Physik Zeit January 1, 1914, P. 19 and January 15, 1914, P. 65, discusses the probable effect of chemical reactions on the electron emission of hot bodies or illuminated metal surfaces and expresses the theory that the effect is due in part at least to residual gases in the evacuated space and evidently believes that were the gases all removed the effect would cease.

Greinacher (Verh. d. D. phys. Ges. 15,797, 1913) and Pohl & Pringsheim (Phys. Zeit 14,1112, 1913) express a similar view.

In a recent paper (Fortschritte auf den Gebiet der Roentgen strahlen Bd 18, 256) Lilienfeld & Rosenthal describe an X-ray tube which they believe to have so completely evacuated that the conduction of current had become independent of the degree of vacuum (i.e. of the residual gas). They say: "And it is to be expected that finally a vacuum will be reached in which the transport of electricity will be entirely carried by negative electrons emitted from the incandescent cathode. As an actual fact the reverse takes place as established above." A consideration of the operation of the device makes it clear that the authors were mistaken as to the degree of vacuum. One of the tests of positive ionization is conductivity in the space as evidenced by current flowing between two unheated electrodes in the space when a voltage is impressed on them. This is exactly what takes place in the Lilienfeld tube and, in fact, the operation of the tube depends on just this conductivity. This article is referred to as showing that applicant in obtaining a higher vacuum has not merely carried forward the work of others, and that his invention is not merely distinguished by a matter of degree, a higher vacuum. When as disclosed the vacuum is pushed beyond .1 of a micron (.0001 m.m.) and the electrodes are freed from gas a new region is entered, and a fundamentally new device is produced. Applied voltage now may be made almost any value without causing positive ionization and the current follows a 3/2 power law which is not true of any of the devices discussed.

The method claims clearly distinguish over the Rollins and Friedrich references by reciting that the impressed voltage is not high enough to produce considerable gas ionization. As the Rollins and Friedrich devices depend upon gas ionization, they necessarily can never enter the region of pressure of interest in this case. Rollins refers to pressures of a millionth of an atmosphere. This is a dense atmosphere for a pure electron discharge, in fact the pressure is a thousand times too great.

Two of the article claims have also been amended. The "structural limitations" in this case are to be found in the differences of vacuum. The difficulty of stating the limits of vacuum in figures is due to the fact that the most deleterious gas is to be found in the metal parts, particularly the anode, and also to the fact the highest permissable pressure varies with the geometric relations of the tube, the size of, and distances between the electrodes. the impressed voltage, and so forth. The electrical characteristics, however. offer a sure and easy test, whether positive gas ionization is present or not. Applicant's new devices are being used daily to carry kilowatts, not microwatts, and with an impressed potential of many thousands of volts exceeding in many cases a hundred thousand volts.

Were these enormous differences in electrical load capacity nothing more than a matter of degree they would be worthy of the most careful consideration as to patentability, as the Courts have held that changes and improvements of degree are not necessarily devoid of patentability, but it is hoped it has been made clear that they involve a fundamental discovery and a fundamentally new device.

An allowance is solicited.

Respectfully submitted,

Albert G. Davis

ATTORNEY FOR LANGMUIR.

WC/MR.

Div. 16 Room 109
Address only
"Commissioner of Patents,
Washington, D. C.,"
not any official by name.

S-389

F.H.

Paper No. 5
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON June 15, 1914.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER *in charge of the application of*

Irving Langmuir, S. No. 795,610, filed Oct. 16, 1913,
Electrical Discharge Apparatus and the Process of
Preparing the Same.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed May 1, 1914.

Upon reconsideration claims 1 to 5, inclusive, are allowed.

Claims 6 to 9 are rejected as failing to distinguish from the French patent to Lilienfeld, 449,305 of 1913, 250 - 36, (3 sheets, see sheet 1, Figures 1 to 4), which discloses an X-ray tube evacuated to below the pressure at which gas ionization takes place. An auxiliary anode and heated cathode is employed to render the tube conductive to the electrons passing between the main electrodes. The introductory clause "an electrical amplifying device" in claim 9 is insufficient to distinguish from this reference.

Claim 10 is allowable in substance but the word "substantially" or the equivalent thereof should be inserted in line 3 before "independent", and in line 7 "thereby" should be corrected.

Wm A Kinnan
Examiner, Division XVI.

ASG

oath

IN THE UNITED STATES PATENT OFFICE

IN RE Application of :
IRVING LANGMUIR, :
Serial No. 795,610. : ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME
Filed Oct. 16, 1913. :
Div. 16, Room 109. :

Hon. Commissioner of Patents,

S i r:

A supplemental oath is herewith submitted in the above-entitled application covering the apparatus. When apparatus claims 6 to 9 inclusive were filed the necessity for a supplemental oath was overlooked, particularly as the title covers both the apparatus and the process of preparing the same.

It is requested that this oath be made of record in the application.

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Schenectady, N. Y.,

/MD July 8, 1914.

JUN 1914

SUPPLEMENTAL OATH

State of New York :
: ss:
County of Schenectady, :

IRVING LANGMUIR, whose application for letters patent for an improvement in ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME, Serial No. 795,810, was filed in the United States Patent Office on or about the 16th day of October, 1913, being duly sworn, deposes and says that the apparatus as disclosed in the specification and claimed in claims 6 to 9 inclusive, filed by amendment dated December 26, 1913, constitutes a part of his invention, was invented before he filed his original application, above identified, for such invention, was not known or used before his invention, was not patented or described in a printed publication in any country more than two years before his application, was not patented in a foreign country on an application filed more than twelve months before his application, was not in public use or on sale in this country for more than two years before the date of his application, and has not been abandoned.

Irving Langmuir

Sworn to and subscribed before me this 24th day of June 1914.

Benjamin B. Hull
Notary Public.

WGC/GAL

690

Div. 16. Room 109
Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

2-380

W.J.T.

Paper No. 7.
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Aug. 27, 1914.

U. S. PATENT OFFICE
AUG 27 1914
MAILED

Albert G. Davis,
c/o Gen. Electric Co.,
Schenectady, N.Y.

Please find below a communication from the EXAMINER in charge of the application of
Irving Langmuir, Sr.No.795,610, filed Oct. 16, 1913, for
Electrical Discharge Apparatus and the Process of Preparing, etc.

Thomas Ewing
Commissioner of Patents.

The supplemental oath filed July 14, 1914, has been entered. The case awaits response to Office action of June 15, 1914.

Sidney F. Smith,
Actg Examiner, Div. 16.

ASG

8 C

MAIL ROOM
DEC 5 1914
U.S. PATENT OFFICE

IN THE UNITED STATES PATENT OFFICE.

PATENT OFFICE
DEC 21 1914

In re application of :
Irving Langmuir, :
Serial No. 795,610, : **ELECTRICAL DISCHARGE APPARATUS**
Filed Oct. 16, 1913, : **AND THE PROCESS OF PREPARING**
Div. No. 16 Room 109 : **THE SAME.**

C

Hon. Commissioner of Patents,

S i r :-

In response to Office Letter of August 27th, 1914, please amend this case as follows:

✓ ✓ Page 3, line 22, after "voltage" change the period to a comma and add:

C¹

Per W

~~above a minimum voltage depending on the characteristics of each particular device. In other words, the 3/2 power law holds strictly only above a certain minimum voltage for a given device, usually a few volts. If the electron emission is not sufficient, as, for example, when with the cathode at a given temperature the voltage exceeds the value at which all the electrons emitted are utilized, then a further increase in voltage produces substantially no change in current.-~~

~~Insert C¹~~

✓ Line 27, after "conditions." add:

C²

Per W

~~-No current will pass from a cathode which is not a primary source of electrons in a vacuum characteristic of my invention. Even though a discharge is passing between an electron emitting cathode and an anode in a vacuum too low to cause appreciable positive ionization, no discharge will take~~

2.

place between unheated electrodes in the same space by reason of the presence of said electron discharge. -

Insert K2

Claim 6, line 6, cancel "the normal" and substitute - a -

Claim 7, line 5, cancel "the normal" and substitute - a -

Claim 8, line 4, before "current" insert - passage of -

Claim 10, line 3, before "independent" insert - substantially -

Add the following claims:

C³ on E
..I..E
Sub N 17

17 ~~12.~~ ~~11.~~ An electrical discharge ~~amplifying~~ device comprising a gas-tight envelope, an electron-emitting cathode ~~and~~ ~~and a discharge varying conductor~~ a cooperating anode, the space in said envelope being evacuated to such low pressure that no appreciable positive ionization occurs when the impressed voltage is as high as about 200 volts and the current over a working range of voltage varies with the 3/2 power of the impressed voltage.

..E

Per N
Per D..E
I..D3
~~Ins..E~~
+

18 ~~11~~ ~~12.~~ An electrical discharge device comprising a gas-tight evacuated envelope, a cathode adapted to be heated to incandescence, ~~and~~ an anode, the space in said envelope being evacuated to such a degree that the current flowing between said electrodes ~~of~~ varies ~~varying~~ with the 3/2 power of the impressed voltage over a working range of current values exceeding about five milliamperes.

Sub N 18
..E

19 ~~10~~ ~~12~~ ~~13.~~ An electrical discharge ~~amplifying~~ device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, ~~and~~ an anode from which no ionizable gas can be evolved at-

operating voltages exceeding about 200 volts, the space in said envelope being evacuated at a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

20/X ~~13.~~ ~~14.~~ A device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, ~~and~~ an anode from which no ionizable gas can be evolved at operating voltages exceeding about 200 volts and at operating ~~and a discharge carrying part~~ currents exceeding about five milliamperes, the space in said envelope being evacuated at a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that at currents above about five milliamperes and at voltages exceeding about 200 volts, evidences of positive ionization are substantially absent and the current over a working range varies with the 3/2 power of the voltage.

21 ~~12.~~ ~~14.~~ ~~15.~~ An electrical discharge device comprising a sealed envelope, an incandescent cathode, ~~and~~ a tungsten anode deprived of disengageable ~~and a discharge~~ ionizable gas by electron bombardment, positive the space in said envelope being evacuated to such low pressure that current flow produces substantially no perceptible phenomena of positive ionization when the impressed voltage is as high as 200 volts.

22 ~~13.~~ ~~15.~~ ~~16.~~ An electron discharge apparatus comprising an envelope, an electron-emitting cathode, ~~and cooperating electrodes~~

One

J..E

//

..E

J..E

//

..E

Rei E

~~Insert E~~

~~at least one of~~ an anode which has been deprived of gas disengagable by electron bombardment, ~~said envelope being evacuated to such low~~ pressure that conduction of current can take place in the evacuated space independently of gas ionization.

-----oOo-------

Insert F'

The French patent to Lilienfeld # 449,305 of 1913 discloses as the Examiner himself states "an X-ray tube in which an auxiliary anode and heated cathode is employed to render the tube (space) conductive", but it does not follow that this patent discloses a device evacuated below a pressure at which ionization takes place. On the contrary the very fact that the space between the main electrodes is rendered conductive by an auxiliary discharge is clear proof of the fact that gas ionization does occur.

The old type of X-ray tube containing merely two unheated electrodes is self-exciting as the electrons emanating from the cathode collide with gas molecules in their passage to the anode, thereby ionizing these gas molecules. The positive ions in their turn are attracted to the cathode and produce more electrons in their impact upon the cathode surface. The structure disclosed in the Lilienfeld patent is evidently intended to avoid the instability and irregularity of this means for causing ionization by lowering the gas pressure and providing a heated Wehnelt cathode as a source of electrons so as to make the gas ionization positive and controllable. The gas pressure may well be so low that current will not pass between unheated electrodes in the ordinary manner, but the operation of the tube must be dependent upon the presence of gas as otherwise there is no vehicle for the passage of energy through the tube between the main unheated electrodes. This fact is perceived by Dr. Lilienfeld as may be learned from some of his publications. For example, in an article by Dr. Lilienfeld and Dr. Rosenthal in "Fortschritte auf den Gebiet der Röntgenstrahlen" Bd.18,1912, p-256, it is stated, in describing an X-ray tube which is evidently of the same character as the tube described in the French patent, that the device operates by virtue of the presence of positive ions. The authors state that the conductivity momentarily changes with the primary current and that "negative electrons which serve for the transport of current are accompanied by an equivalent number of positive charges." The following language is a translation of a part of the article, which is in the German language.

> "If one now removes to a great degree the matter out of the space by using the best available means for producing a vacuum, excluding ground joints, cements and mercury vapors, it is to be expected that the number of positive charges and therefore also the special density of those charges will become progressively less. And it is to be expected that finally a vacuum will be reached in which the transport of electricity will be entirely carried by negative electrons emitted from the incandescent cathode. As an actual fact the reverse takes place as established above."

In another part of the same article the authors also state that the "current path in a high vacuum traversed by positive and negative charges is evidently a conductor of electricity, and also refer to the fact that the secondary cathode sends out "cathode rays which appear to be liberated from its surface by bombardment with the carriers of positive charges upon its surface in the extremely high vacuum." This article refers to certain prior publications which also set forth this same theory with reference to certain experimental devices other than X-ray tubes. In a later article in this same publication, Volume 22, 1913, there may be found another paper by Dr. Rosenthal on the Lilienfeld Roentgen tube in which the author explains the operation of the tube, assuming that positive ionization occurs. In the interest of brevity only a few statements will be quoted from this paper.

> "For the non-physicist, the operation of the tube may perhaps be theoretically explained as follows: By means of the conductivity-discharge, proceeding from the incandescent electrode, positively as well as negatively charged particles are produced in the chamber of the tube which originally is impermeable to the Roentgen discharge. The positive particles are attracted by the negatively charged concave surface of the Roentgen cathode, rebound upon it, and thereby give the impulse which is necessary for the release of the bundle thrown upon the anti-cathode, and there create the Roentgen rays. As the conductivity current increases, there will be more positive particles in the tube, it will be easier for the cathode surface to produce a sufficient number of them -- consequently the voltage at the surface of the cathode will be smaller, the cathode ray here released will be slower, and the Roentgen ray will be weaker -- and conversely."

Some of the language of the various articles indicates that the author attempted to harmonize his theory of the independence of the tube from the degree of vacuum and his views as to the role of positive ions by assuming a "positive ion" produced in some way independently of gas. In this view, if it is indeed to be ascribed to him, he is alone in the scientific world. However, the claims do not depend on any such theory for their patentability. The "evidences of positive ionization" are observable, well-known phenomena, no matter what we may think about the origin of the positive ion.

The present applicant has found that the gas contained in the electrodes, particularly the anode, is much more subject to ionization and for the operation of a tube operating by pure electron discharge gas in the electrodes is more deleterious than gas residues in the evacuated space. The specification sets forth at length how this ionizable gas may be removed from the anode. That the electrodes in this tube contain gas is indicated by the following statement in the Rosenthal article. "In case of overload gas is somewhat given off by the electrodes so that the tube temporarily loses its hardness."

The article claims are limited not merely by a statement that the highest obtainable vacuum is produced as after all the highest degree of vacuum obtainable varies with the character of the means used for producing the vacuum. The article claims are limited by reference to the electrical characteristics of the present device or by statements to the effect that positive ionization is absent during the operation of the device. The specification contains descriptive matter as to what is meant by positive ionization so that this term is a short statement of a collection of phenomena which are now recognized by scientists as indicating gas ionization. A recent book on X-rays by G. W. C. Kaye (Longmans, Green & Co.) is respectfully called to the Examiner's attention as giving in a clear, readable form some information regarding this type of device which while otherwise available is more or less scattered through the literature.

At a personal interview with the Examiner it was suggested that the description of the electrical characteristics of the device be somewhat amplified. This has been done.

Reconsideration of the claims as amended and favorable consideration of certain new claims added to more completely protect the invention is respectfully solicited.

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Schenectady, N.Y.
Dec. 17, 1914.
WCC.DAL.

698

Div. 16 Room 109

Address only
"The Commissioner of Patents
Washington, D. C."
and not any official by name.

[illegible]
U. S.

Paper No. 9
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Jan. 12, 1915.

Mr. A. G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the **EXAMINER** *in charge of this application of*

I. Langmuir, S. No. 795,610, filed Oct. 16, 1913, Electrical Discharge Apparatus and the Process of Preparing the Same.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Dec. 19, 1914.

Claim 10, line 7, the word "thereby" is misspelled.

Upon careful reconsideration all the claims in this case are deemed allowable with the exception of claim 12. This claim does not distinguish from the French patent 449,306, for example, which shows an evacuated envelope, a cathode adapted to be heated to incandescence and an anode. It is a well settled rule that a claim must distinguish from a reference in some way other than by a mere statement of function. It is suggested, therefore, that claim 12 be amended by inserting after the comma in line 4 the words said envelope being evacuated to such a degree that.

The case is otherwise in condition for immediate allowance.

Wm A Kinnan
Examiner, Division XVI.

OKS

699

PAPER 10

A D

UNITED STATES PATENT OFFICE.

In re Application of :
IRVING LANGMUIR, :
Serial No. 795,610, : ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME
Filed Oct. 16, 1913, :
Div. 16, Room 109. :

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of January 12, 1915, please amend the above-entitled application as follows:-

Claim 10, line 7, correct the spelling of "thereby".

Claim 12, line 4, after "anode," insert - the space in said envelope being evacuated to such a degree that -

Line 5, cancel "varying" and substitute - varies -

REMARKS

The corrections suggested have been made and it is hoped the application may now be found allowable.

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

/GAL

700

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

K.O'D.-8-181

Serial No. 795,610.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE

WASHINGTON Feb. 19 1915.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE

Irving Langmuir, Assor.

Sir: Your APPLICATION for a patent for an IMPROVEMENT in Electrical Discharge Apparatus and the Process of Preparing the Same,
filed Oct. 16, 1913, has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

Thomas Ewing
Commissioner of Patents.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

Albert G. Davis,
% General Electric Co.,
Schenectady, N. Y.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON, D. C.

Mar. 31, 1915

Petition:

Application of I. Langmuir

Serial No. 795610

Invention:

This petition is referred to the Examiner in charge of Division 16 *for recommendation.*

In case he recommends adversely he will state his reasons therefor and furnish a copy thereof to petitioner.

Thomas Ewing
Commissioner of Patents.

702

1/11

E

(R. 78)

UNITED STATES PATENT OFFICE.

In re Application of :
IRVING LANGMUIR, :
Serial No. 795,610, :
Filed Oct. 16, 1913, :
Div. 16, Room 109 :

ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME

PATENT OFFICE
MAR 31

AMENDMENT UNDER RULE 78

E

Honorable Commissioner of Patents,

Sir:-

It is respectfully requested that the Examiner be authorized to enter the following amendment in the above-entitled application without withdrawing the application from issue.

✓ ✓ Page 5, line 5, cancel "wire" and substitute discharge-varying conductor -

✓ Page 6, line 5, after the sentence ending with "indicated" add the following: ~~- The location of the cathode between two anode plates which are electrically connected to each other is not part of my invention but is described and claimed in an application filed by Saul Dushman, Serial No. 9533,~~ Feb. 24, 1915

E¹ N Efe Amdt.

✓ ✓ Claim ~~5~~ 6, line 3, cancel "and"

Same line, after "anode," insert

✓ ✓ - and a discharge-varying conductor -

✓ ✓ Claim 8, line 3, cancel "and"

✓ Same line, after "anode," insert

~~- and means for electrostatically varying a discharge between said electrodes -~~

E² S

✓ Claim 9, line 1, cancel "amplifying" and substitute - discharge -

Claim 11, line 1, cancel "amplifying" and substitute - discharge -

Line 3, cancel "and"

Same line, after "anode," insert - and a discharge-varying conductor, the -

Line 8, before "range" cancel "a" and substitute - working -

Claim 12, line 4, cancel "and"

Same line, after "anode," insert

Per F E^3

~~- and a discharge-varying conductor, -~~

Claim 13, line 1, cancel "amplifying" and substitute - discharge -

Line 3, cancel "and"

Line 5, after "volts," insert ~~- and means for varying the discharge current independently both of the voltage applied to said electrodes and the temperature of the cathode.~~

E^4

F

Claim 14, line 3, cancel "and"

Line 6, after "milliamperes" insert - and a discharge-varying grid -

Claim 15, line 3, cancel "and"

Line 4, after "gas" insert - disengageable -

Same line, before "the" insert - and a discharge varying conductor -

Claim 16, line 2, cancel "and cooperating electrodes" and insert - an electron-emitting cathode, -

Line 3, cancel "at least one of" and substitute - an anode -

Line 4, after "bombardment," insert

E^5

Per F

~~- and means for varying a discharge between said electrodes independently both of a voltage applied thereto and the electron emission of the cathode -~~

Cancel claim 5 and renumber the remaining ✓ claims.

REMARKS:

The claims have been amended by the inclusion of certain limitations and one method claim has been canceled as unnecessary, and for this reason it is believed that a reexamination of this application will not be necessitated.

Respectfully submitted,

Albert G Davis

Attorney for Langmuir.

Schenectady, N. Y.
March 26 1915.

WGC/CAL

Whitehead

12

2—254

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON, D. C.

Apr 5—, 1915—

In compliance with the provisions of order No. 1718, dated June 8, 1907, and which reads as follows:

It is hereby ordered that, except by formal amendment duly signed or as hereinafter provided, no corrections, erasures, or interlineations be made in the body or written portions of the specification or of any other paper filed in an application for patent.

Obvious informalities in the wording of the specification may be corrected by the examiner, but said correction must be in the form of an amendment, approved by the Principal Examiner in writing, placed in the file, and made a part of the record. The changes specified in the amendment will be entered by the clerk in the regular way.

It is directed that no other changes be made by any person in any record of this office without the written approval of the Commissioner of Patents.

Attorneys, employees of the Patent Office, and all others will be held to strict accountability for any violation of this order.

The following changes are made in—

Application Serial No. 795,610

of Irving Langmuir.

In the insertion to page 6, line 5, add "Feb. 20, 1915" after the end of the last line.

In line 13 of amendment E, "Claim 5" should be Claim 6

Wack

Examiner, Division 16

706

Serial No. 795610 Paper No. 13
Letter No.

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

EEG

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON

April 8, 1916.

In the matter of the
Application of
Irving Langmuir,
Electrical Discharge
Apparatus and the Process of Preparing the
Same;
Filed Oct. 16, 1913,
Serial No. 795,610.

Amendment.

Sir:

You are hereby informed that the recommendation of the Examiner that the amendment be admitted under the provisions of Rule 78, has been approved by the Assistant Commissioner and the amendment entered.

By direction of the Commissioner;

Very respectfully,

W. F. Woolard

Chief Clerk.

F.

Irving Langmuir,
c/o Albert G. Davis,
Schenectady, N. Y.

707

X 1/4/16

15

RFC'D MAR 14 1916 C.O.U.S. PAT. OFFICE

H

UNITED STATES PATENT OFFICE.

In re Application of :
IRVING LANGMUIR :
Serial No. 795,610 :
Filed October 16, 1913 :
ALLOWED February 19, 1915

ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.

PETITION FOR RENEWAL.

Hon. Commissioner of Patents,

Sir:-

On October 16, 1913, Irving Langmuir filed an application for Letters Patent on improvements in Electrical Discharge Apparatus and the Process of Preparing the Same, which application was allowed February 19, 1915, but the final fee was not paid within the time allowed by law.

As attorney for Langmuir, I now make renewed application for Letters Patent, and pray that the original specification, oath and drawings may be used as a part of this application.

Enclosed is a cheque for fifteen dollars to pay the renewal filing fee.

Respectfully,

Albert G. Davis

ATTORNEY FOR LANGMUIR.

Schenectady, N. Y.,
March 10, 1916.

708

2—673.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON, D.C.

May 1 1916

Petition:

Application of I Langmuir

Serial No. 84745

Invention:

This petition is referred to the Examiner in charge of Division 16 *for recommendation.*

In case he recommends adversely he will state his reasons therefor and furnish a copy thereof to petitioner

Thomas Ewing
Commissioner of Patents.

15

MAIL ROOM
1918
U.S. PATENT OFFICE

+ Oath

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 795,610, : ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME
Filed October 16, 1913, :
Div. 16, Room 109. :

Honorable Commissioner of Patents,

Sir:-

Please amend the above-entitled application as follows:-

Page 3, line 23, after "invention" insert - and operating independently of positive ionization -

Page 4, line 22, cancel "globe" and substitute - envelope -

Page 7, line 1, before "applying" insert - by -

Claim 5, line 4, before "gas" insert - deleterious -

Claim 6, line 4, before "gas" insert - deleterious -

Claim 7, line 2, after "cathode" insert - and -

Line 3, after "anode," cancel "and means for electrically varying a discharge between said electrodes"

Claim 10, line 3, after "anode" cancel "and a discharge varying conductor,"

Claim 11, line 4, after "anode" cancel "and a discharge varying conductor,"

Claim 12, line 5, after "volts," cancel "and means for varying the discharge current independently both of the voltage applied to said electrodes and the temperature of the cathode"

Claim 13, line 6, before "currents" insert - operating; after "milliamperes" cancel "and a discharge-varying grid"

Claim 14, line 4, after "bombardment," cancel "and a discharge varying conductor"

Claim 15, line 4, after "bombardment," cancel "and means for varying a discharge between said electrodes independently both of a voltage applied thereto and the electron emission of the cathode -

Cancel claims 2 and 4, renumber the remaining claims and add the following claims:

F

Sub. H

Inserted

Per N

14. An electrical device comprising an evacuated envelope, electrodes therein, means for producing emission of electrons from one of said electrodes, independently of the operating voltage, said device being freed from gas to such extent that the conduction of ~~current~~ occurs by a substantially pure electron-discharge, operatively independent of positive ionization.

24 ~~15~~. An electrical device comprising an evacuated envelope, electrodes therein, means for producing emission of electrons from one of said electrodes, independently of the operating voltage, said device being freed from gas to such extent that it is operable over a working range of voltage of at least 200 volts, in such manner that the conduction of current by said device occurs by electron discharge and operatively independent of positive ionization.

25 ~~16~~. An electrical discharge device comprising a gas-tight envelope, an incandescent cathode, an anode, and means for independently heating the cathode, the parts of said apparatus and the enclosed space being deprived of gas to such extent that the

device is operable with currents varying with the 3/2 power of the voltage over a range of impressed voltages determined by the cathode temperature, the current at voltages above this range being substantially constant.

26 ~~12~~. An electrical discharge device comprising a sealed envelope, a cathode, means for producing emission of electrons at said cathode independently of the operating voltage, an anode, and discharge-varying means, said device being freed from gas to such extent that the same is operable to transmit current at an impressed voltage at least as high as about 200 volts without appreciable evidences of positive ionization.

19

27 ~~13~~. An electrical discharge device comprising a sealed envelope, an incandescent cathode, an anode and discharge-varying means, the gas residues in said device being so small that with a substantially constant cathode temperature, conduction of current over a range of voltage varies with the 3/2 power of the voltage and above said range is substantially constant, and being operatively independent of positive ionization.

H4

Remarks

The above amendment is made to draw the proper line of division between the present application and that of Coolidge application, Serial No. 766,549. A supplemental oath is herewith submitted.

Allowance is respectfully solicited.

Respectfully submitted,

Albert G. Davis

Schenectady, N.Y.

WGC/GAL March 10 1916.

Attorney for Langmuir.

SUPPLEMENTAL OATH

State of New York :
: ss:
County of Schenectady :

IRVING LANGMUIR, whose application for Letters Patent for an improvement in ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME, Serial No. 795,610 was filed in the United States Patent Office on or about the 16th day of October, 1913, being duly sworn, deposes and says that the apparatus as disclosed in the specification and claimed in claims 1 to 18, inclusive, four of which, namely, 14 to 18, inclusive, are submitted by the accompanying amendment, constitutes a part of his invention, was invented before he filed his original application above identified, for such invention, was not known or used before his invention, was not patented or described in a printed publication in any country more than two years before his application, was not patented in a foreign country on an application filed more than twelve months before his application, was not in public use or on sale in this country for more than two years before the date of his application, and has not been abandoned.

Irving Langmuir

Sworn to and subscribed before me this 10th day of
March 1916.

Notary Public.

16

MAIL ROOM
MAR 1916
U.S. PATENT OFFICE

UNITED STATES PATENT OFFICE.

In re Application of :
IRVING LANGMUIR : ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.
Serial No. 795,610 :
Filed October 16, 1913 :
ALLOWED February 19, 1916. :

G

SUPPLEMENTAL AMENDMENT.

Hon. Commissioner of Patents,

Sir:-

Please amend claim 14, submitted by the accompanying amendment of March 10, 1916 as follows:

Claim 14, line 6, cancel "current" and insert,

---energy with operating currents and voltages great enough to cause appreciable positive ionization of gas.---

G'
Par H

Respectfully submitted,

Albert G. Davis
ATTORNEY FOR LANGMUIR.

Washington, D. C.,
March 14, 1916.

WGG/MET.

----------0u0----------

714

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

BU. 9-121

Serial No.
56,242

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON May, 31, 1916.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

Irving Langmuir. Assor.

Sir: Your APPLICATION for a patent for an IMPROVEMENT in Electrical Discharge Apparatus and the Process of Preparing the Same.

filed Oct. 16, 1915. has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING; and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

Respectfully,

Thomas Ewing
Commissioner of Patents.

Albert G. Davis.
c/o Gen. Elec. Co.
Schenectady. N. Y.

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 84,242, : ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.
Filed October 16, 1913, :
Renewed March 14, 1916, :
ALLOWED February 10, 1918.

AFFIDAVIT

City of Washington, :
: ss:-
District of Columbia, :

IRVING LANGMUIR, of Schenectady, County of Schenectady, State of New York, being duly sworn, deposes and says that he is the same Irving Langmuir who filed the above-identified application for Letters Patent.

That he has read and is familiar with the description of experiments in J. J. Thomson's "Conduction of Electricity Through Gases", 1906 Edition, pp. 192 to 193, involving a hot cathode device;

That he has personally made numerous experiments involving the conduction of electricity through a rarified gas both below and above the pressure of .001 m.m. which is given as the lowest possible pressure attainable in the experiments described in the above article;

That he knows from his general familiarity with the development of vacuum pumps and methods of producing high vacua that up to the year 1906, the date of publication of the above book, the only air pumps available for producing high vacua were mercury pumps. Since no statement is made by J. J. Thomson of special precautions to remove mercury vapor, and since it was not customary at that time to use means for excluding mercury vapor, it is to be pre-

2

sumed that mercury vapor was present in the evacuated tube. That as far as he is aware the only apparatus for measuring pressures as low as .001 m.m. known at the time of publication of J. J. Thomson's book was the McLeod gauge which does not indicate the presence of condensable vapors, such as mercury vapor or water vapor.

That from his own observation based on numerous experiments, he knows that in an incandescent cathode device of the type described by J. J. Thomson in which the residual gas pressure is as high as .001 m.m. the current will not vary with the 3/2 power of the applied voltage, even if the residual gases are non-condensable gases such as could be indicated by a McLeod gauge. In the presence of mercury vapor or water vapor, the deviation of the current-voltage relation from the 3/2 power law will be even more marked.

Irving Langmuir

Sworn to and subscribed before me this 29d day of April A.D. 1916.

Cornelia Eckhart
Notary Public.

WOC/GAL

PAPER NO. 17
AMDT. H
(R. 78)

UNITED STATES PATENT OFFICE

13413

In re Application of :
IRVING LANGMUIR, :
Serial No. 84,848, :
Filed October 16, 1913, :
Renewed March 14, 1916, :
Allowed February 19, 1915. :

ELECTRICAL DISCHARGE APPARATUS
AND THE PROCESS OF PREPARING
THE SAME

L

AMENDMENT UNDER RULE 78

Honorable Commissioner of Patents,

Sir:

H

Please amend the above application as follows without withdrawing the same from issue.

Page 5, line 10, after the sentence ending with "volts" insert:

H

Par L
Lang 829

- J. J. Thomson in the 1906 edition of his book "Conduction of Electricity Through Gases" describes on pages 192 and 193 an apparatus comprising an incandescent cathode and an anode located in a glass vessel evacuated to a pressure of .001 m.m. of mercury. This pressure is too high to enable a pure electron discharge to occur, particularly in the presence of mercury vapor which was inevitably present. In devices made in accordance with my invention the residual gas is reduced to a materially lower pressure. -

Page 4, after the sentence ending with "operable" insert: Devices made and operated in accordance with my invention are capable of transmitting currents materially exceeding one-tenth of a milliampere without causing positive ionization to take any essential part in the operation of the device, though the voltage is materially above the ionizing voltage.

H²

N

Cancel claim 14 and substitute the following claim:

H³

14. An electrical device comprising a gas-tight envelope, electrodes therein, means for producing an emission of electrons from one of said electrodes, independently of the operating voltage, said device being

~~evacuated to a pressure materially below about .001 millimeter of mercury pressure, the residual gas pressure being so low that conduction of electricity can occur therein operatively independent of positive ionization with currents and voltages which would with other conditions be great enough to cause appreciable positive gas ionization.~~

Add the following claim:-

~~28. An electrical device comprising an evacuated gas-tight envelope, electrodes therein, means for producing an emission of electrons from one of said electrodes, independently of the operating voltage, the pressure of residual gas in said device being so low that conduction of electricity therethrough occurs operatively independent of positive gas ionization with currents materially greater than one-tenth of a milliampere.~~

Remarks

This amendment is made to distinguish claim 14 over a description on pages 192 and 193 of J. J. Thomson's book "Conduction of Electricity Through Gases", 1906 Edition. This publication was not cited during the prosecution of the case but was called to the attention of applicant's attorney after the application was allowed. At a personal interview with the Primary Examiner at which Dr. Langmuir, the inventor, was present, the work of Richardson and J. J. Thomson in the field of incandescent cathode devices was discussed and claims such as submitted herewith were indicated as suitable by the Examiner to distinguish over the Thomson reference.

As pointed out by Dr. Langmuir at the interview and in the accompanying affidavit, the device described by J. J. Thomson could not have operated at a gaseous pressure of .001 m.m. of mercury (the lowest possible with the air-pump employed) without positive ionization as would be indicated by a deviation from the 3/2 power law of current-voltage relation. In a device in which gas ionization is not absent the current will increase with the electromotive force, (but not by the 3/2 power ratio) and then reach a saturation value as described by Thomson, but the fact that a saturation value is obtainable does not prove that gas ionization is absent.

An affidavit by Dr. Langmuir is hereby submitted in accordance with the Examiner's suggestion to set forth the facts brought out in the interview. Attention is particularly directed to the fact that so far as may be inferred from the information given by Thomson and the general knowledge of the art, mercury vapor must have been present in the Thomson device. Hydrogen gas will permit higher residual gas pressures without vitiating an electron discharge by positive ionization but even in the case of hydrogen, pressures as high as .001 m.m. of mercury are too high to avoid positive ionization when using voltages and currents high enough to cause appreciable positive ionization.

The current values given by Thomson on page 194 are extremely minute, 1000×10^{-9} to 1290×10^{-8} amperes. (one to 12.9 millionths of an ampere) With these minute currents the more easily recognizable evidences of positive gas ionization such as blue glow, glass fluorescence and disintegration of the cathode are practically absent and J. J. Thomson not being aware of any such delicate test as the 3/2 power current-voltage law could not be expected to be aware that the operation of his device was accompanied by gas ionization.

A new claim is also submitted by this amendment distinguishing over the Thomson reference by reciting that the device is capable of transmitting current values materially greater than one-tenth of a milliampere. The values quoted by Thomson from Richardson's work are of a lower order of magnitude, and as explained above it was only by virtue of the minuteness of the current values that Thomson failed to observe evidences of positive ionization.

It is believed that from the understanding of the situation brought out at the interview this amendment will be found proper to clearly distinguish over the J. J. Thomson reference which after all describes nothing more than a mere laboratory experiment which left the subject clouded in mystery and which never led to any industrially useful devices. In 1904 the year following the publication of the Richardson article to which J. J. Thomson refers (foot-note page 194), Wilson in Phil. Trans. p. 243, makes the statement that:

> "It is probable that a pure platinum wire heated in a perfect vacuum would not discharge any electricity at all, either positive or negative, to an extent appreciable on a galvanometer."

Pring and Parker in 1912 (Phil. Mag. 23,192) conclude that Richardson's results must have been erroneous. Other illustrations might be given of the confusion of theory and observation.

Since the work of Langmuir and Coolidge no doubt exists that a pure electron discharge is a reality. Even Sir. J. J. Thomson in a recent address (See the J. of the Inst. of Metals, 1915, Vol. XIV) uses the Coolidge tube as an illustration to show that the presence of gas is not absolutely essential for the emission of electrons.

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Approved:

R. F. Whitehead

Asst. Commissioner.

Schenectady, N. Y.

April 27, - 1916.

WGG/GAL

The proposed corrections being made to avoid the prior art, it is recommended that this amendment be entered under Rule 78, without withdrawing the case from issue. The final fee has not been paid.

W. A. Kinnan

Examiner Div. 16

84242. 15

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

ESG

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON

May 31, 1916.

In the matter of the
Application of
Irving Langmuir,
Electrical Discharge
Apparatus and Process
of Preparing the Same;
Renewed March 14, 1916,
Serial No. 84,242.

Amendment.

Sir:

You are hereby informed that the recommendation of the examiner that the amendment be admitted under the provisions of Rule 78, has been approved by the Assistant Commissioner and the amendment entered.

By direction of the Commissioner:

Very respectfully,

Chief Clerk.

F.

Irving Langmuir,
c/o Albert G. Davis,
Schenectady, N. Y.

722

Div. 16 Room 109

Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

3—360

F. H.

Paper No. 10

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

Copy sent
assignee
and appli-
cant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON June 16, 1916.

U. S. PATENT OFFICE
JUN 16 1916
MAILED

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

I. Langmuir, S. No. 84,242, filed Mar. 14, 1916, Electrical Discharge Apparatus and the Process of Preparing the Same, renewal of 795,610, filed Oct. 16, 1913.

Thomas Ewing
Commissioner of Patents.

The following claims are suggested to applicant for purposes of interference and if presented the application will be withdrawn from issue. Applicant is given twenty days from date of this letter within which to present them. Failure to present such claims within the time stated will be held an abandonment of their subject-matter.

In a thermionic device, a vacuum tube, a heated electron-emitting cathode and an anode enclosed in said tube, a circuit outside of said tube connecting said cathode and anode, and a source of direct current included in said circuit, the vacuum in said tube being so high that no sudden increase in current due to gas ionization is possible except at voltages higher than that required to produce the saturation current at the operating temperature of the cathode.

In a thermionic device, a vacuum tube, a heated electron-emitting cathode and an anode enclosed in said tube, a circuit outside of said tube connecting said cathode and anode, and a source of direct current included in said circuit, the vacuum in said tube being so high that a working margin of safety exists between the voltage at which all electrons capable of being emitted by the filament at the temperature at which the latter is maintained flow to the plate and the voltage at which there is appreciable ionization of the residual gas of said tube.

A vacuum tube device of the thermionic type, having the area of the filament and the degree of vacuity so related to the temperature and the impressed voltage at which the tube is to be worked, that no appreciable ionization takes place when substantially all the electrons emitted are drawn to the anode.

A thermionic device wherein an electron discharge takes place between a heated cathode and an anode in a vacuum, the degree of said vacuum being so coordinated with the volume and velocity of said discharge that no gas ionization can occur during normal operation.

Wm. A. Kinnan
Examiner, Division XVI.

S.

Approved:

Jun 15 1918

J. T. Newton
First Assistant Commissioner.

Sys

28 I

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 84242, :
Filed March 14, 1916, :
Div. 16. Room 109. :

ELECTRICAL DISCHARGE APPARATUS
AND THE PROCESS OF PREPARING
THE SAME

I

26

Honorable Commissioner of Patents.

Sir:-

Please amend the above-entitled application by adding the following claims:-

Pen

n

29 ~~20~~. In a thermionic device, a vacuum tube, a heated electron-emitting cathode and an anode enclosed in said tube, a circuit outside of said tube connecting said cathode and anode, and a source of direct current included in said circuit, the vacuum in said tube being so high that no sudden increase in current due to gas ionization is possible except at voltages higher than that required to produce the saturation current at the operating temperature of the cathode.

30 ~~21~~. In a thermionic device, a vacuum tube, a heated electron-emitting cathode and an anode enclosed in said tube, a circuit outside of said tube connecting said cathode and anode, and a source of direct current included in said circuit, the vacuum in said tube being so high that a working margin of safety exists between the voltage at which all electrons capable of being emitted by the filament at the temperature at which the latter is maintained flow to the plate and the voltage at which there is appreciable ionization of the residual gas of said tube.

~~91. ~~24~~. A vacuum tube device of the thermionic type, having the area of the filament and the degree of vacuity so related to the temperature and the impressed voltage at which the tube is to be worked that no appreciable ionization takes place when substantially all the electrons emitted are drawn to the anode.~~

~~92 ~~25~~. The thermionic device wherein an electron discharge takes place between a heated cathode and an anode in a vacuum, the degree of said vacuum being so coordinated with the volume and velocity of said discharge that no gas ionization can occur during normal operation.~~

not patentable over Thomson [illegible]

nsert R3

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Schenectady, N. Y.
June 22 1916.

WGG/GAL

726

Address only
The Commissioner of Patents.
Washington, D. C.

[illegible]

DEPARTMENT OF THE INTERIOR.

UNITED STATES PATENT OFFICE.

Washington, D. C., July 20 *, 191* 6

Irving Langmuir, Assor.

Sir:

Your application for patent for an improvement in Electrical Discharge Apparatus and the Process of Preparing the Same.

serial No 84242 *, allowed* March 31, 1916.

ha s *been* WITHDRAWN *from the* ISSUE FILES *in this office. The reasons therefor will be communicated to you by the Examiner.*

Until a new notice of allowance is sent you the final fee will not be required.

Very respectfully,

Thomas Ewing
Commissioner of Patents.

Albert G. Davis,
c/o General Electric Company,
Schenectady, N. Y.

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

727

Letter No.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON July 17, 1916.

To the

Honorable Commissioner of Patents.

Sir:

It is requested that the application of Irving Langmuir, 84,242, filed Mar. 14, 1916, renewal of 795,610, filed Oct. 16, 1913, allowed Mar. 21, 1916, be withdrawn from issue for the purpose of interference. The final fee has not been paid.

Respectfully,

Wm A. Kinnan
Examiner, Division XVI.

Approved.

R. F. Whitehead

7-19-16 [illegible]
[illegible]

728

INTERFERENCE.

Interference No. 40380 Paper No. 22

Name, Irving Langmuir

Serial No. 84,242

Title, Electrical Discharge Apparatus and Process of Preparing the Same

Filed, Mar. 14, 1916

Interference with H. D. Arnold

DECISIONS OF

Law ~~Primary~~ Examiner, Intf. dissolved as to counts 1, 2, 3, 4, 6, 7, 8 Dated, Feb. 25, 1921

Ex'r of Interferences, Favorable Dated, Oct. 21/22.

Board, " Dated, April 21/23.

Commissioner, Adverse Dated, OCT 27 1923

Court Favorable Dated June 1, 1925

REMARKS:

Termination of Intf. noted by P.E.
July 11, 1925

This should be placed in each application or patent involved in interference in addition to the interference letter by Primary Examiner.

Forwarded from Div. 16 to
Examiner of Interferences.

3—318

Paper No. 22
[Interference.]

July 31, 1916. DEPARTMENT OF THE INTERIOR. F.H.

UNITED STATES PATENT OFFICE,
WASHINGTON, D. C.

Copy sent assignee.

U. S. PATENT OFFICE,
INTERFERENCE DIVISION
AUG 8 1916
MAILED

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a copy of a communication from the Examiner concerning the application of I. Langmuir, S. No. 84,242, filed Mar. 14, 1916, Electrical Discharge Apparatus and the Process of Preparing the Same, Renewal of 795,610, Oct. 16, 1913.

Room No. 109

Very respectfully,
Thomas Ewing
Commissioner of Patents.

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

40380

The case, above referred to, is adjudged to interfere with others, hereafter specified, and the question of priority will be determined in conformity with the Rules.

The statement demanded by Rule 110 must be sealed up and filed on or before SEP 5 1916 *, with the subject of the invention, and name of party filing it, indorsed on the envelope. The subject-matter involved in the interference is*

1. In a thermionic device, a vacuum tube, a heated electron-emitting cathode and an anode enclosed in said tube, a circuit outside of said tube connecting said cathode and anode, and a source of direct current included in said circuit, the vacuum in said tube being so high that no sudden increase in current due to gas ionization is possible except at voltages higher than that required to produce the saturation current at the operating temperature of the cathode.

2. In a thermionic device, a vacuum tube, a heated electron-emitting cathode and an anode enclosed in said tube, a circuit outside of said tube connecting said cathode and anode, and a source of direct current included in said circuit, the vacuum in said tube being so high that a working margin of safety exists between the voltage at which all electrons capable of being emitted by thefilament at the temperature at which the latter is maintained flow to the plate and the voltage at which there is appreciable ionization of the residual gas of said tube.

3. A vacuum tube device of the thermionic type, having the area ofthe filament and the degree of vacuity so related to the temperature and the impressed voltage at which the tube is to be worked

that no appreciable ionization takes place when substantially all the electrons emitted are drawn to the anode.

4. An electrical discharge device comprising a gas-tight envelope, an incandescent cathode, and a gas-free anode, the space in said envelope being evacuated to below the pressure at which deleterious gas ionization takes place, the current passed by said device over a working range of voltage and temperature varying with the 3/2 power of the impressed voltage for voltages above a minimum voltage depending on the temperature of the cathode.

5. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

6. An electrical discharge device comprising a gas-tight evacuated envelope, a cathode adapted to be heated to incandescence, an anode, the space in said envelope being evacuated to such a degree that the current flowing between said electrodes varies with the 3/2 power of the impressed voltage over a working range of current values exceeding about five milliamperes.

7. An electrical discharge device comprising a gas-tight envelope, an incandescent cathode, an anode, and means for independently heating the cathode, the parts of said apparatus and the enclosed space being deprived of gas to such extent that the device is operable with currents varying with the 3/2 power of the voltage over a range of impressed voltages determined by the cathode temperature, the current at voltages above this range being substantially constant.

The interference involves your application above identified and

An application for Thermionic Devices and Method of Constructing and Operating the Same, filed by Harold DeForest Arnold, 140 South Munn Avenue, East Orange, N. J., whose attorneys are DeWitt C. Tanner and John G. Roberts, 463 West St., New York, N. Y., and whose assignee is the Western Electric Co., of New York, N. Y.

The relation of the counts ofthe interferto the claims of the respective parties is as follows:

Counts:	Arnold:	Langmuir:
1	2	20
2	5	21
3	11	22
4	16	4
5	17	5
6	18	9
7	19	16

Wm A Kinnan

Examiner, Division XVI.

24

X

IN THE UNITED STATES PATENT OFFICE.

In re Application of
Irving Langmuir,
Serial No. 84,242,
Filed March 14, 1916,
Div. 16, Room 109.

ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.

Hon. Commissioner of Patents,

Sir:-

It is respectfully requested that this application be referred to the Primary Examiner for consideration and admission of the following amendments to the specification and claims.

As suggested in the brief filed by Langmuir in connection with the motion by the party Arnold in Interference 40,380 invoking the supervisory authority of the Commissioner to secure an order to take testimony in respect to certain references, the proposed claims are submitted as descriptive in the opinion of the party Langmuir of novel features of the present invention over the references cited; it is requested, if found desirable in the progress of the interference proceedings, that some or all of these claims be proposed by the Patent Office to the party Arnold as prospective counts of the issue:

✓ Page 2, line 27, after the sentence ending with "cathode" insert:

~~- As determined by Frank and Hertz (Ber. d. Deut. Phys. Ges. Vol. 15, 34, 1913) and by earlier investigators referred to by Frank and Hertz, the ionization of gases at low pressures by collision~~

K'

Pen

~~with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. The ionization voltage values found by Frank and Hertz are as follows: for helium 20.5 volts, neon 16 volts, argon 12 volts, hydrogen 11 volts, oxygen 9 volts and nitrogen 7.5 volts. -~~

✓✓ Page 3, line 27, after the paragraph inserted by amendment of Dec. 17, 1914, add the following:

~~- In a device in which the conduction of current is purely electronic, and the effect of positive ions is negligible, the conduction of current is governed, over a certain range, on the one hand by the effect of the impressed voltage (which tends to propel the electrons across the vacuous space), and on the other hand by the mutual repulsion of the electrons in the space, which tends to limit or inhibit the current. This last mentioned phenomenon, the current limiting effect of the electric field of the electrons on each other, termed the "space charge effect", is discussed and analysed by me in a paper read before the Physical Society on October 18, 1913, which was abstracted in the Physical Review for November 1913, and published in full in the Physical Review for December 1913 and again published in somewhat modified form in the Physikalische Zeitschrift for January and March 1914.~~

Perrin

K^2

The geometric proportions of the device also affect the amount of current which will pass with a given voltage, but as these conditions remain fixed for a given device they may be represented by a constant in an equation expressing the relation between the current and the voltage.

As already stated above, the current (I) will vary in the particular device described herein, with the 3/2 power of the voltage (V), the equation thus being:

$I = aV^{3/2}$ (a being [illegible] constant).

As is well known, if we produce a logarithmic graph of any equation in which one variable of the equation varies as a power of the other variable, as for example, an equation of the general form $y = x^n$, (as by plotting logarithms of x as abscissae and logarithms of y as ordinates) we find that this graph is a straight line.

Hence, the relation between current and voltage in a device operating by pure electronic conduction independent of gas ionisation may be expressed by the statement that when with a sufficient electron emission the logarithms of the current values transmitted between cathode and anode are plotted as ordinates against the logarithms of the respective voltages impressed between cathode and anode as abscissae, the slope of the line obtained does not increase for increasing voltage values over a working range of voltages.

As above indicated, one of the first indications of positive ionization may be observed by erratic readings in measuring devices connected in circuit with an electron discharge device under observation. These erratic readings, of course, will produce a sudden change or discontinuity in the logarithmic graph plotted as above described, and any such irregularities will be more manifest when observed as deviations from a straight line than when the readings are plotted directly.

In a device in which positive ionization occurs, the exponent of the impressed voltage (V) will not be a constant but will increase as the voltage increases and consequently also as the amount of ionization increases.

As shown in the paper in the Physical Review, December 1913, positive ionization causes with a progressive increase of voltage a progressive increase of the exponent of V in the equation $I = aV^{3/2}$, and hence the slope of the logarithmic plot increases when positive gas ionization occurs.

~~ert C2~~

Add the following claims;

81-84. A thermionic device comprising a vacuum tube, a heated electron emitting cathode and an anode enclosed within said tube, the parts of said tube and the space therein being deprived of gas to such an extent that

C3

Pen

over a working range of voltages exceeding the ionization voltage characteristic of whatever residual gas remains within the tube, a current through the evacuated space is operatively independent of positive gas ionization.

34 ~~25~~. A thermionic device comprising a vacuum tube, a cathode and an anode contained therein, and means for heating said cathode to incandescence, the parts of said tube and the space therein being deprived of gas to such an extent that, with the cathode at a sufficiently high temperature, a current may be passed through the evacuated space with a range of impressed voltages exceeding about 30 volts which is unaccompanied by such indications of positive ionization as a sudden change of current or blue glow.

9

20 ~~26~~. An electrical device comprising the combination of a sealed evacuated envelope, a cathode adapted to be independently heated, and an anode within said envelope, an external circuit connected to said electrodes, and a source of electromotive force applied to said circuit, the degree of vacuity and the electron emission of the cathode being so related to the potential of said source that the flow of current over a range of voltage materially above the ionization voltage is governed by the electric field of the electrons in the vacuous space and the potential applied to said electrodes, operatively independent

R3

of gas ionization. M'fallons

Per n

~~36. A thermionic device comprising a vacuum tube, a cathode and an anode contained therein, and means for heating said cathode to incandescence, the parts of said tube and the space therein being deprived of gas to such extent that, with the cathode at a sufficiently high temperature, the slope of the line obtained by plotting the logarithms of currents transmitted thru the vacuous space as ordinates against the logarithms of voltages impressed upon said electrodes as abscissae does not increase for increasing voltage values over a working range of voltages exceeding the ionization voltage.~~

~~37. A thermionic device comprising a vacuum tube, a cathode and an anode contained therein, and means for heating said cathode to incandescence, the parts of said tube and the space therein being deprived of gas to such extent that with the cathode at a sufficiently high temperature the line obtained by plotting the logarithms of currents transmitted thru the vacuous space as ordinates against the logarithms of impressed voltages as abscissae is a straight line for voltage values over a working range of voltages exceeding the ionization voltage, and there is no sudden change nor discontinuity in the line.-~~

Respectfully submitted,

Albert G. Davis
Attorney for Langmuir.

Schenectady, New York.,
WGC/AG/W January 29th, 1917.

Paper No. 5
Amendt. C.

IN THE UNITED STATES PATENT OFFICE.

In re application of
Irving Langmuir,
Serial No. 795,610,
Filed October 16, 1913,
Div. No. 16, Room 109.

ELECTRICAL DISCHARGE APPARATUS, PROCESS OF PREPARING ETC.

SUPPLEMENTAL PROPOSED AMENDMENT.

Honorable Commissioner of Patents,

S i r:-

C

On or about January 29, 1917, an amendment to this application was proposed containing certain claims and certain proposed changes or additions to the specification. Under date of February 23, 1917, the Honorable Acting Commissioner of Patents, to whom the amendment was submitted in the course of proceedings in the interference, Arnold vs. Langmuir, No. 40,380, in which this case is involved, held as follows:

> "Langmuir has filed an amendment to his application containing certain claims and requests that they be added to the issue of the interference. Under the circumstances this amendment may be considered by the Law Examiner in connection with the motion to dissolve."

The following is a proposed amendment supplemental to the prior proposed amendment above referred to.

✓ ✓ Cancel the insertion directed to be entered on page 3, line 10 of the specification, after the sentence ending with the word "volts", this insertion being contained in an amendatory paper dated April 29,1916.

✓ Page 3, line 22, following the insertion after the word "voltages" directed by the amendment dated December 17, 1914, add the following:

5

- This current is termed the saturation current, and the region in which the current is substantially independent of the voltage or closely approaches thereto may be termed the saturation region or more briefly designated merely as saturation. -

L¹

u n

✓ Page 3, line 27, following the long insertion directed to be added at that point by the amendment of January 29, 1917, add the following:

- The effect of ionization is especially marked in that region of operation where the current is limited by the space charge effect already discussed, and changes in curvature of the discharge characteristic may occur as indicated unaccompanied by any visible evidence of ionization such as blue glow or the like. At saturation on the other hand, the discharge is much less sensitive, and in fact the discharge may actually exhibit marked blue glow effects along with a flat or straight saturation curve. -

u

n

L²

✓ Please add the following claims, the same being numbered from 1 to 9 inclusive.

4 1. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the governing or limiting action on the space current due to the electric field of said electrons is substantially unaffected by positive ionization and by secondary electron emission from the

L³

walls of the tube.

2. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped [illegible] permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization.

3. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

4. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed upon electrodes of the device and when the electron emission has any value such that the space current is below the

saturation region at such voltages, that the slope of the line obtained by plotting the logarithms of values of said current as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae shows no increase for increasing voltage values.

12.8

5. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae, is straight and continuous.

6. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the tube and when the electron emission has any value such that the space current is below the saturation region at such voltages, that said current varies as the three halves power of said impressed voltages.

7. A discharge device comprising a tube and

electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on ~~electrons~~ electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

~~electrodes See Langmuir [illegible] page 5 #1~~

8. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, substantially unaffected by positive ionization, the heating effect in the tube due to said current occurring substantially only at one or more of said electrodes.

9. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with

stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts.

Renumber all of the previous claims to correspond beginning with present claim 1 as claim 10. N 15 follows

Insert N 15

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Schenectady, N. Y.

May 19, 1919.

ADL/BBC.

744

Paper No. 26
Amdt. M

UNITED STATES PATENT OFFICE.

Division No. 16. Room 109.

In re application of
Irving Langmuir,
Serial No. 84,242,
Filed October 16, 1913

Electrical Discharge Apparatus and the Process of Preparing the Same.

Hon. Commissioner of Patents,

M

S i r:

I desire to amend the above entitled application as follows:

Please add the following claims:

4 21 ~~30~~. Apparatus for controlling an electric current comprising a vacuum tube, an anode and an electron emitting cathode in the circuit of said current and within said tube, the degree of evacuation of the tube and the relation of its parts being such that for voltages materially above ionization voltage the current is governed or limited by the electric field of the electrons in said tube substantially unaffected by positive ionization, and a third electrode in said tube by which an auxiliary controlling electromotive force may be superposed to modify the effect of said electric field and control said current in a stable and reproducible manner.

M'

2 22 ~~31~~. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a

Rec'd Mar 17/21

space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner. (4)

N° 20 follows

Insert N 20

REMARKS.

The foregoing claims are added in accordance with the stipulation of even date herewith, filed in Interference No. 40,380, Arnold vs. Langmuir, in which the present application is involved.

Having been notified by the opposing party in the Interference in which this case is now involved, that he is at this time making the foregoing claims they are now made by this applicant, with the request that they be included in the interference issue, if the Patent Office approves.

Respectfully submitted,

Albert G. Davis
Attorney for Applicant.

746

Div. 16 Room 112 LBC

Address only
"The Commissioner of Patents,
Washington, D. C."
and not any official by name.

Paper No. 27

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON

U. S. PATENT OFFICE
APR 5 1921
MAILED

Mr. Albert G. Davis,
General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

Irving Langmuir, Ser. #84,242, filed Mar. 14, 1916;
renewal of Ser. #795,670, filed Oct. 16, 1913.

Electrical Discharge Apparatus and the Process of Preparing same.

M. H. COULSTON
Commissioner of Patents.

The following counts have been added to interference No. 40,380, ARNOLD vs. LANGMUIR in accordance with the decisions of the Law Examiner dated Feb. 25, 1921 and March 18, 1921:

2. An electrical device comprising the combination of a sealed evacuated envelope, a cathode adapted to be independently heated, and an anode within said envelope, an external circuit connected to said electrodes, and a source of electromotive force applied to said circuit, the degree of vacuity and the electron emission of the cathode being so related to the potential of said source that the flow of current over a range of voltage materially above the ionization voltage is governed by the electric field of the electrons in the vacuous space and the potential applied to said electrodes, operatively independent of gas ionization.

3. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the governing or limiting action on the space current due to the electric field of said electrons is substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

4. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization.

5. A discharge tube having electrodes at least one of
which is adapted to emit electrons, the gas content or resi-
due of said tube and the relation of the parts of the tube
being such that the tube is capable of being so operated in
a range below saturation and materially above ionization vol-
tages that in that range the space current is governed by the
combined effect of the electric field of said electrons and
the potentials applied to said electrodes, the governing or 3
limiting of the current being substantially unaffected by
positive ionization and by secondary electron emission from
the walls of the tube.

6. A discharge device comprising a tube and electrodes
therein one of which is adapted to emit electrons, the degree
of evacuation and the relation of the parts of the device
being such that the device is capable of being so operated, 4
when voltages materially higher than ionization voltages are
impressed upon electrodes of the device and when the electron
emission has any value such that the space current is below
the saturation region at such voltages, that the slope of the
line obtained by plotting the logarithms of values of said
current, as ordinates against the logarithms of the corres- 4
ponding values of said impressed voltages as abscissae shows
no increase for increasing voltage values.

7. A discharge device comprising a tube and electrodes
therein one of which is adapted to emit electrons, the degree
of evacuation and the relation of the parts of the device
being such that the device is capable of being so operated,
when voltages materially higher than ionization voltages are
impressed on electrodes of the device and when the electron 5
emission has any value such that the space current is below
the saturation region at such voltages, that the line obtained
by plotting the logarithms of any values of said current below
the saturation region as ordinates against the logarithms of
the corresponding values of said impressed voltages as abscissae
is straight and continuous.

8. A discharge tube having electrodes at least one of
which is adapted to emit electrons, the gas content or residue
of said tube and the relation of the parts of the tube being
such that the tube is capable of being so operated, when vol-
tages materially higher than ionization voltages are impressed 6
on electrodes of the tube and when the electron emission has
any value such that the space current is below the saturation
region at such voltages, that said current varies as the three
halves power of said impressed voltages.

9. A discharge device comprising a tube and electrodes
therein one of which is an electron emitting cathode, the de-
gree of evacuation of said device and the relation of the parts
of the device being such that the device is capable of being so
operated, when voltages materially higher than ionization vol- 7
tages are impressed on electrodes of the device and when the
electron emission is such that the space current is below the
saturation region at such voltages, that said current is sub-
stantially independent of the cathode temperature and unaffected
by secondary electron emission from the walls of the tube.

Ser. #84,242 - #3.

10. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, substantially unaffected by positive ionization, the heating effect in the tube due to said current occurring substantially only at one or more of said electrodes. 8

11. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts. 9

12. Apparatus for controlling an electric current comprising a vacuum tube, an anode and an electron emitting cathode in the circuit of said current and within said tube, the degree of evacuation of the tube and the relation of its parts being such that for voltages materially above ionization voltage the current is governed or limited by the electric field of the electrons in said tube substantially unaffected by positive ionization, and a third electrode in said tube by which an auxiliary controlling electromotive force may be superposed to modify the effect of said electric field and control said current in a stable and reproducible manner.

13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

The preliminary statement required by Rule 110, as to the added counts only, should be filed on or before MAY 2 1921

The relation of all the counts to the claims of the parties is now as follows:

Counts:	Arnold:	Langmuir:
1	17	14
2	20	35
3	21	1
4	22	2
5	23	3
6	24	4
7	25	5

Ser. #84,242 - #4.

Counts:	Arnold:	Langmuir: (con
8	26	6
9	27	7
10	28	8
11	29	9
12	30	38
13	31	39

In applicant's claim 7, line 7, "electrons" should be changed to electrodes to agree with count 9 as declared.

H.S.M.

Exr., Div. 16.

750

Arnold · Langmuir

25

[illegible] —28

IN THE UNITED STATES PATENT OFFICE

In re application of
Irving Langmuir

Ser. No. 84,242
Filed Mar. 14, 1916

Electrical Discharge Apparatus and the Process of Preparing the Same.
Div. 16

HONORABLE COMMISSIONER OF PATENTS:

SIR,

I hereby appoint ALEXANDER D. LUNT, of Schenectady, New York, whose address is care of General Electric Company, Schenectady, New York, as my associate attorney, with full power of substitution and revocation, to prosecute the above entitled application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

Respectfully,

Albert G. Davis

Schenectady, N. Y.
September 11, 1922

Attorney for Applicant

PAPER NO. 29 n
AMENDMENT

IN THE UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 84,242, :
Filed (Renewed) March 14, 1916, :
Division 51. Room 240 :

ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.

SEP [illegible] 1925
DIV 51 FILED

n

Honorable Commissioner of Patents,

S i r:-

Please amend the above-entitled application as follows:

Page 1:

Line 6, after "PREPARING" insert -AND USING-

Line 13, cancel "having" and substitute - which make possible -

Line 15, change "operable" to - operation -

Line 16, after "voltages" insert - but the invention is also applicable and useful for moderate loads and moderate voltages -

n'

Line 31, cancel "an ordinary" and substitute - a Roentgen -

Page 2:

Cancel lines 2 to 22 inclusive, and the first eight words in line 23, and substitute:

n^2

- The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the vacuous space. If these electrons when moving above a certain velocity collide with gas molecules they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tube are the result of the action and interaction of the electrons and the ions; these phenomena are in general erratic and non-reproducible.

Line 24, cancel "electrically"

Line 25, before "is" insert - ~~it~~ -

n3

Line 25, before "The" insert - ~~as~~ As gas ionization continues at higher voltages a blue glow may appear.

Line 27, after "cathode." cancel the matter inserted by amendment of January 29, 1917, and substitute: - The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. These voltages are different for different gases. In the case of gases such as nitrogen, hydrogen, oxygen, argon, helium and neon, they are of the order of magnitude of fifteen to twenty-five volts.

n4

Line 30, after "device" insert - with three electrodes -

Page 3:

Line 5, before "somewhere" insert - to be important -

Line 6, after "volts" insert:

n 5

Copied

- Another discharge device previously used to some extent was the Fleming Valve. This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the voltages at which positive ionization by collision occurs. It was

N5

not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects.

Line 10, after "volts" change the period to a semi-colon and insert - indeed no prior discharge devices are known to me operating in a practically usable manner and without substantial positive ionization effects with currents as great as about one-tenth of a milliampere with voltages as high as about forty volts.

n6

Lines 15 and 16, mark so that there will be no new paragraph at this point.

Line 17, after "blue glow" insert - , glass fluoresence-; after "all" insert - readily -

Line 18, after "are" insert - ordinarily -

Cancel everything between the period in line 18 and the period in line 24, and insert:-

n7

In most devices of simple construction which embody my invention, the discharge current passing through a given space with the cathode at a sufficiently high temperature with respect to the voltages employed, varies directly with the 3/2 power of the impressed voltages. This 3/2 power law can be readily derived mathematically for a tube in which there is substantially no positive ionization on the assumption that the whole surface of the cathode is at a uniform potential, that the electrons escape from the cathode with negligible velocities and that the walls of the tube do not carry appreciable electric charges.

In most simple devices embodying my invention, these conditions are so well fulfilled that the current does vary in proportion to the 3/2 power of the voltage over wide ranges of voltage above the ionizing voltages. This means that if the logarithm of the current is plotted against the logarithm of the voltage, the resulting plot is a straight line whose slope is 3/2. Or, in many cases it is more convenient to make use of the equivalent relation, that the 2/3 power of the current plotted as ordinates against the anode voltages as abscissae gives a straight line.

In devices in which there is substantial positive ionization, on the other hand, even when the pressures of gas are so low that only very small currents could be carried by positive ions, the currents begin to increase with voltage more rapidly than according to the 3/2 power law as soon as the anode voltage materially exceeds the ionizing potential of the gas.

In devices embodying my invention which have more than two electrodes, or with special constructions, as where the cathode is a filament, so long that it cannot be considered an equi-potential surface, the 3/2 power law may be more or less masked. However, the effects thus introduced will be readily understood by those skilled in the art, and appropriate methods of identifying the pure electron discharge can easily be found corresponding to the special construction. For example, when such tubes have more than two electrodes and the temperature of the cathode is sufficiently high with respect to the voltages employed, the discharge will usually be characterized by a linear relation between the 2/3 power of the total electron current from the cathode and the voltage applied to any other electrode, the remaining electrodes being kept at constant potential. Another test that can often be made with a three electrode tube is to connect the grid directly to the anode, or to the negative end of the cathode, and observe whether the current varies as the 3/2 power of the voltage.

If for a given cathode temperature the voltage is sufficiently high to cause all of the electrons emitted or liberated at the cathode to be drawn away, then a further increase in voltage produces substantially no change in the current. The current thus determined is called the saturation current, and the range of operation in which the current is substantially independent of the voltage or approaches this condition may be called the saturation range or more briefly designated merely as saturation. If for a given cathode temperature the voltage is not high enough to cause all of the electrons which are emitted or liberated at the cathode to be drawn away, the operation occurs in a range below the saturation range. Operation in this range may be spoken of as operation below saturation.

A change in the temperature of the cathode in a hot cathode device embodying my invention will produce no change in the discharge when the operation is below saturation, even though the ionization voltage is materially exceeded. That is, the current-voltage curve is not changed by a change in the cathode temperature under such conditions.

The discharge in devices embodying my invention is practically independent of the pressure when the pressure is below a certain value which depends upon the size and shape of the device and upon the current and voltage of the discharge.

Page 5:

Line 22, cancel the insertions made by the amendments of December 17, 1914, and May 19, 1917.

Line 27, cancel the insertion made by the amendment of December 17, 1914.

Line 27, also cancel the long insertion made by the amendment of January 29, 1917, and

Line 27, also cancel the insertion made by the amendment of May 19, 1919.

Line 27, insert after the period the following:

N8

In a device in which the conduction of current is purely electronic, and the effect of positive ions is negligible, the conduction of current is governed, over a certain range, on the one hand by the effect of the impressed voltage, which tends to propel the electrons across the vacuous space, and on the other hand by the mutual repulsion of the electrons in the space, which tends to limit or inhibit the current. This last mentioned phenomenon, the current limiting effect of the electric field of the electrons on each other, termed the "space charge effect", is discussed and analyzed by me in a paper read before the Physical Society on October 18, 1913, which was abstracted in the Physical Review for November, 1913, and published in full in the Physical Review for December, 1913, and again published in somewhat modified form in the Physikalische Zeitschrift for April 1, and May 15, 1914. It is the basis of the 3/2 power law referred to herein.

The geometric proportions of the device also affect the amount of current which will pass with a given voltage, but as these conditions remain fixed for a given device they may be represented by a constant in an equation expressing the relation between the current and the voltage.

As stated above, the current (I) in the particular device described herein, when operating below saturation, will vary with the 3/2 power of the voltage (V), the equation being:

Hand set

$$I = aV^{3/2} \quad (a \text{ being a constant})$$

center

As is well known, if we produce a logarithmic graph of any equation in which one variable of the equation varies as a power of the other variable, as for example, an equation of the general form $y = x^n$, (as by plotting logarithms of x as abscissae and logarithms of y as ordinates) we find that this graph is a straight line. Hence the relation between current and voltage in a device operating below saturation and by pure electronic conduction independent of gas ionization may be expressed by the statement that when with a sufficient electron emission the logarithms of the current values transmitted between cathode and anode are plotted as ordinates against the logarithms of the respective voltages impressed between cathode and anode as abscissae, the slope of the line obtained does not ordinarily increase for increasing voltage values over a working range of voltages extending materially above the ionization voltages.

A substantial amount of positive ionization ordinarily causes the logarithmic plot of the current with respect to the voltage to bend upwardly and away from the 3/2 power line when the ionizing voltage is materially exceeded. The absence of a bend in the logarithmic plot at voltages somewhat above the ionization voltage is ordinarily a reliable indication that the tube is a pure electron discharge tube, though saturation complete or partial at voltages somewhat greater than the ionization voltages may prevent such a bend in the plot of an ionizing tube.

As above indicated, one of the indications of positive ionization is the occurrence of erratic readings in measuring devices connected in circuit with an electron discharge device under observation. Such erratic readings, of course, will produce a sudden change or discontinuity in the logarithmic graph plotted as above described, and any such irregularities will be more manifest when observed as deviations from a straight line than when the readings are plotted directly.

The effect of positive ionization upon the magnitude of the discharge is especially marked in that region of operation where the current is limited by the space charge effect already discussed, and changes in curvature of the discharge characteristic may occur as indicated unaccompanied by any visible evidence of ionization such as blue glow or the like. At saturation on the other hand, the discharge is ordinarily much less sensitive, and in fact the discharge may actually exhibit marked blue glow effects along with a flat or straight saturation curve.

Page 8.

Line 28, after "invention" cancel the insertion of March 14, 1916.

Line 31, before "with" insert ~~--~~, and such devices may be made which will operate without substantial positive ionization at voltages far above the ionization voltages -

Line 32, cancel "minute"

Line 32, cancel "above referred"

Page 4:

Line 1, cancel "to" and substitute - of the prior art -

Line 1, after "operable" insert - without substantial positive ionization -

Line 1, after the amendment of April 29, 1916, change the period to a comma and add - though the voltage is materially above the ionization voltages -

Cancel lines 2 to 17 inclusive.

Page 6:

Line 5, cancel the amendment added by amendment of March 29, 1915, and substitute the following:

- It will be noted that both in Figure 1 and Figure 2 the electrons are afforded a short and direct path from the cathode to the anode and that this path is so related to the position of the walls of the tube as to minimize the tendency for electrons to pass to the walls of the tube. In such a tube electron bombardment of the walls of the tube is avoided, together with the heating of such walls and the secondary emission of electrons therefrom which said bombardment causes. The energy of the discharge is delivered mainly, or entirely, at the anode, anodes, or upon other interior members instead of at the walls of the tube. -

n10

Page 6:

Line 21, cancel "In fact," and begin "the" with a capital letter.

n11

Line 21, after "heating" insert -, especially of solid anodes such as shown in Figure 2, -

Cancel lines 24 to 31 inclusive, and insert:

n12

- Bombardment is a very effective means of removing occluded gas from anodes. -

Page 7:

Lines 25 to 27, cancel the sentence "In the case", etc. through "may suffice"

Line 27, make the sentence beginning "After the metal" begin a new paragraph.

Line 28, before "take" insert - readily -

Line 31, cancel "without further" and substitute - with less -

Page 8:

Lines 9 and 10, correct the spelling of "permissible"

Line 12, place a comma after "gas" (second occurrence)

Line 22, cancel "copending"

Line 23, after "concurrently herewith" inserted by amendment of April 30, 1914, insert - upon which Patent 1,273,783 was granted on July 23, 1918. -

n13

Line 24, correct the spelling of "assymmetric"

5 5

Page 10:

Line 8, insert after "described" - and claimed -

At the end of the specification before the preamble to the claims add the following:

copies

Residual gas left in a tube when it is sealed off or occluded gas driven off from the inner wall of the tube, or from the elec-

trodes, during the use of the tube, varies in pressure from time to time according to the condition of operation of the tube and may produce irregularities in the discharge when operating in the saturation region as well as when operating below saturation. The irregularities below saturation are due mainly to the disturbing effect of the resulting positive ions upon the space charge. The irregularities in the saturation region are due to changes in the rate of emission or liberation of electrons at the cathode. It is obvious that the advantages of stable and reproducible operation and freedom from destructive bombardment of the cathode by positive ions, which advantages are severally or collectively to be secured by the means hereinabove described, are not limited to operation below saturation but are also important in operation in the saturation region.

N14

The positive ionization herein referred to is that positive ionization which occurs as the result of collisions between electrons and gas molecules in the space between the electrodes and causes, as by producing changes in space charge, unstable and nonreproducible operation.

At the end of the original specification, cancel claims 10 and 11.

In the amendment of December 26, 1915:

Substitute for claim 12:

N15

10. An electrical discharge device comprising a gas-tight envelope, an electron-emitting cathode, a cooperating anode, and a discharge-varying conductor, the space in said envelope being evacuated to below the pressure at

N15

which deleterious gas ionization takes place, constituting a device in which the current passed when operated below saturation and over a working range of voltage materially above the ionization voltages is controlled by space charge substantially unaffected by positive ionization.

a' follows

Insert a

Cancel claim 13.

Renumber claim 14 as claim 11.

Substitute for claim 15:

n16

a 12. An electrical discharge device, comprising a gas-tight envelope, an electron emitting cathode, an anode deprived of ionizable gas and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that when operated below saturation and materially above the ionization voltages, the current is controlled by space charge substantially unaffected by positive ionization.

In the amendment of April 30, 1914:

Cancel claim 16.

In the amendment of December 17, 1914:

Substitute for claim 1[illegible]:

13. An electrical discharge device comprising a gas-tight envelope, an electron emitting cathode, a cooperating anode, the space and materials in said envelope being sufficiently free of gas so that substantially no positive ionization occurs when the impressed voltage is as high as 60 volts, and the current over a working range of voltage up to 60 volts varies with the 3/2 power of the impressed voltage.

Cancel claim 18.

Substitute for claims 19 to 22 inclusive:

n 18

4 14. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to 100 volts with currents up to 1 milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said envelope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

15. A device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which no ionizable gas can be evolved at operating voltages up to about 200 volts with operating currents up to about five milliamperes, the space in said envelope being evacuated at a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that with currents up to about five milliamperes at voltages up to about 200 volts, evidences of positive ionization are substantially absent and the current over a working range below saturation varies with the 3/2 power of the voltage.

16. An electrical discharge device comprising a sealed envelope, an incandescent cathode, and a tungsten anode, said anode deprived of ionizable gas disengageable by electron bombardment, and the space in said envelope being evacuated to a sufficiently low pressure so that current flow produces substantially no phenomena of positive ionization when the impressed voltage is as high as 100 volts and the current is as large as 1 milliampere,

and the energy of the discharge is delivered mainly upon said anode.

17. An electron discharge apparatus comprising an envelope, an electron emitting cathode, and an anode, said anode being free of gas disengageable by electron bombardment and said envelope being sufficiently free of gas, so that conduction of current can take place in the evacuated space independently of gas ionization at voltages materially above the ionizing voltages with currents of more than one-tenth of a milliampere, and with the energy of the discharge delivered mainly at said anode.

In the amendment of March 10, 1916:

Cancel claims 24 and 25.

Substitute for claims 26 and 27:

9

19

18. An electrical discharge device comprising a sealed envelope, a cathode, means for producing emission of electrons at said cathode independently of the operating voltage, an anode, and discharge varying means independent of the cathode and anode, said device being freed from gas to such extent that the same is operable to transmit current at an impressed voltage at least as high as about 200 volts without evidences of substantial positive ionization.

19. An electrical discharge device comprising a sealed envelope, an incandescent cathode, an anode and discharge-varying means independent of the cathode and anode, the gas residues in said device being so small that the conduction of current is stable and reproducible over a range of voltage materially above the ionization voltages with currents in excess of one milliampere and with the energy of the discharge delivered mainly upon electrodes.

23 31

In the amendment of April 29, 1916:

Cancel claims 25 and 28.

In the amendment of June 22, 1916:

Cancel claims 29, 30, 31 and 32.

In the amendment of January 29, 1917:

Cancel claims 33 and 34.

Change the number of claim 35 to 20.

Cancel claims 36 and 37.

In the amendment filed May 19, 1919:

Claim 4, line 4, from the end, cancel the comma.

Claim 7, line 7, change "electrons" to

- electrodes -

In the amendment filed March 15, 1921:

Change the numbers of claims 38 and 39 to

21 and 22, respectively.

Add the following claims:

20
n

- 23. A discharge device comprising a tube and electrodes therein, ~~one~~ of which is a cathode, the discharge passing in the main directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltages, that the slope or location of the logarithmic line of current with respect to voltage is not changed by changes in the temperature of the cathode.-

- 24. A discharge device comprising a tube and electrodes therein, one of which is a cathode adapted to be heated and to emit electrons thereby, the discharge passing directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltage, that the plot of the current against the voltage is not changed with changes in the temperature of the cathode.

25. A discharge device comprising a sealed off envelope having therein a cathode adapted to be heated independently of the discharge and to deliver electrons thereby, and an anode, the inner wall of the envelope and the electrodes being sufficiently free of occluded gas, and the free gas within the envelope being such, so that the finished device is capable of sustained operation below saturation in a stable and reproducible manner with currents of more than one milliampere at voltages materially higher than the ionization voltages and with the energy of the discharge delivered mainly at an electrode or electrodes.

26. A discharge device comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes, the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge, so that the device is capable of passing a sustained discharge of one tenth of a milliampere at forty volts, without developing any substantial positive ionization effects.

27. A discharge device comprising a sealed off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge

and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of one milliampere at fifty volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

28. A discharge device comprising a sealed-off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of two milliamperes at one hundred volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

29. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to forty volts with currents up to one-tenth milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said envelope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

30. In the process of producing a discharge device, removing the occluded gas from the interior surface of the envelope thereof and from the electrodes to such an extent that the finished sealed-off device will operate, without liberating any substantial amount of gas into the

space within the envelope, at voltages materially above the ionization voltage with currents greater than one milliampere and with substantially all the energy of the discharge delivered to an anode or anodes.

31. In the process of producing a hot cathode discharge device, treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein, continuing these operations until the occluded and original free gas is so thoroughly removed as to enable the finished sealed-off device to operate below saturation in a stable and reproducible manner at a voltage above fifty volts and with a current greater than one milliampere and with the energy of the discharge delivered mainly at one or more anodes.

32. The process of producing a discharge device which consists in treating the envelope and enclosed parts thereof to liberate gas therefrom and removing from the envelope gas which is thereby liberated and free gas originally contained in the envelope, the treatment being sufficiently powerful and being sufficiently prolonged and the removal of the liberated and original free gas from the envelope being sufficiently thorough, so that the finished sealed-off device is capable of sustained operation substantially without positive ionization at voltages as high as one hundred volts with currents as great as one milliamper, and with substantially the entire energy of the discharge delivered upon the anode or anodes of the device.

REMARKS

Claims 1 to 9 inclusive, and claims 11, 20, 21 and 22, were the counts in the interference and have not been changed except to correct obvious clerical errors in claims 4 and 7.

Claim 10 and claims 12 to 19 inclusive, are respectively prior claims 12, 15, 17, 19, 20, 21, 22, 26 and 27, all amended to more clearly or more accurately define the invention with the aid of the light thrown thereon during the interference.

Claims 23 to 32 inclusive, are new claims which are believed to define the invention so clearly as to render discussion thereof here unnecessary.

Prior claims 10, 11, 13, 16, 18, 23, 24, 25, 28 29, 30, 31, 32, 33, 34, 36 and 37 have been cancelled, some because they did not accurately or sufficiently define the invention and others because they did not state the invention as clearly as do the remaining claims as now presented. Among the cancelled claims are the claims which were withdrawn in the interference and which the Law Examiner refused to add to the issue or dissolved out of the same.

The case is believed to be in condition for allowance and an early allowance is requested.

Respectfully submitted,

Alexander S Lunt

Attorney for LANGMUIR

Schenectady, New York,
July 30 , 1925.

FB/CAL

770

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

9—1810

Serial No. 84242

Div. 8

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON Sep. 23, 1925.

Irving Langmuir, Assor to General Electric Company, a corp. of N. Y.

Sir: Your **APPLICATION** for a patent for an **IMPROVEMENT** in ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING AND USING THE SAME filed Oct.16,1913 has been examined and **ALLOWED** (32 claims).

The final fee, **TWENTY DOLLARS**, must be paid not later than **SIX MONTHS** from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed within two years after the date of this notice with an additional fee of $20, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you should also send, **DISTINCTLY AND PLAINLY WRITTEN**, the name of the **INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE** (which is the date of this circular), **DATE OF FILING**, and, if assigned, the **NAMES OF THE ASSIGNEES.**

If you desire to have the patent issue to **ASSIGNEES**, an assignment containing a **REQUEST** to that effect, together with the **FEE** for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of **TEN CENTS EACH**. The money should accompany the order. Postage Stamps will not be received.

Final fees will **NOT** be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

Thomas E. Robertson
Commissioner of Patents.

Alexander D. Lunt.
Schenectady,
New York.

11—[illegible] G P O

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

101

27.

9

MEMORANDUM

OF

FEE PAID AT UNITED STATES PATENT OFFICE.

(Be careful to give correct Serial No.)

September 24 1925
191

Serial No. 84,242.

INVENTOR:

Irving Langmuir

PATENT TO BE ISSUED TO

General Electric Company

NAME OF INVENTION, AS ALLOWED:

Electrical Discharge Apparatus and the Process of Preparing and Using the Same.

DATE OF PAYMENT:

September 24 1925.

FEE:

$20.00

DATE OF FILING:

Renewed Mar. 14 1916.

DATE OF CIRCULAR OF ALLOWANCE:

September 23, 1925.

The Commissioner of Patents will please apply the accompanying fee as indicated above.

A. D. Lunt
Attorney.

SEND PATENT TO

A. D. Lunt
c/o General Electric Company
(Patent Dept)
Schenectady,
New York

Sig. 8.

772

ISSUE DIVISION
SEP 25 1925
U. S. PATENT OFFICE

Paper 30

IN THE UNITED STATES PATENT OFFICE

B

In re Application of :
IRVING LANGMUIR :
Serial No. 84,242, : ELECTRICAL DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.
Filed October 16, 1913, :
Renewed March 14, 1916, :
Allowed September 23, 1925. :

Honorable Commissioner of Patents,

Sir:-

It is respectfully requested that the attached supplemental oath be filed with the above-entitled application.

Respectfully,

Attorney for LANGMUIR

Schenectady, New York,
September 24, 1925.

HO/GAL

773
Paper 30

10-181-C 300 3-9-23

25
L

IN THE UNITED STATES PATENT OFFICE

In re Application of

Irving Langmuir	Electrical Discharge Apparatus and the Process of Preparing the Same
Serial No. 84,242	
Filed October 16,1913	
Renewed March 14, 1916	
Allowed Sept. 23, 1925	

SUPPLEMENTAL OATH

State of New York
County of Schenectady } ss:

Irving Langmuir, whose application for Letters Patent for an improvement in Electrical Discharge Apparatus and the Process of Preparing the Same Serial No. 84,242 was filed in the United States Patent Office on or about the 16th October 1913, being duly sworn, deposes and says that the subject matter of the claims, as they now stand amended, was part of his invention, was invented before he filed his original application, above identified, was not known or used before his invention, was not patented or described in a printed publication in any country more than two years before his application, was not patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to his application, was not in public use or on sale in this country for more than two years before the date of his application, and has not been abandoned.

Irving Langmuir

Sworn to and subscribed before me this
24th day of September, 1925
Paul S. [illegible]
Notary Public

774 ~~Report No. 39.~~

United States District Court

District of Delaware.

#31

HONORABLE COMMISSIONER OF PATENTS,
Washington, D. C.

SIR:

In compliance with the Act of February 18, 1922 (~~42~~ 42 Stat. L.), you are advised that there was filed on the 26th day of January, 1926, in this court an action, suit, or proceeding No. 939 In Equity entitled:

Name General Electric Company, a corporation of the State of New York, Plaintiff,
Address Schenectady, N. Y.

versus

Name The DeForest Radio Company, a corporation of the State of Delaware., Defendant,
Address

brought upon the following patents:

	PATENT NO.	DATE OF PATENT	PATENTEE
1	1,558,436	Oct. 20, 1925	Irving Langmuir
2			
3			
4			
5			

In the above-entitled case, on the day of , 192

the following patents have been included by (insert amendment, answer, cross bill, or other pleading):

	PATENT NO.	DATE OF PATENT	PATENTEE
1			
2			
3			
4			
5			

In the above-entitled case the following decision has been rendered or decree issued:

In witness whereof I have affixed my hand this twenty-eighth day of January, 1926, at Wilmington, Delaware.

H C Mahaffy Jr
Clerk of said Court.

Oct. 20, 1925. **1,558,436**

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS AND PROCESS OF PREPARING AND USING THE SAME

Original Filed Oct. 16, 1913

Fig.1.

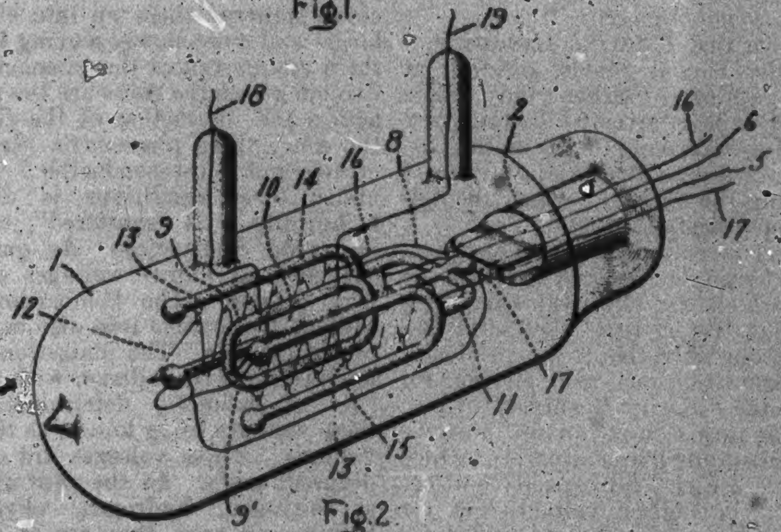

19
18
16
6
5
2
8
16
14
10
13
9
17
1
12
17
11
15
13
9'

Fig.2.

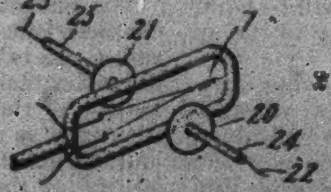

23
25
21
7
20
24
22

Fig.3.

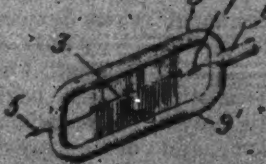


Fig.4.

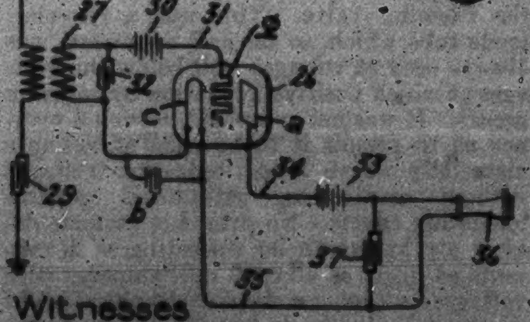
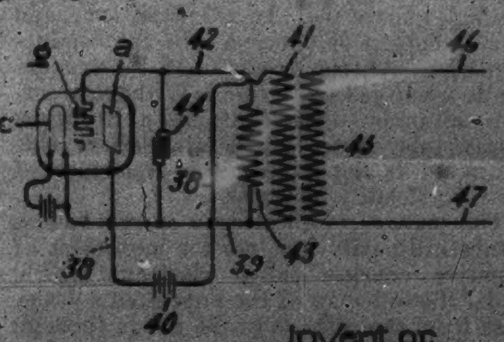

28
27
30
31
S
26
32
C
a
29
b
34
33
37
36
35

Fig.5.


S
a
42
41
46
C
44
45
38
47
38
39
43
40

Witnesses

J. Ellis Glen

Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

Patented Oct. 20, 1925. **1,558,436**

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRICAL DISCHARGE APPARATUS AND PROCESS OF PREPARING AND USING THE SAME.

Application filed October 16, 1913, Serial No. 795,610. Renewed March 14, 1916. Serial No. 84,342.

To all whom it may concern:

Be it known that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical Discharge Apparatus and Processes of Preparing and Using the Same, of which the following is a specification.

The present invention relates to electrical vacuum discharge devices, and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization such as occurring, for example, in the ordinary Roentgen tube.

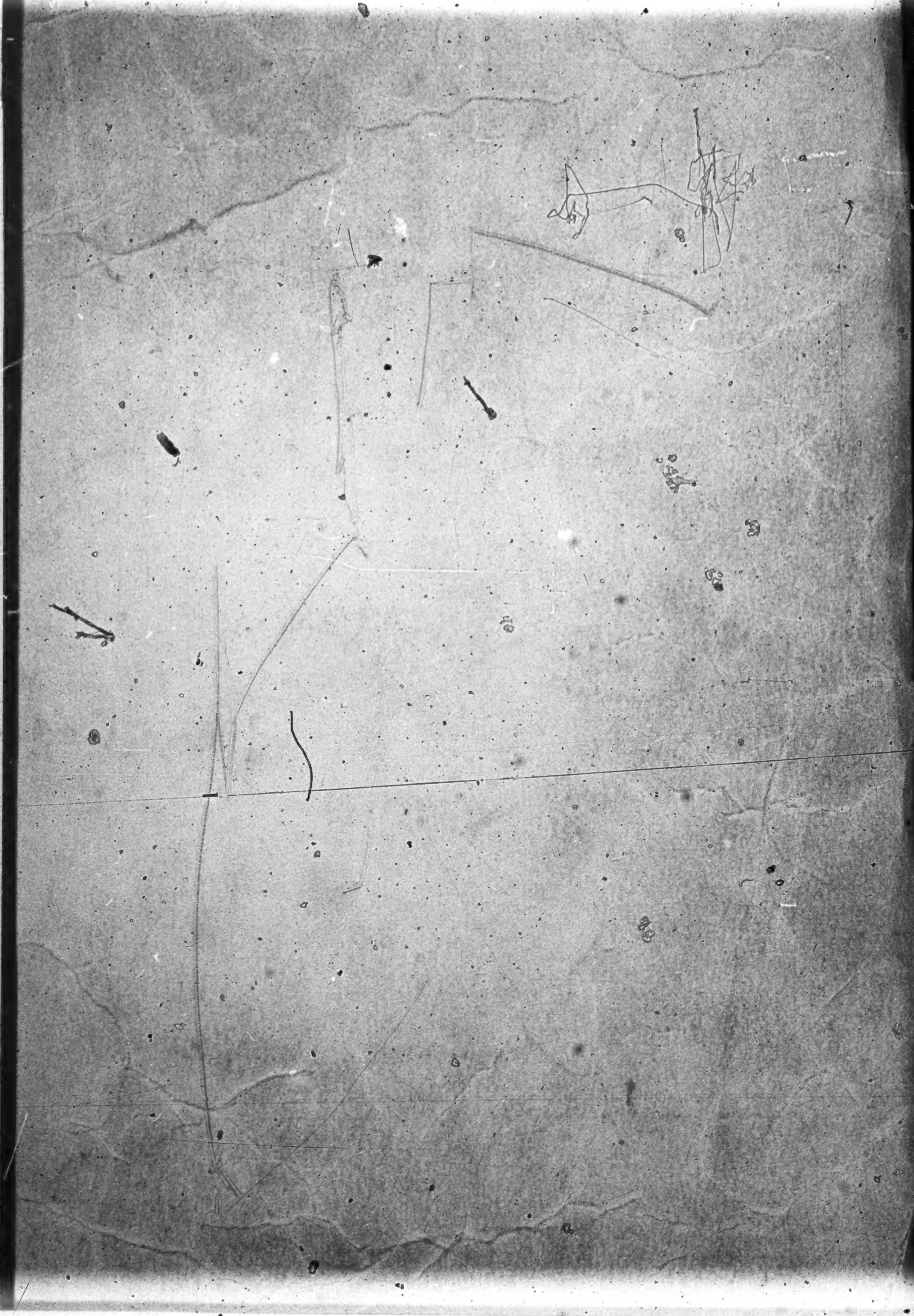
My present invention comprises improvements in electron-discharge apparatus which make possible a high load capacity and operation with the highest voltages but the invention is also applicable and useful for moderate loads and moderate voltages. The novel features of my invention will be pointed out with greater particularity in the appended claims.

Figs. 1 and 2 of the accompanying drawings, Fig. 2 being a partial view, illustrate two types of discharge devices embodying my invention; Fig. 3 is a fragmental view showing a cathode construction, and Figs. 4 and 5 are diagrams of electrical systems illustrating certain applications of my electron discharge tubes.

In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas. In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas a Roentgen X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the vacuous space. If these electrons when moving above a certain velocity collide with gas molecules they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of the electrons and the ions; these phenomena are in general erratic and non-reproducible. The cathode under these conditions is disintegrated, technically it is "sputtered", which causes its rapid destruction. As gas ionization continues at higher voltages a blue glow may appear. The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. These voltages are different for different gases. In the case of gases such as nitrogen, hydrogen, oxygen, argon, helium and neon, they are of the order of magnitude of fifteen to twenty-five volts.

The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device with three electrodes known as the "Audion." This device has been used as a receiver for radio-telegraphy and depends in its operation upon the rapid change of the discharge current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts. Another discharge device previously used to some extent was the Fleming valve. This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the voltages at which positive ionization by collision occurs. It was not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects. No prior hot cathode devices are known to me operating with currents as great as about 5 milliamperes with voltages as high as about 200 volts; indeed no prior discharge devices are known to me operating in a practically usable manner and without substantial positive ionization



effects with currents as great as about one-tenth of a milliampere with voltages as high as about forty volts.

In devices made in accordance with my invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas. The cathode is not heated by the discharge itself. Blue glow, glass fluorescence and in fact all readily visible indications of a discharge are ordinarily absent. In most devices of simple construction which embody my invention, the discharge current passing through a given space with the cathode at a sufficiently high temperature with respect to the voltages employed, varies directly with the 3/2 power of the impressed voltages. This 3/2 power law can be readily derived mathematically for a tube in which there is substantially no positive ionization on the assumption that the whole surface of the cathode is at a uniform potential; that the electrons escape from the cathode with negligible velocities and that the walls of the tube do not carry appreciable electric charges.

In most simple devices embodying my invention, these conditions are so well fulfilled that the current does vary in proportion to the 3/2 power of the voltage over wide ranges of voltage above the ionizing voltages. This means that if the logarithm of the current is plotted against the logarithm of the voltage, the resulting plot is a straight line whose slope is 3/2. Or, in many cases it is more convenient to make use of the equivalent relation, that the 2/3 power of the current plotted as ordinates against the anode voltages as abscissae gives a straight line.

In devices in which there is substantial positive ionization, on the other hand, even when the pressure of gas are so low that only very small currents could be carried by positive ions, the currents begin to increase with voltage more rapidly than according to the 3/2 power law as soon as the anode voltage materially exceeds the ionizing potential of the gas.

In devices embodying my invention which have more than two electrodes, or with special constructions as where the cathode is a filament, so long that it cannot be considered an equi-potential surface, the 3/2 power law may be more or less masked. However, the effects thus introduced will be readily understood by those skilled in the art, and appropriate methods of identifying the pure electron discharge can easily be found corresponding to the special construction. For example, when such tubes have more than two electrodes and the temperature of the cathode is sufficiently high with respect to the voltages employed, the discharge will usually be characterized by a linear relation between the 2/3 power of the total electron current from the cathode and the voltage applied to any other electrode, the remaining electrodes being kept at constant potential. Another test that can often be made with a three electrode tube is to connect the grid directly to the anode, or to the negative end of the cathode, and observe whether the current varies as the 3/2 power of the voltage.

If for a given cathode temperature the voltage is sufficiently high to cause all of the electrons emitted or liberated at the cathode to be drawn away, then a further increase in voltage produces substantially no change in the current. The current thus determined is called the saturation current, and the range of operation in which the current is substantially independent of the voltage or approaches this condition may be called the saturation range or more briefly designated merely as saturation. If for a given cathode temperature the voltage is not high enough to cause all of the electrons which are emitted or liberated at the cathode to be drawn away, the operation occurs in a range below the saturation range. Operation in this range may be spoken of as operation below saturation.

A change in the temperature of the cathode in a hot cathode device embodying my invention will produce no change in the discharge when the operation is below saturation, even though the ionization voltage is materially exceeded. That is, the current-voltage curve is not changed by a change in the cathode temperature under such conditions.

The discharge in devices embodying my invention is practically independent of the pressure when the pressure is below a certain value which depends upon the size and shape of the device and upon the current and voltage of the discharge.

As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterized by regularity and reproducibility with given conditions. In a device in which the conduction of current is purely electronic, and the effect of positive ions is negligible, the conduction of current is governed, over a certain range, on the one hand by the effect of the impressed voltage, which tends to propel the electrons across the vacuous space, and on the other hand by the mutual repulsion of the electrons in the space, which tends to limit or inhibit the current. This last mentioned phenomenon, the current limiting effect of the electric field of the electrons on each other, termed the "space charge effect," is discussed and analyzed by me in a paper read before the Physical Society on October 18, 1913, which was abstracted in the Physical Review for November, 1912, and published in full in the Physical Review for December, 1913, and again published in somewhat modified form in the Physikalische Zeitschrift for April 1, and May 15, 1914. It is the basis of the 3/2 power law referred to herein.

The geometric proportions of the device also affect the amount of current which will pass with a given voltage, but as these conditions remain fixed for a given device they may be represented by a constant in an equation expressing the relation between the current and the voltage.

As stated above, the current (I) in the particular device described herein, when operating below saturation, will vary with the 3/2 power of the voltage (V), the equation being:

$$I = aV^{3/2}, \text{ (a being a constant)}$$

As is well known, if we produce a logarithmic graph of any equation in which one variable of the equation varies as a power of the other variable, as for example, an equation of the general form $y = ax^n$, (as by plotting logarithms of x as abscissæ and logarithms of y as ordinates) we find that this graph is a straight line. Hence the relation between current and voltage in a device operating below saturation and by pure electronic conduction independent of gas ionization may be expressed by the statement that when with a sufficient electron emission the logarithms of the current values transmitted between cathode and anode are plotted as ordinates against the logarithms of the respective voltages impressed between cathode and anode as abscissæ, the slope of the line obtained does not ordinarily increase for increasing voltage values over a working range of voltages extending materially above the ionization voltages.

A substantial amount of positive ionization ordinarily causes the logarithmic plot of the current with respect to the voltage to bend upwardly and away from the 3/2 power line when the ionizing voltage is materially exceeded. The absence of a bend in the logarithmic plot at voltages somewhat above the ionization voltage is ordinarily a reliable indication that the tube is a pure electron discharge tube, though saturation complete or partial at voltages somewhat greater than the ionization voltages may prevent such a bend in the plot of an ionizing tube.

As above indicated, one of the indications of positive ionization is the occurrence of erratic readings in measuring devices connected in circuit with an electron discharge device under observation. Such erratic readings, of course, will produce a sudden change or discontinuity in the logarithmic graph plotted as above described, and any such irregularities will be more manifest when observed as deviations from a straight line than when the readings are plotted directly.

The effect of positive ionization upon the magnitude of the discharge is especially marked in that region of operation where the current is limited by the space charge effect already discussed, and changes in curvature of the discharge characteristics may occur as indicated unaccompanied by any visible evidence of ionization such as blue glow or the like. At saturation on the other hand, the discharge is ordinarily much less sensitive, and in fact the discharge may actually exhibit marked blue glow effects along with a flat or straight saturation curve.

Devices made in accordance with my invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents, and such devices may be made which will operate without substantial positive ionization at voltages far above the ionization voltages with currents thousands of times greater than the currents at which the devices of the prior art were operable without substantial positive ionization. Devices made and operated in accordance with my invention are capable of transmitting currents materially exceeding one-tenth of a milliampere without causing positive ionization to take any essential part in the operation of the device, though the voltage is materially above the ionization voltages.

Before describing the method of preparing my new type of apparatus, I will describe the structure of the apparatus illustrated by Figs. 1 to 3.

As shown in Fig. 1 the various parts of the apparatus may be mounted in a tube, or envelope 1, upon a pedestal 2, similar to the mount used in incandescent lamps. The cathode 3 is centrally located and may consist of a short straight filament not shown in Fig. 1, but indicated by the position of terminals 5, 6, and shown plainly in Fig. 3. The cathode shown in Fig. 2 consists of a V-shaped conductor. Either form may be used, the particular form of cathode being ordinarily determined by convenience of construction. Preferably the cathode conductor is held taut by a spring 7 to avoid contact of the cathode conductor with the grid by sagging when the metal is expanded at a high temperature. The filament 3 is mounted between two oppositely disposed supports, 9, 9′, in this case constituting a closed loop, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this frame-work is wound a discharge-varying conductor 10, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. By means of this grid 10 potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge.

The supporting framework for the cathode and grid is attached to a rod 11, mounted upon the stem of the tube. Adjacent to the cathode and grid is the anode 12 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 13 upon fork-shaped supports 14 and 15, but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 16 and 17. The grid is indicated in Fig. 1 as being attached to leading-in conductors 18 and 19 at opposite ends, although but one terminal is ordinarily necessary.

In some cases it is desirable to use a plate shaped anode; Fig. 2 illustrates such an arrangement suitable particularly for rectifying alternating current. The tube itself and other extraneous parts have not been shown in Fig. 2, as they are similar to Fig. 1. The cathode construction has already been referred to and the anodes 20 and 21 also preferably consist of tungsten and may be connected electrically with each other. Current connections are made by conductors 22, 23, the supports 24, 25 being merely indicated. It will be noted that both in Figure 1 and Figure 2 the electrons are afforded a short and direct path from the cathode to the anode and that this path is so related to the position of the walls of the tube as to minimize the tendency for electrons to pass to the walls of the tube. In such a tube electron bombardment of the walls of the tube is avoided, together with the heating of such walls and the secondary emission of electrons therefrom which said bombardment causes. The energy of the discharge is delivered mainly, or entirely, at the anode, anodes, or upon other interior members instead of at the walls of the tube.

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. The heating, especially of solid anodes such as shown in Figure 2, may take place in a suitable vacuum furnace, the temperature preferably being raised to 2,500° C. or even higher. Bombardment is a very effective means of removing occluded gas from anodes.

The bombardment is carried out when the evacuation has proceeded to a high degree by applying a potential between the cathode 8 and the anode 12, Fig. 1, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionization, and as already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon. The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50,000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating voltage. In the case of a plate-shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes.

After the metal has been freed from occluded gas reabsorption of gas will not readily take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated with less electron bombardment of the anode or anodes.

The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionization by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow, disintegration of the cathode, and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance. It is also true that when the anode has been carefully freed from gas, residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated.

Electron discharge apparatus thus provided with a gas-free pretreated anode or anodes, may be constructed to handle currents at a very high voltage by proper mechanical design of the parts subjected to static strains, suitable proportioning of the parts and so forth as described, for example, in my application Serial No. 795,600 filed concurrently herewith upon which Patent 1,273,788 was granted on July 23, 1918.

The asymmetric conductivity existing between the heated and unheated electrodes of a device of the character described may be utilized for various technical purposes. Reference has already been made to the rectification of current. As shown in Fig. 4 an electron discharge tube may be used for detecting electromagnetic waves in radio-telegraphy. As shown in this Fig. 4 the grid *g* and heated cathode *c* of an electron discharge tube 26 are connected respectively to the terminals of the secondary of a transformer 27, the primary of which is included in the antenna circuit 28. The antenna is grounded through a condenser 29 in the usual manner. The cathode *c* is heated by a local source of energy, as battery *b*. A battery 30 in the grid circuit 31 has its negative terminal connected to the grid *g*. A condenser 32 shunts the secondary of the loosely coupled transformer 27. The inductance of the transformer and the capacity of the condenser are adjusted to make the receiving circuit resonant to the frequency of the oscillations to be received. The oscillations set up by the incoming signals are superimposed upon the negative grid potential and causes a variation of current transmitted between cathode *c* and anode *a* by a local source of energy such as a battery 33 included in the local or plate circuit 34, 35, of the discharge tube. This circuit is connected to an ordinary telephone receiver 36, preferably shunted by means of a condenser 37, whereby the signals are detected.

Fig. 5 illustrates how an electron discharge tube may be used in a system for producing alternating current from direct current. The anode *a* and cathode *c* are connected respectively to conductors 38, 39, one of which includes a local source of energy, such as a battery 40. The terminals of these conductors are connected to an inductive coil 41. The cathode and grid *g* are also connected respectively by conductors 39 and 42 to a second inductive coil 43 which may be in a variable inductive relation to the coil 41. As soon as a flow of current starts in the plate circuit 38, 39, current is induced in the coil 43 of the grid circuit 39, 42. When by reason of this current the grid becomes negatively electrified, the flow of current in the plate circuit is reduced, and as the plate current decreases the grid electrification changes to positive, which again allows the current in the plate circuit to increase. These changes take place with a frequency depending on the electrical characteristics of the circuits. Across the grid circuit 39, 42, of the discharge tube, in some cases is connected a condenser 44, the capacity of which may be varied to control the frequency of the oscillations set up by the system. The oscillations may be transformed to higher or lower voltage by a transformer coil 45 to the terminals of which are connected transmitting conductors 46, 47. The system shown in Fig. 5 is described and claimed in a copending application, Serial No. 797,-987, filed October 29, 1913.

Residual gas, left in a tube when it is sealed off or occluded gas driven off from the inner wall of the tube, or from the electrodes, during the use of the tubes, varies in pressure from time to time according to the conditions of operation of the tube and may produce irregularities in the discharge when operating in the saturation region as well as when operating below saturation. The irregularities below saturation are due mainly to the disturbing effect of the resulting positive ions upon the space charge. The irregularities in the saturation region are due to changes in the rate of emission or liberation of electrons at the cathode. It is obvious that the advantages of stable and reproducible operation and freedom from destructive bombardment of the cathode by positive ions, which advantages are severally or collectively to be secured by the means hereinabove described, are not limited to operation below saturation but are also important in operation in the saturation region.

The positive ionization herein referred to is that positive ionization which occurs as the result of collisions between electrons and gas molecules in the space between the electrodes and causes, as by producing changes in space charge, unstable and non-reproducible operation.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the governing or limiting action on the space current due to the electric field of said electrons is substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

2. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization.

3. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

4. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed upon electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the slope of the line obtained by plotting the logarithms of values of said current as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae shows no increase for increasing voltage values.

5. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous.

6. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the tube and when the electron emission has any value such that the space current is below the saturation region at such voltages that said current varies as the three halves power of said impressed voltages.

7. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

8. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, substantially unaffected by positive ionization, the heating effect in the tube due to said current occurring substantially only at one or more of said electrodes.

9. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage

of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization with currents of at least 5 milliamperes and with voltages of at least 200 volts.

10. An electrical discharge device comprising a gas-tight envelope, an electron-emitting cathode, a cooperating anode, and a discharge-varying conductor, the space in said envelope being evacuated to below the pressure at which deleterious gas ionization takes place, constituting a device in which the current passes when operated below saturation and over a working range of voltage materially above the ionization voltages is controlled by space charge substantially unaffected by positive ionization.

11. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable, positive ionization when the impressed voltage is as high as 200 volts

12. An electrical discharge device, comprising a gas-tight envelope, an electron emitting cathode, an anode deprived of ionizable gas and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that when operated below saturation and materially above the ionization voltages, the current is controlled by space charge substantially unaffected by positive ionization.

13. An electrical discharge device comprising a gas-tight envelope, an electron emitting cathode, a cooperating anode, the space and materials in said envelope being sufficiently free of gas so that substantially no positive ionization occurs when the impressed voltage is as high as 60 volts, and the current over a working range of voltage up to 60 volts varies with the 3/2 power of the impressed voltage.

14. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to 100 volts with currents up to 1 milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said envelope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

15. A device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which no ionizable gas can be evolved at operating voltages up to about 200 volts with operating currents up to about five milliamperes, the space in said envelope being evacuated at a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that with currents up to about five milliamperes at voltages up to about 200 volts, evidences of positive ionization are substantially absent and the current over a working range below saturation varies with the 3/2 power of the voltage.

16. An electrical discharge device comprising a sealed envelope, an incandescent cathode, and a tungsten anode, said anode deprived of ionizable gas disengageable by electron bombardment, and the space in said envelope being evacuated to a sufficiently low pressure so that current flow produces substantially no phenomena of positive ionization when the impressed voltage is as high as 100 volts and the current is as large as 1 milliampere, and the energy of the discharge is delivered mainly upon said anode.

An electron discharge apparatus comprising an envelope, an electron emitting cathode, and an anode, said anode being free of gas disengageable by electron bombardment and said envelope being sufficiently free of gas, so that conduction of current can take place in the evacuated space independently of gas ionization at voltages materially above the ionizing voltages with currents of more than one-tenth of a milliampere, and with the energy of the discharge delivered mainly at said anode.

18. An electrical discharge device comprising a sealed envelope, a cathode, means for producing emission of electrons at said cathode independently of the operating voltage, an anode, and discharge varying means independent of the cathode and anode, said device being freed from gas to such extent that the same is operable to transmit current at an impressed voltage at least as high as about 200 volts without evidences of substantial positive ionization.

19. An electrical discharge device comprising a sealed envelope, an incandescent cathode, an anode and discharge-varying means independent of the cathode and anode, the gas residues in said device being so small that the conduction of current is stable and reproducible over a range of voltage materially above the ionization voltages with currents in excess of one milliampere and with the energy of the discharge delivered mainly upon electrodes.

20. An electrical device comprising the combination of a sealed evacuated envelope, a cathode adapted to be independently heated, and an anode within said envelope,

an external circuit connected to said electrodes, and a source of electro motive force applied to said circuit, the degree of vacuity and the electron emission of the cathode being so related to the potential of said source that the flow of current over a range of voltage materially above the ionization voltage is governed by the electric field of the electrons in the vacuous space and the potential applied to said electrodes, operatively independent of gas ionization.

21. Apparatus for controlling an electric current comprising a vacuum tube, an anode and an electron emitting cathode in the circuit of said current and within said tube, the degree of evacuation of the tube and the relation of its parts being such that for voltages materially above ionization voltage the current is governed or limited by the electric field of the electrons in said tube substantially unaffected by positive ionization, and a third electrode in said tube by which an auxiliary controlling electromotive force may be superposed to modify the effect of said electric field and control said current in a stable and reproducible manner.

22. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

23. A discharge device comprising a tube and electrodes therein, one of which is a cathode, the discharge passing in the main directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltages, that the slope or location of the logarithmic line of current with respect to voltage is not changed by changes in the temperature of the cathode.

24. A discharge device comprising a tube and electrodes therein, one of which is a cathode adapted to be heated and to emit electrons thereby, the discharge passing directly between electrodes, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated below saturation and at voltages materially higher than the ionization voltage, that the plot of the current against the voltage is not changed with changes in the temperature of the cathode.

25. A discharge device comprising a sealed off envelope having therein a cathode adapted to be heated independently of the discharge and to deliver electrons thereby, and an anode, the inner wall of the envelope and the electrodes being sufficiently free of occluded gas, and the free gas within the envelope being such, so that the finished device is capable of sustained operation below saturation in a stable and reproducible manner with currents of more than one milliampere at voltages materially higher than the ionization voltages and with the energy of the discharge delivered mainly at an electrode or electrodes.

26. A discharge device comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes, the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge, so that the device is capable of passing a sustained discharge of one tenth of a milliampere at forty volts, without developing any substantial positive ionization effects.

27. A discharge device comprising a sealed off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of one milliampere at fifty volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

28. A discharge device comprising a sealed-off envelope and electrodes therein, one of which is a cathode adapted to be heated independently of the discharge and to emit electrons thereby, the inner wall of the envelope and the electrodes being so free from occluded gas that the device is capable of passing a sustained discharge of two milliamperes at one hundred volts with the energy of the discharge delivered mainly at an electrode or at electrodes without liberating any substantial amount of gas into the space within the envelope.

29. An electrical discharge device comprising a gas-tight envelope, a cathode adapted to be heated to incandescence, an anode from which substantially no ionizable gas can be evolved at operating voltages up to forty volts with currents up to one-tenth milliampere, the envelope so shaped and the electrodes so positioned as to substantially avoid secondary electron emission from the wall of the envelope, the space in said en-

velope being evacuated to a pressure not in substantial excess of a few hundred thousandths of a millimeter of mercury.

30. In the process of producing a discharge device, removing the occluded gas from the interior surface of the envelope thereof and from the electrodes to such an extent that the finished sealed-off device will operate, without liberating any substantial amount of gas into the space within the envelope, at voltages materially above the ionization voltage with currents greater than one milliampere and with substantially all the energy of the discharge delivered to an anode or anodes.

31. In the process of producing a hot cathode discharge device, treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein, continuing these operations until the occluded and original free gas is so thoroughly removed as to enable the finished sealed-off device to operate below saturation in a stable and reproducible manner at a voltage above fifty volts and with a current greater than one milliampere and with the energy of the discharge delivered mainly at one or more anodes.

32. The process of producing a discharge device which consists in treating the envelope and enclosed parts thereof to liberate gas therefrom and removing from the envelope gas which is thereby liberated and free gas originally contained in the envelope, the treatment being sufficiently powerful and being sufficiently prolonged and the removal of the liberated and original free gas from the envelope being sufficiently thorough, so that the finished sealed-off device is capable of sustained operation substantially without positive ionization at voltages as high as one hundred volts with currents as great as one milliampere and with substantially the entire energy of the discharge delivered upon the anode or anodes of the device.

In witness whereof, I have hereunto set my hand this 15th day of October 1913.

IRVING LANGMUIR.

2—421

785

1913

CONTENTS:

1. Application ___ papers. O K
2. Amendt A Dec 29 1913
3. Rejection Feb 21 1914
4. Amdt B May 1, 1914
5. Rejection June 15 1914
6. Supl oath July 13 1914
7. Letter Aug 27-1914
8. Amendt C Dec 19-1914
9. Rejection Jan 12 1915
10. Amendt D Feb 17 1915
11. Amendt E (R. 78) Mar 30-1915
12. Exs amdt Apr 5-1916
13. Notice of entry of Amendt Apr. 5/15
14. Renewal Mar. 14 1916
15. Amdt F & Oath Mar. 14-1916
16. Amendt G Mar. 14-1916
17. Amdt H & Affdt (R. 78) Apr. 29-1916
18. Notice of entry of Amendt May 31/16
19. Letter June 15, 1916
20. Amendt I June 23-1916
21. Withdrawn from Issue July 19 1916
22. [illegible] Memo
23. Letter AUG 8 1916
24. Amendt K Jan 30 1917
25. Amendt L May 20-1919
26. Amendt M Mar 17-1921
27. Int'f Letter APR 5 1921
28. Genl Power of atty, Sept 7/22
29. Amendt N Sep 22-1925
30. Oath Sept 25, 1925
31. Notice of Suit Jan 29-1926
32.
33.
34.
35.
36.
37.
38.
39.
40.
41.
42.
43.
44.
45.
46.
47.
48.
49.
50.

DEFENDANT'S EXHIBIT No. 63.

DEPARTMENT OF THE INTERIOR,

UNITED STATES PATENT OFFICE.

[illegible] all persons to whom these presents shall come, Greeting:

THIS [illegible] TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper, Contents and Drawings, in the matter of the

Letters Patent of

Irving Langmuir, Assignor to
General Electric Company,

Number 1,244,216, Granted October 23, 1917,

for

Improvement in Electron-Discharge Apparatus and Methods of Preparation,

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-seventh day of August, in the year of our Lord, one thousand nine hundred and twenty-four and of the Independence of the United States of America the one hundred and forty-ninth.

Karl Fenning
Acting Commissioner of Patents.

DIV. 16 **1914** (EX'R'S BOOK) ~~236~~ 109-114-8

NUMBER (Series of 1900), ~~[illegible]~~ Series of 1915

176926

PATENT No. 1244216

Name Irving Langmuir
Assor to General Electric Company, a corp of N.Y.

of Schenectady
County of
State of New York
Invention
Electron Discharge Apparatus and Method of Preparation

Division of App., No. ________ filed ________ 191

PARTS OF APPLICATION FILED.

	ORIGINAL	RENEWED
Petition	July 15, 1914	June 25, 1917
Affidavit	" " , 1914	, 191
Specification	" " , 1914	, 191
Drawing	" " , 1914	, 191
Photo Copy	" 23, 1914	, 191
First Fee Cash	$15 July 15, 1914	$15, June 25, 1917
" " Cert	, 191	, 191
Appl. filed complete	July 15, 1914	June 25, 1917

	ORIGINAL	RENEWED
Examined and Passed for Issue	Nov. 6, 1915	Examined June 30, 1917
	Wm A Kinnan Exr. Div. 16	Wm A Kinnan Exr. Div. 16
Notice of Allowance	Nov. 22, 1915 By Commissioner.	July 2, 1917 By Commissioner.
Final Fee Cash	, 191	$20 Sept. 26, 1917
" " Cert	, 191	, 191

Patented OCT 23 1917 , 191

Attorney Albert G. Davis c/o General Electric Company
Schenectady N.Y.

Associate Attorney

(No. of Claims Allowed 11) Title as Allowed Electron Discharge Apparatus & Method of Preparation (a 250-27)
(O.G. Cls. 1,3,5,10)

Sig-9

B

1244216

PETITION

To the Honorable Commissioner of Patents:

Your petitioner Irving Langmuir

a citizen of the United States, residing at Schenectady

in the County of Schenectady State of New York

whose Post Office address is C/o General Electric Co., Schenectady, N. Y.,

prays that Letters Patent may be granted him for the improvement in

Electron Discharge Apparatus and Method of Preparation (D-19806)

set forth in the accompanying specification.

And he further prays that you will recognize Mr. Albert G. Davis, of Schenectady, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

Irving Langmuir

[illegible]

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN, that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the County of Schenectady, State of New York, have invented certain new and useful improvements in ELECTRON-DISCHARGE APPARATUS AND METHOD OF PREPARATION, of which the following is a specification.

The present invention relates to electrical devices operating with a pure electron discharge and comprises a novel cathode material and the method of its preparation.

In a previous application, Serial No. 795,610, filed October 16, 1913, I have described and claimed a new type of electrical discharge apparatus comprising an envelope containing electrodes one of which emits electrons and being so highly evacuated that positive ionization is negligible. Some of the characteristics of this "pure electron discharge" are absence of conductivity in the space between independent unheated electrodes, a variation of the current over a certain range with the 3/2 power of the voltage, the absence of blue glow in the space, the absence of gas fluorescence and the lack of cathodic disintegration.

Various refractory materials, platinum, carbon, tungsten and molybdenum, have been used as cathode materials and it has been found that the emissivity of electrons of these various materials while differing to some degree ~~are all~~ is of the same order of magnitude.

I have discovered that the electron emissivity of pure thorium is of an entirely different order of magnitude than the emissivity of refractory materials heretofore used in electron discharge devices. It is not necessary that the electrode should consist entirely of thorium. When, for example, a thorium compound, such as the oxid~~e~~, has been added during the process of production to one of the highly refractory metals, for example, tungsten, and the metal subjected to a preliminary heat treatment in a high vacuum, the electron emission in a high vacuum is enormously increased. This increased emissivity is not due to the presence of thorium oxid~~e~~ in the manner of the Wehnelt cathode for various reasons hereinafter explained, but according to all indications is a property of metallic thorium on the surface of the cathode.

Apparatus suitable for preparing and utilizing a thoriated cathode in an electron discharge apparatus is somewhat diagrammatically shown in the accompanying drawings, in which Fig. 1 shows a simple type of apparatus in which the anode consists of a film of refractory metal on the inside wall of the envelop~~e~~ produced by vaporizing a refractory metal at high temperature; Fig. 2 is a device operable as a rectifier having a thoriated cathode and plate-shaped anodes; and Fig. 3 illustrates a modification in which active thorium material may be transferred to the cathode from an independent thoriated conductor.

The device shown in Fig. 1 comprising an envelope 1 consisting of glass, quartz or the like provided with two filamentary conductors 2, 3, of highly refractory metal, such for example as tungsten, at least one of which, say filament 2, is thoriated. They are connected to leading-in wires 4, 5, sealed into a stem 6 in the well-known manner. The envelope is connected to a vacuum system by a tube 7, containing a trap 8 which may be surrounded by a freezing bath, such as liquid air, contained in a Dewar flask 9 or even an ice and salt mixture. It is the function of the freezing bath to prevent mercury, or other vapors, from the vacuum pumps from reaching the envelop~~e~~ 1.

The preliminary evacuation of the envelop~~e~~ is carried out by the usual methods of producing high vacuum, which includes baking out the envelop~~e~~ to remove water vapor. The final stages of the evacuation is preferably but not necessarily carried out by a Gaede molectlar pump to the highest possible vacuum obtainable by this means, - that is, to about .001 micron. While the apparatus is still on the pump the filaments 2, 3, are heated to a temperature of about 2900° K. (absolute) for a short time and the envelop~~e~~ 1 is baked out in an oven at a temperature of about 360 to 450° K. The apparatus may then be sealed from the vacuum system at the contraction 10. It is then preferably immersed in liquid air and both filaments 2,3 aged by heating for about 1/2 hour to a temperature of 2400 to 2500° K. One of the filaments, for example, filament 3, is then incandesced by a passage of current to a temperature of about 3000° K. which causes rapid vaporization of the metal, thereby producing a gas-free conducting deposit or coating 11 which has been shown on the inner surface of the envelop~~e~~. Conductors 12, 13 sealed into the envelop~~e~~ make contact with this coating and enable it to be used as an anode for an electrical discharge. A device having a gas-free film anode and the method of its preparation has been described and claimed by me in a co-pending application, Serial No. 843,569, filed June 6, 1914. The method of producing high vacuum by vaporizing tungsten is claimed by me in a co-pending application, Serial No. 838,768, filed May 15, 1914. Pressures much below .001 micron of mercury may be attained thereby. The cathode conductor 2 is prepared by introducing a thorium compound, such as the nitrate of thorium to the oxid~~e~~ of

Per B

B

the refractory metal before reduction, or by adding either ~~the~~ thorium nitrate or thoria to the metal powder after reduction but before consolidation of the metal by sintering and mechanical working to the solid metal state has taken place as described, for example, with reference to thoriated tungsten in U. S. patent No. 1,082,933. The proportion of thoria in the unsintered metal usually varies from about 1/2% to 10% but in some cases may be even greater. The proportion of thorium compound in the cathode within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but with a greater proportion of thorium compound the desired active condition of the filament may be reached and maintained with greater ease than with a lesser amount.

The thoriated cathode 2 is now heated to about 2900° K. for about one minute. The treatment of the filament at a temperature of 2900° has no marked effect on the subsequent electron emission of the cathode when at lower temperature but appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2400° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2300° K. and the treatment at this temperature is usually continued for about one minute, but even outside of this range a marked change is produced. Apparently a concentration of metallic thorium or of some other oxidisable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at a temperature below this forming temperature.

With a filament thus prepared I have obtained at a temperature of about 1300° to 1380° K. substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000° K., that is, about three milliamperes per sq. cm. Preferably a thoriated cathode is operated around 1700° to 1800° K., at which temperatures its life is indefinitely long.

Subsequently heating the filament to a higher temperature, for example, to 2800° K., causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure metal. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2300° K., the active condition is restored.

A similar heat treatment of pure tungsten has no effect on its electron emissivity at incandescence. The active thorium material may be transferred by distillation to an adjacent surface. For example, if the filament 3 consisting of pure tungsten has not been completely destroyed during the preparation of the apparatus, the heating of the cathode to a temperature above 2300° after the preparation of the surface film results in the distillation of some of the thorium material to conductor 3 so that when the conductor 3 is used as a cathode with respect to the anode 11, it is found that its electron emission has been greatly increased.

One of the most striking proofs that the active surface film is not due to the effect of the thoria as in the Wehnelt cathode is furnished by the effect of a minute trace of oxygen on the behavior of the cathode. If in some manner a trace of oxygen is admitted, the electron emission immediately falls as low or even lower than the low value observed when a cathode of pure tungsten is slightly oxidized. In other words, the electron emission becomes very much lower than that of the unoxidized metal. When subsequent to oxidation a trace of hydrocarbon vapor is admitted, the electron emission suddenly rises as though reduction were taking place. If the carbon is in excess, the electron emissivity immediately drops to a low value as though a carbide were formed with the excess of carbon. (3) B'

Insert B'

Cathodes containing only a small amount of thorium compound are deleteriously affected by disintegration of the surface produced by positive ion bombardment and in this respect may be extremely sensitive. In this case, it is necessary when using voltages high enough to cause ionization of residual gases to carry the vacuum far beyond the point at which a disruptive discharge no longer takes place, which ordinarily is about 1/10 of a micron of mercury pressure. The Wehnelt or oxide cathode apparently depends on positive ionization for its activity. At any rate its emissivity is increased by an increase in positive ionization. When large amounts of thorium are present in my improved cathode, it is not so sensitive to positive ion bombardment and it is possible to obtain to a large extent the advantages of a thoriated cathode even in the presence of pressures of gas up to atmospheric pressure.

Another proof that the high electron emission is due to a skin of thorium is the fact that metallic thorium itself, particularly when free from surface oxidation, exhibits a very high electron emissivity for a given temperature as compared with tungsten. Difficulties are encountered with the use of metallic thorium as cathode material due to its relatively low melting point and its susceptibility to oxidation ~~oxidation~~.

Rec B

At 2000° to 2300° K., the active thorium is slowly diffusing to the surface from the interior of the metal.

As the temperature is raised a point is reached where the distillation of thorium from the surface exceeds the rate at which the metal diffuses to the surfaces. It is possible, however, to operate a refractory thoriated cathode at a temperature between 2000° and 2200° K. for a long time without destroying its high electron emission, but operation at a higher temperature is not advisable. A sufficiently great electron emission can be secured through the indicated temperature range with an accompanying saving of energy necessary for heating the cathode.

The apparatus shown in Fig. 2 does not differ essentially from the apparatus shown in Fig. 1, plate-shaped anodes 15, 16 consisting of a highly refractory metal such as tungsten being used instead of the film anode of vaporized metal used in the apparatus shown in Fig. 1. The envelope 17 is baked out and evacuated as already described in connection with Fig. 1. The ionizable gas should be removed from the anodes during the final stages of the exhaust after the pressure has been reduced below about 1/10 of a micron of mercury by subjecting the anodes to an electron discharge from the cathode 18 whereby ionizable gas is evolved, as disclosed in my co-pending application, Serial No. 795,610 of October 16, 1913. This gas should be removed as fast as liberated and the discharge voltage progressively increased, care being taken not to materially exceed the voltage at which blue glow takes place so as to avoid injury to the cathode. The final stage of the evacuation is produced by vaporizing a tungsten conductor in a side chamber (not shown in the drawing), thereby producing the very high vacuum necessary for the operation of the thoriated cathode. The anodes 15, 16 may be both connected to one terminal of a secondary of the transformer

19, by conductors 20, 21, the cathode being connected to the other terminal by conductor 22, including a load circuit 23. The cathode 18 has been merely indicated by dotted lines as being a V-shaped filament supported by terminal wires 24, 25, and maintained taut at its bight by a spring 26, but it is to be understood that it may have any convenient form. Thorium compound, for example, the oxide, is introduced during the process of manufacture as already described. The apparatus here shown is suitable for the rectification of alternating current when the cathode is maintained at incandescence by a battery 27, preferably at a temperature of 1700 to 1800° K.

It is not absolutely necessary that the thorium should be introduced into the body of the metal during the process of manufacture. As shown in Fig. 3 a cathode 28 located opposite an anode 29 is provided with a film of active thorium material vaporized from the coiled filamentary cathode 30 heated by a battery 31. The cathode 30 may consist either of a thoriated cathode prepared as already described, or of metallic thorium. The enclosing envelope has not been shown, but it is to be understood that these parts are to be operated in the high vacuum already indicated as being desirable. When the coil 30 consists of thoriated wire it is first rendered active by heat treatment at a temperature of 2200° to 2300° K., as already described, and is then heated to a temperature of about 2900° K. to distill off active material, some of which is condensed on the cathode 28. When the coil 30 consists of metallic thorium, it should be heated to a temperature near its melting point to distill some of the thorium over on to the surface of the cathode 28.

As positive ionization is very much decreased at low voltages, it is permissible to have present an inert gas at a pressure of say .01 micron when the voltage impressed between the cathode and anode does not arise above the ionizing potential of the gas. Advantage can be taken of this fact to use an electron discharge device containing a thoriated cathode as a voltage sensitive cut-out device. Below the voltage at which disintegration of the surface begins, a device such as shown in Fig. 1 may be used to pass a current of about 3/10 of an ampere per sq. cm. when the cathode is at a temperature of about 1700° to 1800° K. When the voltage rises above the critical value, the current immediately drops to a very small value, thus practically interrupting the circuit. The cathode may be restored when the voltage has fallen by again heating it to about 2200° to 2350° K.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. In an electrical discharge device, an electrode comprising in part at least oxidisable thorium material, said electrode having at a temperature of about 1300 to 1380° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

Ⓑ

2. In an electrical discharge device, an electrode comprising in part at least oxidisable thorium and having when at incandescence in a vacuum so highly attenuated that positive ionization is substantially absent, an electron emission materially greater per unit of surface than tungsten at the same temperature.

3. A cathode for electron-discharge apparatus consisting largely of a highly refractory metal and a surface layer of material having an electron emissivity at a given temperature materially greater per unit surface than said refractory metal independently of and in the absence of positive ionization.

4. In a device operating by pure electron discharge independent of positive ionization, a conductor comprising a refractory metal and a surface film of thorium material vaporizable at a temperature above about 2300° ~~C.~~ K. and having a greater electron emission when at incandescence in a non-striking vacuum than said refractory metal.

Ⓑ

5. In an electrical discharge device, an electrode comprising metallic tungsten and a surface film of thorium material vaporizable at a temperature above about 2300° ~~C.~~ K. removable from said surface by positive ionization

Ⓑ

and having an electron emission per unit surface many times greater than pure tungsten at the same temperature.

6. In an electrical discharge device, an electrode comprising metallic tungsten and thoria said electrode having been subjected to a temperature of about 2200 to 2350° K. and having an electron emission a thousand times as great per unit of surface as tungsten in a vacuum too high to permit of positive ionization.

7. In an electrical discharge device, a cathode comprising metallic tungsten and thoria, said electrode having received a heat treatment at about 2000 to 2350° K. and having an electron emission when at incandescence at a given temperature of a higher order of magnitude than pure tungsten at the same temperature.

8. The process of preparing an electrode comprising a refractory metal and thoria for use in a pure electron discharge apparatus which consists in heating said electrode to a temperature adjacent the melting point of said refractory metal and then heating to a temperature of about 2200 to 2300° ~~K~~ absolute.

Per B

9. The process which consists in heating a conductor comprising tungsten and thoria to a temperature of about 2800 to 2900° absolute ~~K~~. and then lowering the temperature to about 2200 to 2300° absolute ~~K~~. holding said temperature for a short interval and finally operating said conductor as cathode in a non-striking vacuum at a temperature below 2000° absolute ~~K~~.

B

B

cls. 10-11

B

Insert B2

IN WITNESS WHEREOF, I have hereunto set my hand this 14th day of July, 1914.

Irving Langmuir

WGG:MD

WITNESSES:

William C. White,

Helen Orford

800

AFFIDAVIT

STATE OF New York }
COUNTY OF Schenectady } SS:

Irving Langmuir, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Schenectady in the County of Schenectady, State of New York, and that he verily believes himself to be the original, first, and sole inventor of the improvements in

Electron Discharge Apparatus and Method of Preparation

described and claimed in the annexed specification; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any country foreign to the United States.

Irving Langmuir

Sworn to and subscribed before me this 14th

day of July, 191

Helen Oxford
Notary Public.

[illegible]

19806

12

Fig. 2.

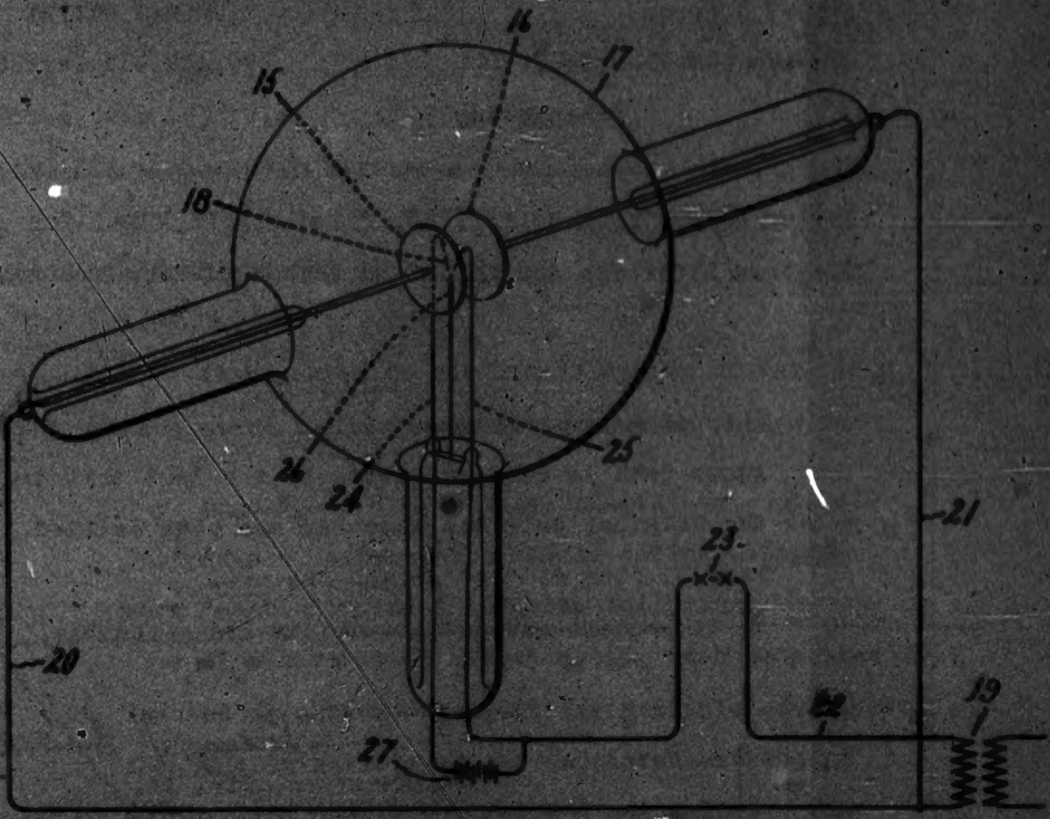
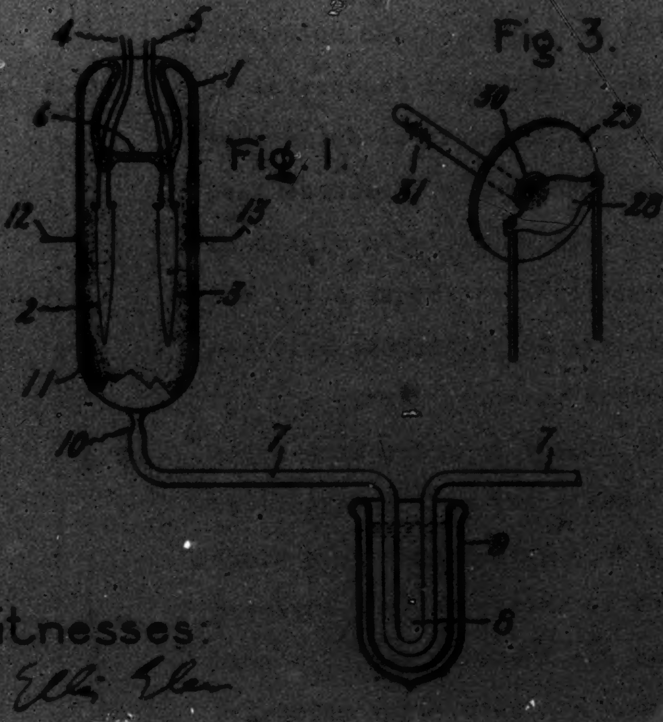

15
16
17
18
26
24
25
21
23
20
22
19
27

Fig. 3.

Fig. 1.


4
5
1
6
12
13
2
3
11
10
7
7
9
8
30
29
31
28

Witnesses:
J. Ellis Glen
Anthony Hart

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

802

Div. 16 Room 102. Go/E.

Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

S-580

Paper No. 2.
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON Oct. 3, 1914.

Albert G. Davis,
c/o Gen. Elec. Co.,
Schenectady, N.Y.

Please find below a communication from the ***EXAMINER*** *in charge of the application of*
Irving Langmuir, Sr. No. 851,095, filed Jy. 15, 1914, for
Electron Discharge Apparatus and Method of Preparation.

Thomas Ewing
Commissioner of Patents.

This case has been examined.

A new oath is required owing to the fact that the year in which the original oath was executed has been omitted.

Page 3, line 6, "is" should be are.

As at present advised the claims are allowable.

Sidney F. Smith
Actg Examiner, Div. 16.

AG

Q

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 851,095, : ELECTRON DISCHARGE APPARATUS AND METHOD OF PREPARATION.
Filed July 15, 1914, :
Div. 16, Room 109. :

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of October 3, 1914, please amend the above-entitled case as follows:-

✓ Page 3, line 6, change "stages" to - stage -

✓ Page 6, after the sentence ending with the word "carbon", line 6, add the following:

- When a volatile alkali metal, such as potassium, is used as a reducing agent for a thoriated cathode, the high emissivity of the thoriated cathode is quickly and easily secured and maintained. The potassium may be distilled into the main envelope or introduced in a thin walled exhausted glass capsule which is broken after the necessary vacuum has been produced in the envelope.. The advantages of an alkali metal, such as potassium, as a reducer are (1) a vapor pressure so low that objectionable positive ionization of its own vapor is negligible, (2) the strong reducing action maintains the thorium reduced in spite of traces of water vapor which may be liberated from the glass (3) the oxidation products of the potassium have no perceptible vapor pressure, (4) an excess of potassium does not combine with the filament and hence does no harm. Potassium vapor does not produce an increase of

Per B

Q

electron emission of a pure tungsten cathode.

Add the following claim:

~~10. A cathode for electron discharge apparatus consisting largely of tungsten and containing thorium having an electron emissivity at a given temperature materially greater per unit surface than tungsten at the same temperature independently of and in the absence of positive ionization.~~

A2

Sub B2

--------o--------

A new oath is herewith submitted as required by the Examiner.

An allowance is respectfully requested.

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Schenectady, N. Y.
October 8, 1914.

WCC/GAL

IN THE UNITED STATES PATENT OFFICE

IN RE Application of :
IRVING LANGMUIR, : ELECTRON DISCHARGE APPARATUS
Serial No. 851,095. : AND METHOD OF PREPARATION
Filed July 15, 1914. :
Div. 16, Room 109. :

A F F I D A V I T

State of New York :
ss.
County of Schenectady :

IRVING LANGMUIR, being duly sworn, deposes and says that he is a citizen of the United States and resident of Schenectady, in the County of Schenectady, State of New York, and that he verily believes himself to be the original, first, and sole inventor of the improvements in Electron Discharge Apparatus and Method of Preparation described and claimed in the above-entitled application; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to said application; or patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to said application; or in public use or on sale in the United States for more than two years prior to said application; and that no application for patent on said improvements was filed by him or his representatives or assigns in any country foreign to the United States prior to the filing of the said United States application.

Irving Langmuir

Sworn to and subscribed before me this 6th
day of October 1914.

Helen Orford
NOTARY PUBLIC

18

Div. 16 Room 101
Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

PK

Paper No. 6
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Nov. 9, 1914.

U. S. PAT. OFFICE
NO

Albert G. Davis,
c/o General Electric Co.,
Schenectady, N.Y.

Please find below a communication from the EXAMINER *in charge of the application of*

Irwing Langmuir, S.N. 851,095, filed July 15,1914, Electron Discharge Apparatus and Method Preparation.

Thomas Ewing
Commissioner of Patents.

In response to amendment filed Oct. 9, 1914.

As at present advised the claims in this case are each allowable, but the matter inserted after line 6, page 6 is found to constitute new matter, since no basis is found for this disclosure either in the original specification of this case, or in the specifications of the three applications referred to in this case. This insertion should accordingly be canceled.

JLG

Wm A Kinnan
Examiner Div. 16.

5 B

UNITED STATES PATENT OFFICE

B

In re Application of :
IRVING LANGMUIR :
Serial No. 851,095. : ELECTRON DISCHARGE APPARATUS AND METHOD OF PREPARATION.
Filed July 15, 1914. :
Div. 16, Room 103. :

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of November 9, 1914, please amend the above-entitled application as follows:-

Page 1, line 28, cancel "are all" and substitute - is

Page 4, line 1, after "either" cancel "the" and substitute - thorium -

Line 3, after "consolidation" insert - of the metal -

Line 23, after "and" insert - the treatment at this temperature -

Page 6, cancel the paragraph inserted by amendment after the sentence ending with line 6, and insert

Ex. Amdt.
B1

- In an application Serial No. 58,377 filed by me on October 28, 1915, I have more fully described and also claimed a thoriated cathode device containing reducing material. -

Line 30, correct the spelling of "oxidation" which in applicant's copy appears to end in "ien"

Claim 1, line 3, after "material" insert - , said electrode -

Claim 4, line 5, after "2300°" cancel "C" and substitute - K -

Claim 5, line 4, after "2300°" cancel "C" and substitute - K -

Claim 8, line 5, after "2300°" cancel "C" and substitute - absolute -

Claim 9, line 3, after "2000°" cancel "C" and substitute - absolute -

Line 4, after "2300°" cancel "C" and substitute - absolute -

Line 6, after "2000°" cancel "C" and substitute - absolute -

Cancel claim 10 and rewrite as follows:-

B^2

10. A cathode for electron discharge apparatus consisting largely of tungsten and containing thorium, said cathode having an electron emissivity, independently of and in the absence of positive ionization, at a given temperature materially greater per unit surface than tungsten at the same temperature.

Add the following claim:-

B^3

11. In an incandescent cathode device, an electrode comprising a highly refractory metal and containing oxidizable thorium material, said electrode having an electron emissivity per unit surface many times greater than said refractory metal alone at the same temperature, the electron emissivity of said cathode being lowered by the presence of oxygen and by positive ionization. ?

Remarks

The matter inserted on page 6 has been canceled and a new application has been filed in which this disclosure has been embodied.

The allowed claim 10 has been rewritten to improve the construction but in substance the claim has not been changed.

The new claim added expresses applicant's invention in somewhat different language. As the number of claims is not excessive it is hoped the additional claim will be allowed and the application passed to issue.

Respectfully submitted,

Attorney for Langmuir.

Schenectady, N. Y.
October 29, 1915.

810

Div. 16 Room 109
Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

3—300
F. U

Paper No. 6
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Nov. 15, 1915.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

Irving Langmuir, S. No. 851,095, filed July 15, 1914,
Electron Discharge Apparatus and Method of Preparation.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Oct. 30, 1915.

This case is being passed to issue and the serial number "58,377" and date "28" inserted by examiner's amendment in the blank spaces left in the insertion after line 6, on page 6. If this date is incorrect it should be corrected by amendment under Rule 78.

Wm A Kinnan
Examiner, Division XVI.

OAS

2—354

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON, D. C.

Nov 16, 1915

In compliance with the provisions of order No. 1718, dated June 8, 1907, and which reads as follows:

It is hereby ordered that, except by formal amendment duly signed or as hereinafter provided, no corrections, erasures, or interlineations be made in the body or written portions of the specification or of any other paper filed in an application for patent.

Obvious informalities in the wording of the specification may be corrected by the examiner, but said correction must be in the form of an amendment, approved by the Principal Examiner in writing, placed in the file, and made a part of the record. The changes specified in the amendment will be entered by the clerk in the regular way.

It is directed that no other changes be made by any person in any record of this office without the written approval of the Commissioner of Patents.

Attorneys, employees of the Patent Office, and all others will be held to strict accountability for any violation of this order.

The following changes are made in—

Application Serial No. 851,095

of Irving Langmuir

In the insertion on p. 6, after l. 6 (R'), insert 58,377 after "Serial No." and 28 after "October."

WAK

Examiner, Division 16

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

K.O'D. 2-181 **Serial No.** 851,095.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON Nov. 22, 1915.

Irving Langmuir, Assor.

Sir: Your APPLICATION for a patent for an IMPROVEMENT in Electron Discharge Apparatus and Method of Preparation, filed July 15, 1914 , has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

Thomas Ewing
Commissioner of Patents.

Albert G. Davis,
% General Electric Company,
Schenectady, N. Y.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

#8

16

IN THE UNITED STATES PATENT OFFICE.

In re Application of
Irving Langmuir
Serial No. 851,095
Filed July 15, 1914
ALLOWED November 22, 1915:

ELECTRON DISCHARGE APPARATUS
&
METHOD OF PREPARATION.

Hon. Commissioner of Patents,

Sir:-

On July 15, 1914, Irving Langmuir filed an application for Letters Patent on improvements in Electron Discharge Apparatus and Method of Preparation, which application was allowed November 22, 1915, but the final fee was not paid within the time allowed by law.

As attorney for Langmuir, I now make renewed application for Letters Patent, and pray that the original specification, oath and drawings may be used as a part of this application.

Enclosed is a cheque for fifteen dollars to pay the renewal filing fee.

Respectfully,

Albert G Davis
ATTORNEY FOR LANGMUIR.

Schenectady, N. Y.,
June 21, 1917.

814

851,095.

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

K.C'D. 8-181

Serial No. 176,926.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON July 2, 1917.

Irving Langmuir, Assor.

Sir: Your APPLICATION for a patent for an IMPROVEMENT in Electron Discharge Apparatus and Method of Preparation, filed June 25, 1917 , has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

Thomas Ewing
Commissioner of Patents.

Albert G. Davis,
℅ General Electric Co.,
Schenectady, N. Y.

☞ IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

[illegible]

$20-

RECD
SEP 26
1917
U.S. PAT. OFFICE

MEMORANDUM

OF

FEE PAID AT UNITED STATES PATENT OFFICE

Schenectady, N. Y., Sept. 10, 1917 *191*

Serial No. 176,926

INVENTOR:

I. Langmuir

PATENT TO BE ISSUED TO

GENERAL ELECTRIC COMPANY.

NAME OF INVENTION, AS ALLOWED:

Electron Discharge Apparatus and Method of Preparation

DATE OF FILING:

June 26, 1917

DATE OF CIRCULAR OF ALLOWANCE:

July 2, 1917

The Commissioner of Patents will please apply the accompanying fee as indicated above.

A. G. DAVIS, Attorney.

SEND PATENT TO

A. G. DAVIS,
c/o General Electric Company,
Schenectady, N. Y.

9/26/

818 9

United States District Court

Eastern District of New York

HONORABLE COMMISSIONER OF PATENTS,
Washington, D. C.

SIR:

In compliance with the Act of February 18, 1922 (~~42~~ 42 Stat. L. 392), you are advised that there was filed on the 15th day of May, 1924, in this court an action, suit, or proceeding No. 1723, entitled:

Name General Electric Co, Plaintiff,
Address New York City

versus

Name De Forest Radio Telephone & Telegraph Co [illegible] McPhilben Radio Electric Corp, Defendants
Address Jamaica Queens, N.Y.

brought upon the following patents:

PATENT NO.	DATE OF PATENT	PATENTEE
1. 1244216	Oct. 23 1917	Plaintiff
2.		
3.		
4.		
5.		

In the above-entitled case, on the .... day of ...., 192 the following patents have been included by .... (insert amendment, answer, cross bill, or other pleading):

PATENT NO.	DATE OF PATENT	PATENTEE
1.		
2.		
3.		
4.		
5.		

In the above-entitled case the following decision has been rendered or decree issued:

In witness whereof I have affixed my hand this 9th day of June, 1924, at Brooklyn New York

Percy G. B. Gilkes
Clerk of said Court

I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF PREPARATION.

APPLICATION FILED JULY 15, 1914. RENEWED JUNE 25, 1917.

1,244,216. Patented Oct. 23, 1917.

Fig. 2.

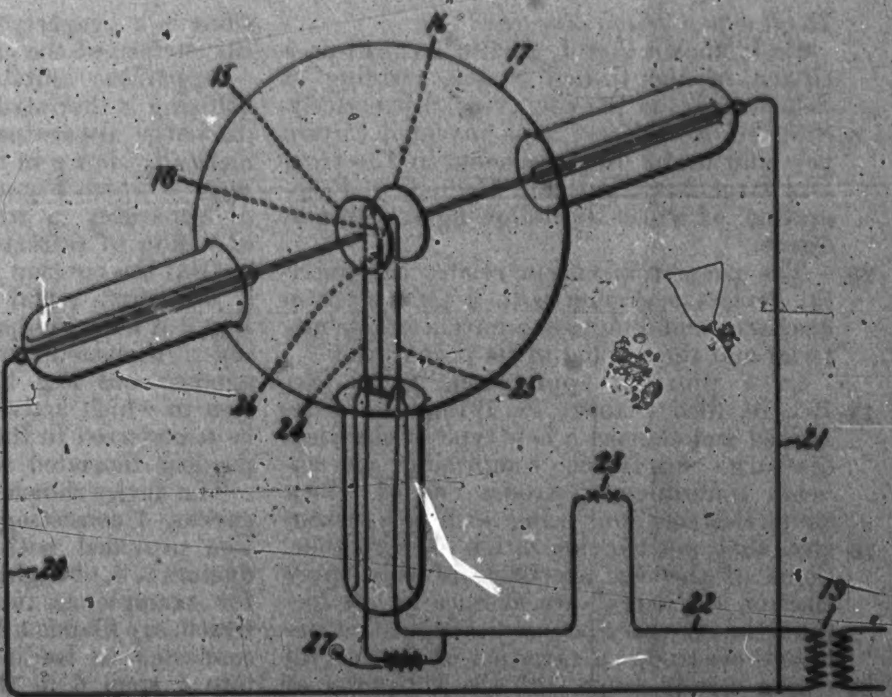

15
16
17
18
26
24
25
21
23
22
20
27
19

Fig. 3.

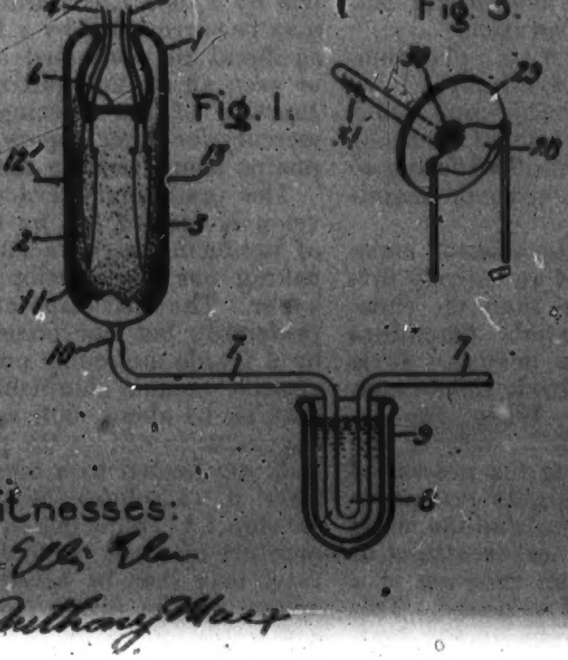

30
29
31
28

Fig. 1.

4
5
1
6
12
13
2
3
11
10
7
7
9
8

Witnesses:
J. Ellis Elen
Anthony Macy

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS AND METHOD OF PREPARATION.

1,244,216. Specification of Letters Patent. Patented Oct. 23, 1917.

Application filed July 15, 1914, Serial No. 851,095. Renewed June 25, 1917. Serial No. 176,936.

To all whom it may concern:

Be it known that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus and Methods of Preparation, of which the following is a specification.

The present invention relates to electrical devices operating with a pure electron discharge and comprises a novel cathode material and the method of its preparation.

In a previous application, Serial No. 795,610, filed October 16, 1913, I have described and claimed a new type of electrical discharge apparatus comprising an envelop containing electrodes one of which emits electrons and being so highly evacuated that positive ionization is negligible. Some of the characteristics of this "pure electron discharge" are absence of conductivity in the space between independent unheated electrodes, a variation of the current over a certain range with the 3/2 power of the voltage, the absence of blue glow in the space, the absence of gas fluorescence and the lack of cathodic disintegration.

Various refractory materials, platinum, carbon, tungsten and molybdenum, have been used as cathode materials and it has been found that the emissivity of electrons of these various materials while differing to some degree is of the same order of magnitude.

I have discovered that the electron emissivity of pure thorium is of an entirely different order of magnitude than the emissivity of refractory materials heretofore used in electron discharge devices. It is not necessary that the electrode should consist entirely of thorium. When, for example, a thorium compound, such as the oxid, has been added during the process of production to one of the highly refractory metals, for example, tungsten, and the metal subjected to a preliminary heat treatment in a high vacuum, the electron emission in a high vacuum is enormously increased. This increased emissivity is not due to the presence of thorium oxid in the manner of the Wehnelt cathode for various reasons hereinafter explained, but according to all indications is a property of metallic thorium on the surface of the cathode.

Apparatus suitable for preparing and utilizing a thoriated cathode in an electron discharge apparatus is somewhat diagrammatically shown in the accompanying drawings, in which Figure 1 shows a simple type of apparatus in which the anode consists of a film of refractory metal on the inside wall of the envelop produced by vaporizing a refractory metal at high temperature; Fig. 2 is a device operable as a rectifier having a thoriated cathode and plate-shaped anodes; and Fig. 3 illustrates a modification in which active thorium material may be transferred to the cathode from an independent thoriated conductor.

The device shown in Fig. 1 comprising an envelop 1 consisting of glass, quartz or the like provided with two filamentary conductors 2, 3, of highly refractory metal, such for example as tungsten, at least one of which, say filament 2, is thoriated. They are connected to leading-in wires 4, 5, sealed into a stem 6 in the well-known manner. The envelop is connected to a vacuum system by a tube 7, containing a trap 8 which may be surrounded by a freezing bath, such as liquid air, contained in a Dewar flask 9 or even an ice and salt mixture. It is the function of the freezing bath to prevent mercury, or other vapors, from the vacuum pumps from reaching the envelop 1.

The preliminary evacuation of the envelop is carried out by the usual methods of producing high vacuum, which includes baking out the envelop to remove water vapor. The final stage of the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means,—that is, to about .001 micron. While the apparatus is still on the pump the filaments 2, 3, are heated to a temperature of about 2900° K. (absolute) for a short time and the envelop 1 is baked out in an oven at a temperature of about 360 to 450° K. The apparatus may then be sealed from the vacuum system at the contraction 10. It is then preferably immersed in liquid air and both filaments 2, 3 aged by heating for about ½ hour to a temperature of 2400 to 2500° K. One of the filaments, for example, filament

3, is then incandesced by a passage of current to a temperature of about 3000° K. which causes rapid vaporization of the metal, thereby producing a gas-free conducting deposit or coating 11 which has been shown on the inner surface of the envelop. Conductors 12, 13 sealed into the envelop make contact with this coating and enable it to be used as an anode for an electrical discharge. A device having a gas-free film anode and the method of its preparation has been described and claimed by me in a copending application, Serial No. 848,569, filed June 8, 1914. The method of producing high vacua by vaporizing tungsten is claimed by me in a co-pending application, Serial No. 838,768, filed May 15, 1914. Pressures much below .001 micron of mercury may be attained thereby. The cathode conductor 2 is prepared by introducing a thorium compound, such as the nitrate of thorium to the oxid of the refractory metal before reduction, or by adding either thorium nitrate or thoria to the metal powder after reduction but before consolidation of the metal by sintering and mechanical working to the solid metal state has taken place as described, for example, with reference to thoriated tungsten in U. S. Patent No. 1,082,933. The proportion of thoria in the unsintered metal usually varies from about ½ to 10% but in some cases may be even greater. The proportion of thorium compound in the cathode within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but with a greater proportion of thorium compound the desired active condition of the filament may be reached and maintained with greater ease than with a lesser amount.

The thoriated cathode 2 is now heated to about 2900° K. for about one minute. The treatment of the filament at a temperature of 2900° has no marked effect on the subsequent electron emission of the cathode when at lower temperature but appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2200° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2300° K. and the treatment at this temperature is usually continued for about one minute, but even outside of this range a marked change is produced. Apparently a concentration of metallic thorium or of some other oxidizable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at a temperature below this forming temperature.

With a filament thus prepared I have obtained at a temperature of about 1300° to 1380° K. substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000° K., that is, about three milliamperes per sq. cm. Preferably a thoriated cathode is operated around 1700° to 1800° K., at which temperatures its life is indefinitely long.

Subsequently heating the filament to a higher temperature, for example, to 2800° K., causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure metal. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2300° K., the active condition is restored.

A similar heat treatment of pure tungsten has no effect on its electron emissivity at incandescence. The active thorium material may be transferred by distillation to an adjacent surface. For example, if the filament 3 consisting of pure tungsten has not been completely destroyed during the preparation of the apparatus, the heating of the cathode to a temperature above 2300° after the preparation of the surface film results in the distillation of some of the thorium material to conductor 3 so that when the conductor 3 is used as a cathode with respect to the anode 11, it is found that its electron emission has been greatly increased.

One of the most striking proofs that the active surface film is not due to the effect of the thoria as in the Wehnelt cathode is furnished by the effect of a minute trace of oxygen on the behavior of the cathode. If in some manner a trace of oxygen is admitted, the electron emission immediately falls as low or even lower than the low value observed when a cathode of pure tungsten is slightly oxidized. In other words, the electron emission becomes very much lower than that of the unoxidized metal. When subsequent to oxidation a trace of hydrocarbon vapor is admitted, the electron emission suddenly rises as though reduction were taking place. If the carbon is in excess, the electron emissivity immediately drops to a low value as though a carbid were formed with the excess of carbon. In an application Serial No. 58,377 filed by me on October 28, 1915, I have more fully described and also claimed a thoriated cathode device containing reducing material.

Cathodes containing only a small amount of thorium compound are deleteriously affected by disintegration of the surface produced by positive ion bombardment and in this respect may be extremely sensitive. In this case, it is necessary when using voltages high enough to cause ionization of residual gases to carry the vacuum far beyond the point at which a disruptive discharge no longer takes place, which ordinarily is about $\frac{1}{10}$ of a micron of mercury pressure. The Wehnelt or oxid cathode apparently depends on positive ionization for its activity. At any rate its emissivity is increased by an increase in positive ionization. When large amounts of thorium are present in my improved cathode, it is not so sensitive to positive ion bombardment and it is possible to obtain to a large extent the advantages of a thoriated cathode even in the presence of pressures of gas up to atmospheric pressure.

Another proof that the high electron emission is due to a skin of thorium is the fact that metallic thorium itself, particularly when free from surface oxidation, exhibits a very high electron emissivity for a given temperature as compared with tungsten. Difficulties are encountered with the use of metallic thorium as cathode material due to its relatively low melting point and its susceptibility to oxidation.

At 2000° to 2300° K., the active thorium is slowly diffusing to the surface from the interior of the metal. As the temperature is raised a point is reached where the distillation of thorium from the surface exceeds the rate at which the metal diffuses to the surfaces. It is possible, however, to operate a refractory thoriated cathode at a temperature between 2000° and 2200° K. for a long time without destroying its high electron emission, but operation at a higher temperature is not advisable. A sufficiently great electron emission can be secured through the indicated temperature range with an accompanying saving of energy necessary for heating the cathode.

The apparatus shown in Fig. 2 does not differ essentially from the apparatus shown in Fig. 1, plate-shaped anodes 15, 16 consisting of a highly refractory metal such as tungsten being used instead of the film anode of vaporized metal used in the apparatus shown in Fig. 1. The envelop 17 is baked out and evacuated as already described in connection with Fig. 1. The ionizable gas should be removed from the anodes during the final stages of the exhaust after the pressure has been reduced below about $\frac{1}{10}$ of a micron of mercury by subjecting the anodes to an electron discharge from the cathode 18 whereby ionizable gas is evolved, as disclosed in my co-pending application, Serial No. 795,610 of October 16, 1913. This gas should be removed as fast as liberated and the discharge voltage progressively increased, care being taken not to materially exceed the voltage at which blue glow takes place so as to avoid injury to the cathode. The final stage of the evacuation is produced by vaporizing a tungsten conductor in a side chamber (not shown in the drawing), thereby producing the very high vacuum necessary for the operation of the thoriated cathode. The anodes 15, 16 may be both connected to one terminal of a secondary of the transformer 19, by conductors 20, 21, the cathode being connected to the other terminal by conductor 22, including a load circuit 23. The cathode 18 has been merely indicated by dotted lines as being a V-shaped filament supported by terminal wires 24, 25, and maintained taut at its bight by a spring 26, but it is to be understood that it may have any convenient form. Thorium compound, for example, the oxid, is introduced during the process of manufacture as already described. The apparatus here shown is suitable for the rectification of alternating current when the cathode is maintained at incandescence by a battery 27, preferably at a temperature of 1700 to 1800° K.

It is not absolutely necessary that the thorium should be introduced into the body of the metal during the process of manufacture. As shown in Fig. 3 a cathode 28 located opposite an anode 29 is provided with a film of active thorium material vaporized from the coiled filamentary cathode 30 heated by a battery 31. The cathode 30 may consist either of a thoriated cathode prepared as already described, or of metallic thorium. The inclosing envelop has not been shown, but it is to be understood that these parts are to be operated in the high vacuum already indicated as being desirable. When the coil 30 consists of thoriated wire it is first rendered active by heat treatment at a temperature of 2200° to 2300° K., as already described, and is then heated to a temperature of about 2900° K. to distil off active material, some of which is condensed on the cathode 28. When the coil 30 consists of metallic thorium, it should be heated to a temperature near its melting point to distil some of the thorium over on to the surface of the cathode 28.

As positive ionization is very much decreased at low voltages, it is permissible to have present an inert gas at a pressure of say .01 micron when the voltage impressed between the cathode and anode does not arise above the ionizing potential of the gas. Advantage can be taken of this fact to use an electron discharge device containing a thoriated cathode as a voltage sensitive cut-out device. Below the voltage at which disintegration of the surface begins, a device such as shown in Fig. 1 may be used to pass a current of about $\frac{1}{10}$ of an ampere per sq. cm. when the cathode is at a temperature of about 1700° to 1800° K. When the voltage rises above the critical value, the current immediately drops to a very small value, thus practically interrupting the circuit. The cathode may be restored when the voltage has fallen by again heating it to about 2200° to 2300° K.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In an electrical discharge device, an electrode comprising in part at least oxidizable thorium material, said electrode having at a temperature of about 1800 to 1380° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

2. In an electrical discharge device, an electrode comprising in part at least oxidizable thorium and having when at incandescence in a vacuum so highly attenuated that positive ionization is substantially absent, an electron emission materially greater per unit of surface than tungsten at the same temperature.

3. A cathode for electron-discharge apparatus consisting largely of a highly refractory metal and a surface layer of material having an electron emissivity at a given temperature materially greater per unit surface than said refractory metal independently of and in the absence of positive ionization.

4. In a device operating by pure electron discharge independent of positive ionization, a conductor comprising a refractory metal and a surface film of thorium material vaporizable at a temperature above about 2300° K. and having a greater electron emission when at incandescence in a non-striking vacuum than said refractory metal.

5. In an electrical discharge device, an electrode comprising metallic tungsten and a surface film of thorium material vaporizable at a temperature above about 2300° K. removable from said surface by positive ionization and having an electron emission per unit surface many times greater than pure tungsten at the same temperature.

6. In an electrical discharge device, an electrode comprising metallic tungsten and thoria said electrode having been subjected to a temperature of about 2200 to 2350° K. and having an electron emission a thousand times as great per unit of surface as tungsten in a vacuum too high to permit of positive ionization.

7. In an electrical discharge device, a cathode comprising metallic tungsten and thoria, said electrode having received a heat treatment at about 2000 to 2350° K. and having an electron emission when at incandescence at a given temperature of a higher order of magnitude than pure tungsten at the same temperature.

8. The process of preparing an electrode comprising a refractory metal and thoria for use in a pure electron discharge apparatus which consists in heating said electrode to a temperature adjacent the melting point of said refractory metal and then heating to a temperature of about 2200 to 2300° absolute.

9. The process which consists in heating a conductor comprising tungsten and thoria to a temperature of about 2800 to 2900° absolute and then lowering the temperature to about 2200 to 2300° absolute holding said temperature for a short interval and finally operating said conductor as cathode in a non-striking vacuum at a temperature below 2000° absolute.

10. A cathode for electron discharge apparatus consisting largely of tungsten and containing thorium, said cathode having an electron emissivity, independently of and in the absence of positive ionization, at a given temperature materially greater per unit surface than tungsten at the same temperature.

11. In an incandescent cathode device, an electrode comprising a highly refractory metal and containing oxidizable thorium material, said electrode having an electron emissivity per unit surface many times greater than said refractory metal alone at the same temperature, the electron emissivity of said cathode being lowered by the presence of oxygen and by positive ionization.

In witness whereof, I have hereunto set my hand this 14th day of July, 1914.

IRVING LANGMUIR.

Witnesses:
William C. White,
Helen Orford.

Copies of this patent may be obtained for five cents each, by addressing the "Commissioner of Patents, Washington, D. C."

B-481

1914

CONTENTS:

1. Application 1 papers. O. K
2. Letter Oct 3 1914
3. Amendt A + Petn Oct. 9-1914
4. Letter Nov 7, 1914
5. Amendt B Oct 30-1915
6. Letter Nov 15-1915
7. Ex. Amdt Nov 16-1915
8. Renewal June 25-1917
9. Notice of Suit June 10-1924
10. (a) June 15-1926
10. Notice of Suit June 5-1925
11. (a) Aug. 7-1926
11. Notice of Suit June 5-1925
12. Notice of Suit May 3-1926
13.
14.
15.
16.
17.
18.
19.
20.
21.
22.
23.
24.
25.
26.
27.
28.
29.
30.
31.
32.
33.
34.
35.
36.
37.
38.
39.
40.
41.
42.
43.
44.
45.
46.
47.
48.
49.
50.

176,926
~~85183~~

828

R Sm

I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF PREPARATION.

APPLICATION FILED JULY 15, 1914. RENEWED JUNE 25, 1917.

1,244,216. Patented Oct. 23, 1917.

Fig. 2.

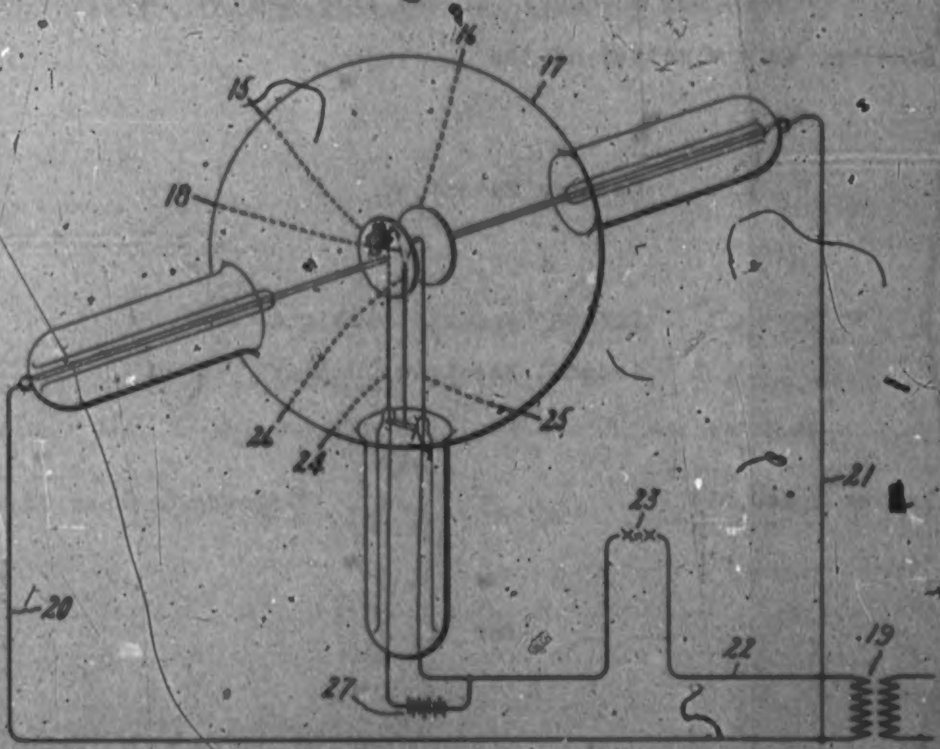
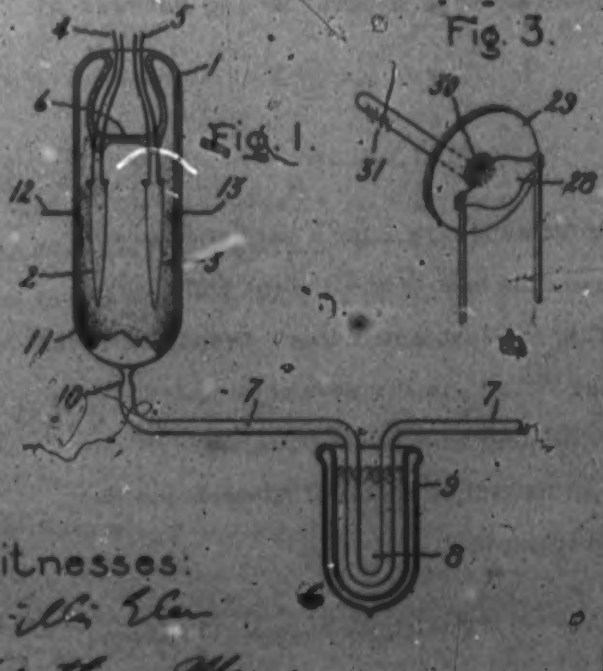

16
17
15
18
26
24
25
21
23
20
22
19
27

Fig. 3.

Fig. 1


4
5
1
6
12
13
2
3
11
10
7
7
9
8
30
29
31
28

Witnesses:
J. Ellis Glen
Anthony Haas

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

DEFENDANT'S EXHIBIT No. 64.

DEPARTMENT OF THE INTERIOR,

UNITED STATES PATENT OFFICE.

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper, Contents and Drawing, in the matter of the

Letters Patent of

Irving Langmuir, Assignor to
General Electric Company,

Number 1,244,217, Granted October 23, 1917,

for

Improvement in Electron-Discharge Apparatus and Methods of Operating the Same.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-seventh day of August, in the year of our Lord, one thousand nine hundred and twenty-four and of the Independence of the United States of America the one hundred and forty-ninth.

Karl Fenning
Acting Commissioner of Patents.

825

NUMBER (Series of 1915) 58377

1915

(EX'R'S BOOK) 131-4-7

DIV. 16

PATENT No. 1244217

Name Irving Langmuir

Assr to General Electric Company, a corp of New York.

of Schenectady

County of

State of New York

Invention Electron Discharge Apparatus and Method of Operating the Same

PARTS OF APPLICATION FILED.	ORIGINAL	RENEWED
Petition	Oct 28, 1915	, 191
Affidavit	" " , 1915	, 191
Specification	" " , 1915	, 191
Drawing	" " , 1915	, 191
Photo Copy	Dec. 30 1915	191
First Fee Cash	$15 Oct 28, 1915	, 191
" Cert.	191	191
Appl. filed complete	Oct 28 1915	191

Examined and Passed for Issue Mar. 23, 1917 | 191

Wm A Kinnan Ex. Div. 16 | Ex. Div.

Notice of Allowance Mar. 26, 1917 By Commissioner | , 191 By Commissioner

Final Fee Cash $20 Sept. 26, 1917 | 191

Cert. , 191 | 191

Patented OCT 23 1917 | 191

Division of App. No. filed , 191

Attorney Albert G. Davis c/o General Electric Company Schenectady N.Y.

Associate Attorney

(No. of Claims Allowed 8) Title as Allowed Electron Discharge Apparatus and Method of Operating the Same (Cl. 250-27)

PETITION

To the Honorable Commissioner of Patents:

our petitioner, Irving Langmuir,

a citizen of the United States, residing at Schenectady

in the County of Schenectady, State of New York

whose Post Office address is c/o General Electric Company, Schenectady, N.Y.

prays that Letters Patent may be granted him for the improvement in

Electron Discharge Apparatus and Method of Operating the Same

D-20,387

set forth in the accompanying specification.

And he further prays that you will recognize Mr. Albert G. Davis, of Schenectady, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

Irving Langmuir

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN, that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, in the County of Schenectady, State of New York, have invented certain new and useful Improvements in Electron Discharge Apparatus and Methods of Operating the Same, of which the following is a specification.

The present invention relates to electrical devices having an electrode consisting at least in part of thorium and having at a given temperature an electron emission per unit surface materially greater than the emission of a refractory metal such as tungsten at the same temperature independently of and in the absence of positive ionization. These devices are described and claimed in a copending application, Serial No. 861,095, of July 15,1914, renewed on June 25, 1917, as application Serial No. 176926 to which the present application is closely related.

Per B.

In the preparation of these devices great care must be exercised to remove the last traces of oxygenous gases, particularly water vapor, and precautions must be observed not to evolve water vapor from the bulb walls during the operation of the device.

In accordance with my present invention, I have improved the above described device and rendered easier the preparation of the same by providing in the envelope a quantity of a vaporizable reagent of low vapor pressure capable of preventing the oxidation of thorium. I prefer to use for this purpose an alkali metal, such for example, potassium.

The accompanying drawing illustrates one practical form of apparatus to which my invention is applicable, namely an incandescent cathode discharge device provided with means for introducing the desired reagent.

The device shown in the drawing which may be used for rectifying alternating current, comprises an envelope 1 consisting of a glass not chemically attacked by alkali metal provided with a cathode 2 consisting for example of thoriated tungsten, and a cylindrical or cup-shaped anode 3, also consisting of a highly refractory metal, such for example, as tungsten. A heating current may be conveyed to the cathode by leading-in conductors 4, 5, sealed into a stem 6 in the usual manner and connected to a threaded socket 7 similar to an incandescent lamp socket. The anode stem 8 is also sealed into a glass stem 9 and attached to an external metal cap 10.

The cathode 2 is prepared by adding a thorium compound, such as nitrate of thorium to the oxide of tungsten before reduction of the metal, or by adding either thorium nitrate or thoria to the metal powder after reduction, but before consolidation of the metal powder by sintering and mechanical working to the solid state as described, for example by reference to thoriated tungsten in U. S. patent # 1,082,933. The proportion of thoria in the unsintered metal usually varies from 1/2 to 10% but in some cases may be even greater. The proportion of thorium compound within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but the favorable conditions will be more easily attained with a greater than with a lesser amount.

The preliminary evacuation of the envelope is carried out by the usual methods of producing a non-striking high vacuum, which includes baking out the envelope to remove water vapor. The final stage of the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means, that is, to about .001 micron. While the apparatus is still on the pump the cathode 2 is heated to a temperature of about 2000° K. (2727° C.) for a short time and the envelope 1 is baked out in an oven at a temperature of about 350 to 450° C.

The substance to be distilled into the envelope, for example, potassium, is indicated at 12 in a small side chamber 13, a small quantity of glass particles, or glass wool, 14 being preferably placed in front of the reducing material. As already indicated all glasses (including the glass wool) used in the apparatus should be unattacked by alkali metal. When the envelope is baked out care should be exercised not to heat the chamber 13 to too high a temperature. The potassium, or other material, is transferred by melting into a communicating chamber 15, after which the chamber 13 may be sealed off. Thereupon, the material is distilled into a second communicating chamber 16 and finally a very small amount is introduced into the main envelope 1, both the chambers 15, 16 being successively sealed off. The redistillation of the reducing material serves to purify it. Altho alkali metals have been indicated as preferable for the purposes of my invention, other reducing materials may be used, for example, hydrocarbon compounds. The bulb is finally sealed from the vacuum system at the contraction 11.

The thoriated cathode 2 is now heated to about 2900° K for about one minute. The treatment of the filament at this temperature appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2400° K and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2800° K. and the treatment at this temperature is usually continued for about one minute. Apparently a concentration of metallic thorium or of some other oxidisable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at or below this forming temperature.

The presence of the reducing agent in the main receptacle maintains the thorium reduced in spite of traces of water vapor which may be liberated from the glass. In any event the high electron emissivity of the thoriated cathode is more easily secured and maintained in the presence of the reducing agent than without it.

With a filament thus prepared I have obtained at a temperature of about 1300° to 1380°K substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000°K. that is, about three milliamperes per sq. cm. A thoriated cathode may be operated around 1700° to 1800°K., at which temperatures its life is long, and thermionic current may be obtained many thousands of times greater than obtainable with pure tungsten at the same temperature.

Subsequently heating the filament to a higher temperature, for example, to 2300°K. causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure tungsten. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2500°K the active condition is restored.

The vapor pressure of potassium, sodium or other alkaline metal at room temperature is so low that objectionable positive ionization of its own vapor during the operation of the pure electron device is negligible and the vapor pressure of the oxidation products ~~production~~ of the alkaline metal have no

Per A

perceptible vapor pressure. For this reason, the alkali metals are to be preferred to carbonaceous compounds as reducing agents in the present device.

The vapor of alkaline metals does not produce an increased emission of a pure tungsten filament thereby furnishing proof that the beneficial effect of the alkaline metal is exerted upon thoria content of the filament and is not due to some ionization phenomena.

Under carefully controlled conditions the benefit of the increased electron emission of a thorium-containing cathode may be secured in a device filled with an inert gas, such, for example, as argon or other monatomic gases, at pressures ranging from a few millimeters of mercury pressure upward, in the presence of potassium or equivalent material for preventing the oxidation of thorium. Care must be exercised to have the cathode at a high enough temperature with reference to the current transmitted so that the vicinity of the cathode is surrounded by free electrons. In other words, the electron emission should be greater than necessary to convey the current thereby preventing a removal of the active thorium material on the surface of the cathode by a bombardment of positive ions.

What I claim as new and desire to secure by Letters Patent of the United States, is:-

1. An electrical discharge device comprising electrodes, one of which contains thorium, an inclosing envelop~~e~~ the space within which is evacuated to a pressure so low that positive ionisation is substantially absent, and a quantity of a vaporizable reagent capable of preventing the oxidation of thorium in communication with the space within said envelop~~e~~.

2. In an electrical discharge device, an inclosing envelop~~e~~, a quantity of alkali metal within said envelop~~e~~, and electrodes therein, one of which comprises in part at least, oxidizable thorium material, said electrodes having at a temperature of ~~about~~ 1500 to 1800° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

3. In an electrical discharge device, an inclosing envelop~~e~~, a quantity of potassium within said envelop~~e~~, and electrodes therein, one of which consists largely of tungsten and containing thorium, said electrode having an electron emissivity at a given temperature materially greater per unit surface than tungsten at the same temperature.

4. An electrical discharge device comprising electrodes, one of which consists of metallic tungsten and a thorium material in an oxidizable state, an inclosing envelop~~e~~, and a quantity of a vaporizable reagent within said envelop~~e~~ capable of preventing the oxidation of thorium at an elevated temperature.

5. The process of improving the operation of an

electron discharge apparatus containing an electrode operating at incandescence comprising a highly refractory metal and a thorium material which consists in bringing into contact with said electrode the vapor of a reagent preventing the oxidation of thorium at an elevated temperature.

6. The process of improving the operation of an electron discharge apparatus containing an electrode of tungsten and thorium operating at incandescence in a non-striking vacuum, which consists in bringing into contact with said electrode the vapor of an alkali metal at a pressure too low to cause appreciable positive ionisation phenomena.

Cls 7-8

Insert A

IN WITNESS WHEREOF, I have hereunto set my hand this 27th day of October 1915.

Irving Langmuir

WCG/EBC.

834.

AFFIDAVIT

STATE OF New York }
COUNTY OF Schenectady } SS:

Irving Langmuir, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Schenectady in the County of Schenectady, State of New York and that he verily believes himself to be the original, first, and sole inventor of the improvements in Electron Discharge Apparatus and Method of Operating the Same described and claimed in the annexed specification; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any country foreign to the United States.

Irving Langmuir

Sworn to and subscribed before me this 27th day of October, 1915

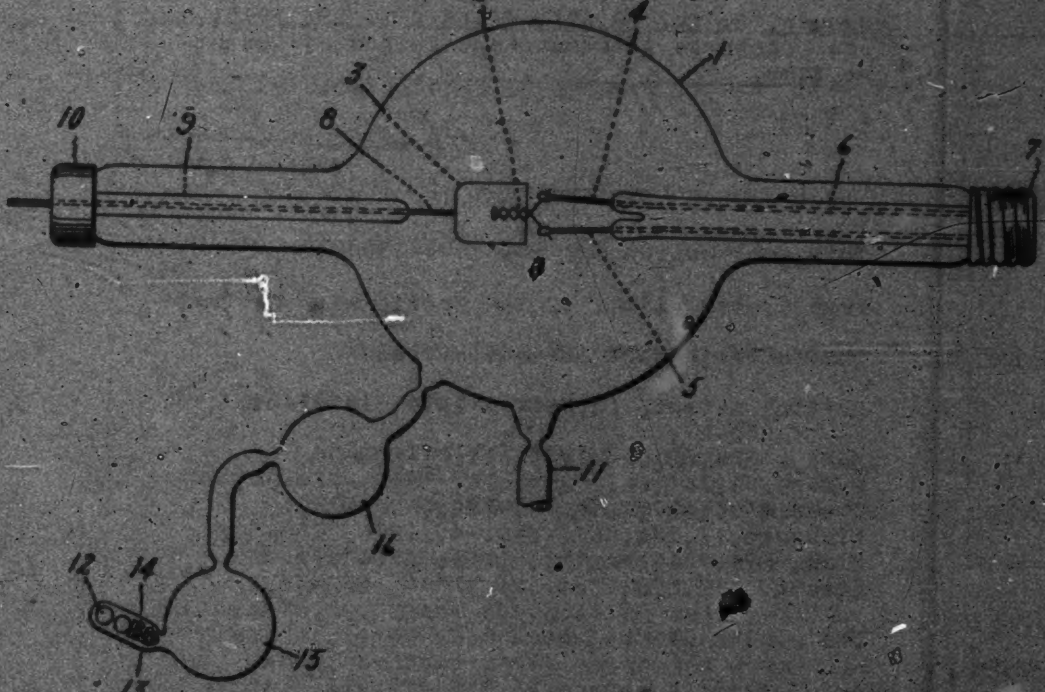
Helen Oxford
Notary Public.

GO-181 500 5-28-15

Serial No. 58,377. Application filed Oct. 23/15.

16

20387.



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Inventor

AFFIDAVIT

STATE OF New York } ss.
COUNTY OF Schenectady

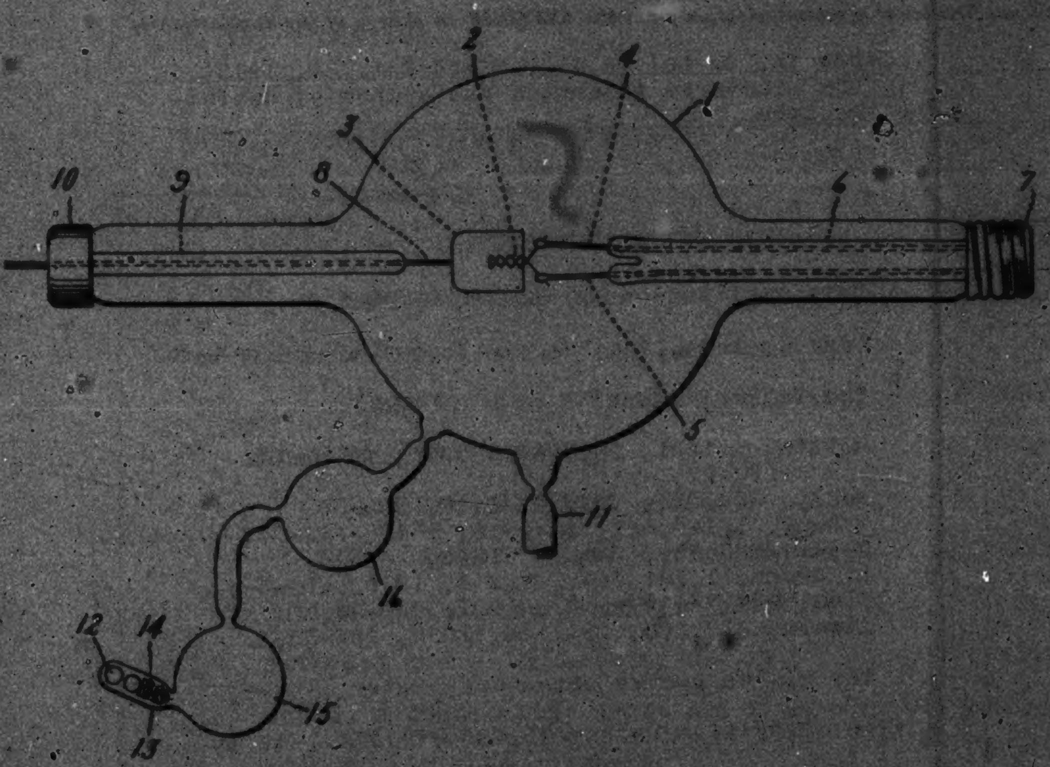
Irving Langmuir, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Schenectady in the County of Schenectady, State of New York and that he verily believes himself to be the original, first, and sole inventor of the improvements in Electron Discharge Apparatus and Method of Operating the Same described and claimed in the annexed specification; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any country foreign to the United States.

Irving Langmuir

Sworn to and subscribed before me this 27th
day of October, 1915

Helen Oxford
Notary Public.

[illegible]


2
4
1
3
8
10
9
6
7
5
11
16
12
14
13
15

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

58377-10

836

Div. 16 Room 112

Address only
"The Commissioner of Patents,"
Washington, D. C.,
and not any official by name.

3—200
A

Paper No. 9
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Apr. 18, 1916.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

I. Langmuir, S. No. 58,377, filed Oct. 28, 1915, Electron Discharge Apparatus and Method of Operating the Same.

Thomas Ewing
Commissioner of Patents.

This application has been examined.

Page 4, last line, is the fourth word correct?

The following art is made of record:

British patent, 15,788 of 1914, (3 sheets),
    250-27,
Soddy, 859,021, July 2, 1907, 250-34,
Skaupy, 1,160,661, Nov. 16, 1915, 250-34,
Dwyer, 596,654, Jan. 4, 1898, 250-24,
Liebmann, 1,166,464, Jan. 4, 1916, 250-34,✓
Blau, 674,754, May 21, 1901, 250-34,
Stearn, 613,090, Oct. 25, 1898, 250-35,X.

The claims are rejected upon Dwyer, above, in view of British patent 15,788 of 1914. It is very common to make an electrode of thorium or a thorium compound. See, for example, Stearn. Dwyer discloses the idea of supplying a reducing agent such as sodium or potassium vapor introduced into the tube. Modifying the structure of British patent 14,788 of 1914, accordingly, is not considered invention.

The claims are also rejected on Soddy, above, who discloses the use of calcium to react chemically with any oxygen in a vacuum tube. The use of potassium instead of calcium is an obvious expedient.

The claims are rejected.

Examiner, Division XVI

PAPER NO. 8
AMENDMENT a

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 58,377, : ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME
Filed October 28, 1915, :
Div. 16, Room 109. :

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of April 18, 1916, please amend the above-entitled application as follows:-

Page 4, line 32, cancel "production" and substitute - products -

Add the following claims:

7. An electrical device comprising the combination of a sealed evacuated envelope, a refractory cathode, means for heating said cathode to incandescence, a coöperating anode and a quantity of potassium within said envelope.

8. An electrical device comprising the combination of an evacuated envelope, a cathode, an anode and a quantity of alkali metal enclosed within said envelope, and means for heating said cathode to incandescence.

REMARKS

The invention claimed in this application should not be regarded as an improvement in the method of producing vacua. It is an improvement in electrical devices operating by the thermionic discharge from an incandescent cathode. It is true that thermionic discharge devices are not broadly new, as shown by British patent

#15,788 of 1914, but this does not preclude further improvements being made in a device of this character.

Stearn patent #613,090 does not describe a thermionic device, and a disclosure with reference to the "vacuum" regulation of Crookes tube device can have no possible bearing on the operation of a thermionic device, in which the cathode emits electrons independently of ionisation of residual gas.

Dwyer patent #956,654 refers to the production of a vacuum by absorbing ammonia-gas with sodium or potassium vapor, but does not have the remotest connection with incandescent cathode devices.

The other patents cited, for example, Soddy patent #869,021, describing methods of obtaining good vacuum, and the Liebmann lamp getter patent #1,166,464, do not teach anyone a thing with reference to the effect of potassium or the like on a heated electron-emitting cathode.

The claims have not been amended as applicant's attorney does not perceive in what manner the references can either singly or in combination properly be used to anticipate the claims. It is not inconsistent with the fact that hot cathode devices broadly are old to this applicant and that sodium and potassium have formerly been used in the production of vacua, that a new improvement may be made in hot cathode devices involving the use of sodium, potassium, or the like. For example, when these devices are operated at a suitable voltage in the presence of such an amount of residual gas that positive ionisation is possible, then there is danger of destroying, or, at least, injuring the cathode by what is known as bombardment by positive ions. The substances described in the application, particularly so, potassium, seem to have little or no effect in disintegrating the cathode, but on the other hand these substances prevent the deleterious effect of gases such as water vapor.

Two additional claims have been added to better protect applicant's invention.

Reconsideration and allowance are respectfully requested.

Respectfully submitted,

Albert G Davis

Attorney for Langmuir.

Schenectady, N. Y.
February 13, 1917.

WGC/GAL

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

K.O'De-181

Serial No. 58,377.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON March 26, 1917.

Irvin Langmuir, Assor.

Sir: Your APPLICATION for a patent for an IMPROVEMENT in Electron Discharge Apparatus and Method of Operating the Same, filed Oct. 28, 1915, has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

Thomas Ewing
Commissioner of Patents.

Albert G. Davis,
℅ General Electric Co.,
Schenectady, N. Y.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

3—478

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON, D. C.

Sept. 24, 1917

Petition:

Application of I. Langmuir

Serial No. 58377

Invention:

This petition is referred to the Examiner in charge of Division 16 *for recommendation.*

In case he recommends adversely he will state his reasons therefor and furnish a copy thereof to petitioner.

J. T. Newton
Commissioner of Patents.

PAPER NO 4

(R 78)

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 58,377, : ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME
Filed Oct. 28, 1915, :
Div. 16, Room 109. :

AMENDMENT UNDER RULE 78

Honorable Commissioner of Patents,

Sir:-

It is respectfully requested that the Examiner be authorized to enter the following amendment in the above-entitled application without withdrawing the application from issue.

Page 1, line 15, after "July 15, 1914" insert - renewed on June 25, 1917 as application Serial No. 176,926 -

This change involves a matter of form only and does not materially affect the application.

Respectfully submitted,

Attorney for Langmuir.

Schenectady, N. Y.
September 21, 1917.

WSC/GAL

The proposed corrections being
merely formal, it is recommended that
this amendment be entered under Rule
78, without withdrawing the case from
issue. The final fee has not been paid

16

R. P. Whitehead

4

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

58377 Letter No. 6

EEG

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON

September 26, 1917.

In the matter of the
Application of
Irving Langmuir,
Electron Discharge Apparatus and Method of Operating the Same;
Filed Oct. 28, 1915
Serial No. 58,377.

Amendment.

Sir:

You are hereby informed that the recommendation of the examiner that the amendment be admitted under the provisions of Rule 78, has been approved by the First Assistant Commissioner and the amendment entered.

By direction of the Commissioner:

Very respectfully,

W. F. Woolard

Chief Clerk.

F.

Irving Langmuir,
c/o Albert G. Davis,
Schenectady, N.Y.

MEMORANDUM
OF
FEE PAID AT UNITED STATES PATENT OFFICE

Schenectady, N. Y., Sept. 10,1917 *191*

Serial No. 58,377

INVENTOR:

I. Langmuir

PATENT TO BE ISSUED TO

GENERAL ELECTRIC COMPANY.

NAME OF INVENTION, AS ALLOWED:

Electron Discharge Apparatus and Method of Operating the Same

DATE OF FILING:

Oct. 28, 1915

DATE OF CIRCULAR OF ALLOWANCE:

March 26, 1917

The Commissioner of Patents will please apply the accompanying fee as indicated above.

A. G. DAVIS, Attorney.

SEND PATENT TO

A. G. DAVIS,
c/o General Electric Company,
Schenectady, N. Y.

MAIL ROOM
JUN 10 1924
U.S. PATENT OFFICE

United States District Court

Eastern District of New York

HONORABLE COMMISSIONER OF PATENTS,
Washington, D. C.

SIR:

In compliance with the Act of February 18, 1922 (~~41~~ 42 Stat. L. 392), you are advised that there was filed on the 15th day of May, 1924, in this court an action, suit, or proceeding No. 1729, entitled:

Name General Electric Co, Plaintiff,

Address New York City

versus

Name De Forest Radio Telephone & Telegraph Co. and Mc [illegible] Radio Electric Corp, Defendant,

Address Jamaica, Queens Co. N.Y.

brought upon the following patents:

PATENT NO.	DATE OF PATENT	PATENTEE
1 1244217	Oct. 23 1917	Plaintiff
2		
3		
4		
5		

In the above-entitled case, on the .... day of ...., 192 , the following patents have been included by .... (insert amendment, answer, cross bill, or other pleading):

PATENT NO.	DATE OF PATENT	PATENTEE
1		
2		
3		
4		
5		

In the above-entitled case the following decision has been rendered or decree issued:

In witness whereof I have affixed my hand this 9th day of June, 1924 at Brooklyn New York

Percy G. B. Gilkes
Clerk of said Court.

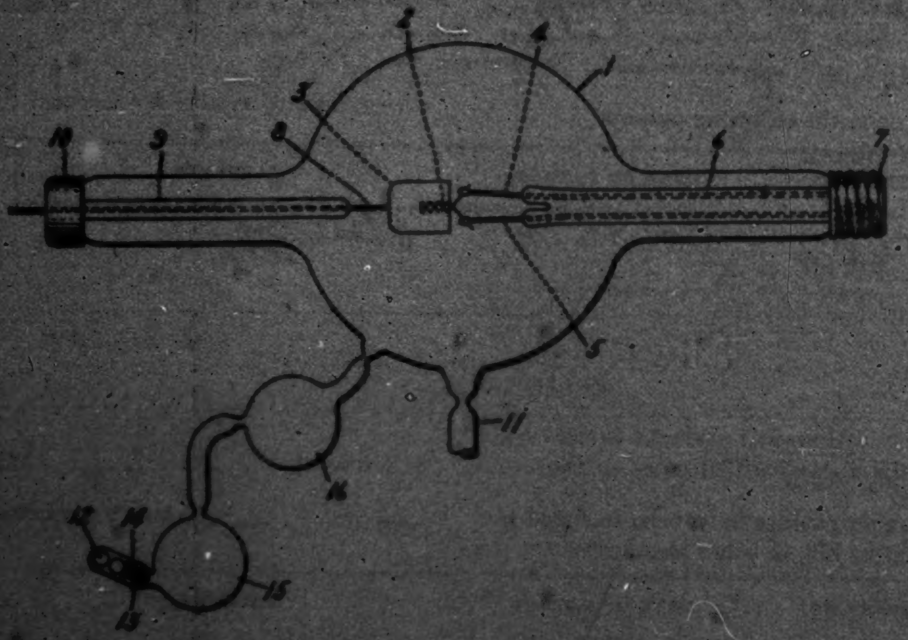
GOVERNMENT PRINTING OFFICE

I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME.

APPLICATION FILED OCT. 29, 1913.

1,244,217. Patented Oct. 23, 1917.


10
9
8
3
2
4
1
6
7
5
11
16
17
14
13
15

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME.

1,244,217. Specification of Letters Patent. **Patented Oct. 23, 1917.**

Application filed October 28, 1915. Serial No. 58,277.

To all whom it may concern:

Be it known that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus and Methods of Operating the Same, of which the following is a specification.

The present invention relates to electrical devices having an electrode consisting at least in part of thorium and having at a given temperature an electron emission per unit surface materially greater than the emission of a refractory metal such as tungsten at the same temperature independently of and in the absence of positive ionization. These devices are described and claimed in a copending application, Serial No. 851,095, of July 15, 1914, renewed on June 25, 1917, as application Serial No. 176,926, to which the present application is closely related.

In the preparation of these devices great care must be exercised to remove the last traces of oxygenous gases, particularly water vapor, and precautions must be observed not to evolve water vapor from the bulb walls during the operation of the device.

In accordance with my present invention, I have improved the above described device and also rendered easier the preparation of the same by providing in the envelop a quantity of a vaporizable reagent of low vapor pressure capable of preventing the oxidation of thorium. I prefer to use for this purpose an alkali metal, such for example, as potassium.

The accompanying drawing illustrates one particular form of apparatus to which my invention is applicable, namely, an incandescent cathode discharge device provided with means for introducing the desired reagent.

The device shown in the drawing which may be used for rectifying alternating current, comprises an envelop 1 consisting of a glass not chemically attacked by alkali metal provided with a cathode 2 consisting for example of thoriated tungsten, and a cylindrical or cup-shaped anode 3, also consisting of a highly refractory metal, such for example, as tungsten. A heating current may be conveyed to the cathode by leading-in conductors 4, 5, sealed into a stem 6 in the usual manner and connected to a threaded socket 7 similar to an incandescent lamp socket. The anode stem 8 is also sealed into a glass stem 9 and attached to an external metal cap 10.

The cathode 2 is prepared by adding a thoria compound, such as nitrate of thorium to the oxid of tungsten before reduction of the metal, or by adding either thorium nitrate or thoria to the metal powder after reduction, but before consolidation of the metal powder by sintering and mechanical working to the solid state as described, for example by reference to thoriated tungsten in U. S. Patent #1,082,933. The proportion of thoria in the unsintered metal usually varies from ½ to 10% but in some cases may be even greater. The proportion of thorium compound within the above limits makes little difference in the maximum electron emission that may be obtained under the best conditions but the favorable conditions will be more easily attained with a greater than with a lesser amount.

The preliminary evacuation of the envelop is carried out by the usual methods of producing a non-striking high vacuum, which includes baking out the envelop to remove water vapor. The final stage of the evacuation is preferably but not necessarily carried out by a Gaede molecular pump to the highest possible vacuum obtainable by this means, that is, to about .001 micron. While the apparatus is still on the pump the cathode 2 is heated to a temperature of about 2900° K. (2727° C.) for a short time and the envelop 1 is baked out in an oven at a temperature of about 360 to 450° C.

The substance to be distilled into the envelop, for example, potassium, is indicated at 12 in a small side chamber 13, a small quantity of glass particles, or glass wool, 14 being preferably placed in front of the reducing material. As already indicated all glasses (including the glass wool) used in the apparatus should be unattacked by alkali metal. When the envelop is baked out care should be exercised not to heat the chamber 13 to too high a temperature. The potassium, or other material, is transferred by melting into a communicating chamber 15, after which the chamber 13 may be sealed off. Thereupon, the material is distilled into a second communicating chamber 16 and finally a very small amount is introduced into the main envelop 1, both the chambers 15, 16 being successively sealed off. The redistillation of the reducing material serves to purify it. Although alkali metals have been indicated as preferable for the purposes of my invention, other reducing materials may be used, for example, hydrocarbon compounds. The bulb is finally sealed from the vacuum system at the contraction 11.

The thoriated cathode 2 is now heated to about 2900° K. for about one minute. The treatment of the filament at this temperature appears to be desirable for purifying the surface of the cathode. The cathode is then incandesced within the range of about 2000° to 2400° K. and by this temperature treatment some change is produced in the cathode which enormously increases its electron-emitting property under the condition described. The greatest activity is obtained between about 2200° to 2300° K. and the treatment at this temperature is usually continued for about one minute. Apparently a concentration of metallic thorium or of some other oxidizable thorium material takes place on the surface of the filament. The filament 2 may now be used as a cathode at or below this forming temperature.

The presence of the reducing agent in the main receptacle maintains the thorium reduced in spite of traces of water vapor which may be liberated from the glass. In any event the high electron emissivity of the thoriated cathode is more easily secured and maintained in the presence of the reducing agent than without it.

With a filament thus prepared I have obtained at a temperature of about 1800° to 1880° K. substantially the same electron emission per sq. cm. as with a pure tungsten filament at about 2000° K., that is, about three milliamperes per sq. cm. A thoriated cathode may be operated around 1700° to 1800° K., at which temperatures its life is long, and thermionic current may be obtained many thousands of times greater than obtainable with pure tungsten at the same temperature.

Subsequently heating the filament to a higher temperature, for example, to 2800° K. causes some change, apparently a distillation of the film of thorium from the surface, as the electron emitting power of the cathode falls to the same order of magnitude as pure tungsten. When the cathode after being thus heated is re-subjected to a temperature of 2200° to 2300° K. the active condition is restored.

The vapor pressure of potassium, sodium or other alkaline metal at room temperature is so low that objectionable positive ionization of its own vapor during the operation of the pure electron device is negligible and the vapor pressure of the oxidation products of the alkaline metal have no perceptible vapor pressure. For this reason, the alkali metals are to be preferred to carbonaceous compounds as reducing agents in the present device.

The vapor of alkaline metals does not produce an increased emission of a pure tungsten filament thereby furnishing proof that the beneficial effect of the alkaline metal is exerted upon thoria content of the filament and is not due to some ionization phenomena.

Under carefully controlled conditions the benefit of the increased electron emission of a thorium-containing cathode may be secured in a device filled with an inert gas, such, for example, as argon or other monatomic gases, at pressures ranging from a few millimeters of mercury pressure upward, in the presence of potassium or equivalent material for preventing the oxidation of thorium. Care must be exercised to have the cathode at a high enough temperature with reference to the current transmitted so that the vicinity of the cathode is surrounded by free electrons. In other words, the electron emission should be greater than necessary to convey the current thereby preventing a removal of the active thorium material on the surface of the cathode by a bombardment of positive ions.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electrical discharge device comprising electrodes, one of which contains thorium, an inclosing envelop the space within which is evacuated to a pressure so low that positive ionization is substantially absent, and a quantity of a vaporizable reagent capable of preventing the oxidation of thorium in communication with the space within said envelop.

2. In an electrical discharge device, an inclosing envelop, a quantity of alkali metal within said envelop, and electrodes therein, one of which comprises in part at least, oxidizable thorium material, said electrodes having at a temperature of about 1800 to 1880° absolute an electron emission substantially equal to that of tungsten at about 2000° absolute.

3. In an electrical discharge device, an inclosing envelop, a quantity of potassium within said envelop, and electrodes therein, one of which consists largely of tungsten and containing thorium, said electrode having an electron emissivity at a given temperature materially greater per unit surface than tungsten at the same temperature.

4. An electrical discharge device comprising electrodes, one of which consists of metallic tungsten and a thorium material in an oxidizable state, an inclosing envelop, and a quantity of a vaporizable reagent within said envelop capable of preventing

the oxidation of thorium at an elevated temperature.

5. The process of improving the operation of an electron discharge apparatus containing an electrode operating at incandescence comprising a highly refractory metal and a thorium material which consists in bringing into contact with said electrode the vapor of a reagent preventing the oxidation of thorium at an elevated temperature.

6. The process of improving the operation of an electron discharge apparatus containing an electrode of tungsten and thorium operating at incandescence in a non-striking vacuum, which consists in bringing into contact with said electrode the vapor of an alkali metal at a pressure too low to cause appreciable positive ionization phenomena.

7. An electrical device comprising the combination of a sealed evacuated envelop, a refractory cathode, means for heating said cathode to incandescence, a coöperating anode and a quantity of potassium within said envelop.

8. An electrical device comprising the combination of an evacuated envelop, a cathode, an anode and a quantity of alkali metal inclosed within said envelop, and means for heating said cathode to incandescence.

In witness whereof, I have hereunto set my hand this 27th day of October, 1915.

IRVING LANGMUIR.

Copies of this patent may be obtained for five cents each, by addressing the "Commissioner of Patents, Washington, D. C."

850

9-481

1915

CONTENTS:

1. Application papers. O. K.
2. Rejection Apr. 18 1916
3. Amendt A Feb. 14 1917
4. Amdt B (R 78) Sep 22 1917
5. Notice of entry of Amendment Sept. 26/17
6. Notice of Suit June 10-1924
7. (a) June 18-1924
7. Notice of Suit June 5-1925
8. (a) Aug 7-1925
8. Notice of Suit June 5-1924
9. Notice of Suit May 3-1926
10.
11.
12.
13.
14.
15.
16.
17.
18.
19.
20.
21.
22.
23.
24.
25.
26.
27.
28.
29.
30.
31.
32.
33.
34.
35.
36.
37.
38.
39.
40.
41.
42.
43.
44.
45.
46.
47.
48.
49.
50.

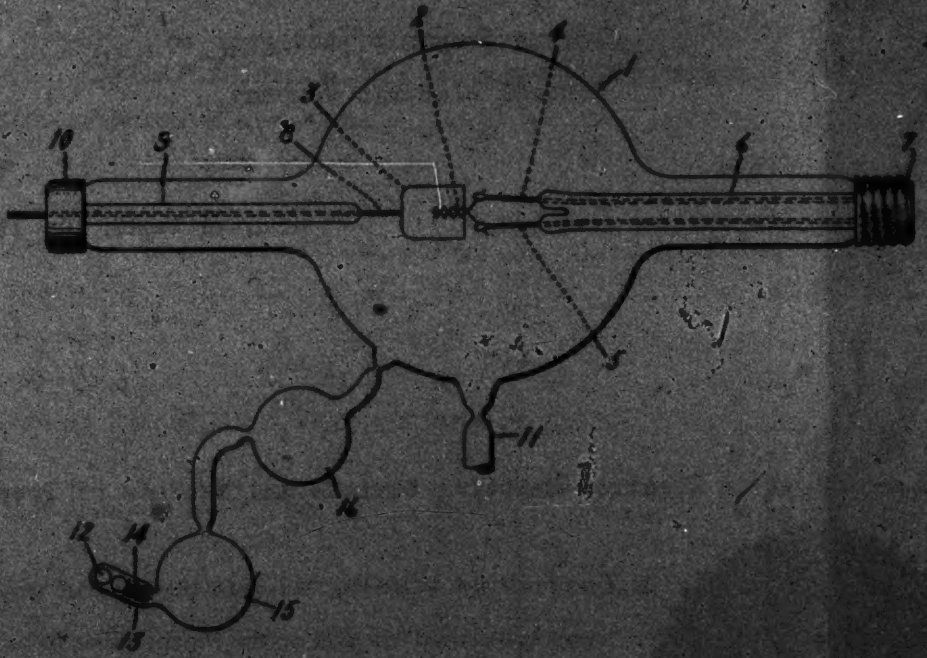
A. Lm

I. LANGMUIR.

ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME.

APPLICATION FILED OCT. 28, 1915.

1,244,217. Patented Oct. 23, 1917.


10
5
8
3
2
4
1
6
7
9
11
16
12
14
13
15

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

Sig. 13

852

DEFENDANT'S EXHIBIT No. [illegible].

DEPARTMENT OF COMMERCE
PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper and Contents, in the matter of the

9 2152

Letters Patent of

Irving Langmuir, Assignor to
General Electric Company,

Nu[illegible]er 1,529,597, Granted March 10, 1925,

for

Impro[illegible]nt in Electron-Emitting Devices and Methods of Preparation.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-first day of July in the year of our Lord, one thousand nine hundred and twenty-five and of the Independence of the United States of America the one hundred and fiftieth.

ATTEST:

Chief of Division.

Thomas E. Robertson
Commissioner of Patents.

853

NUMBER (Series of 1915),
491634

1921

(EXR'S BOOK) ~~27-42-1~~
103-4-1

DIV. ~~16~~ 51

PATENT No. 1529597

MAR 10 1925

Name Irving Langmuir, Assor to General Electric Comp a corpn of New York,

of Schenectady

County of

State of New York.

Invention Electron Emitting ~~Cathodes~~ Bodies and Methods of Preparation

ORIGINAL	RENEWED
Petition Aug. 11, 1921,	192
Affidavit " " , 1921,	192
Specification " " , 1921,	192
Drawing " " , 192 1	192
Photo copy Aug 11, 192 1	192
First Fee Cash $15 Aug. 11, 1921,	192
" " Cert. , 192	192
Appl. filed complete Aug 11, 192	192

PARTS OF APPLICATION FILED.

Examined and Passed for Issue Feb 4, 192 — 192

C. D. [illegible] Ex. Div. 51 — Ex. Div.

Notice of Allowance Feb 5, 1925 By Commissioner — 192 By Commissioner

Final Fee Cash $20 Feb 12, 1925 — MAR 10 1925, 192

" " Cert. , 192 — 192

Patented — 192

Attorney Albert G. Davis of General Elec Co Schenectady NY

Associate Attorney Alexander D. Lunt, of General Electric Co Schenectady New York

DIVISION & APP. NO.

No. of Claims Allowed 25) Print Claims 12, 14, 25 in O.G. (Cl. 250

Title as Allowed Electron Emitting ~~cathodes~~ Bodies and Methods of Preparation

Insert 597

PETITION

To the Honorable Commissioner of Patents:

Your petitioner, IRVING LANGMUIR

a citizen of THE UNITED STATES, residing at SCHENECTADY

in the County of SCHENECTADY, State of NEW YORK

whose Post Office address is c/o GENERAL ELECTRIC CO., SCHENECTADY, N.Y.

prays that Letters Patent may be granted him for the improvement in

ELECTRON EMITTING CATHODES AND METHODS OF PREPARATION

(DOCKET NO. 28,408)

set forth in the accompanying specification.

And he further prays that you will recognize Mr. Albert G. Davis, of Schenectady, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

Irving Langmuir

[illegible]

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN, that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the County of Schenectady, State of New York, have invented certain new and useful Improvements in ELECTRON-EMITTING Devices ~~CATHODES~~ AND METHODS OF PREPARATION, of which the following is a specification.

Per D

This invention comprises an improvement in the electron emitting cathodes of the type described in my prior U. S. Patents Nos. 1,244,216 and 1,244,217.

Per C

In these patents I have described the preparation and advantages of a vacuum tube containing a cathode adapted to be operated at incandescence and containing distributed throughout its mass thorium (or a compound of thorium) as a constituent. This type of electrode consists of a refractory conducting material, such for example as tungsten, with an addition of thoria, the latter being subjected to modifications during the preparation of the cathode in the electron discharge device so that the active material in a finished device according to all indications, consists of metallic thorium or at least of a lower oxide of thorium than thoria (Th O2). The cathode prepared according to the methods set forth in my first patent 1,244,216 which is commonly known as a "thoriated cathode", is very sensitive to traces of oxidizing gas in the bulb, as for example, small traces of water vapor which may be given off from the walls of the bulb during the normal operation of the device. In order to prevent loss of activity of the cathode, I have described in my second patent No. 1,244,217, the beneficial results obtained by the admission to the bulb of a small amount of alkali metal, such as potassium or sodium, or of a hydrocarbon compound.

Per B

Insert C'

D

My present invention in one of its aspects is based on the discovery that carbon in a ~~thoriated~~ cathode of the thoriated type when present in a definitely limited amount, will prevent not only reoxidation of active thorium material but what is more important, will act beneficially to reduce thoria to the active state. Although the thoriated cathodes described in my prior patents can be used with satisfactory results, I have found that a further improvement in regularity and stability can be effected by using carbon as hereinafter described, not only as in accordance with my prior patent in restricted quantities, as an oxidation preventing agent, but, as hereinafter described, as an ingredient of a thoriated cathode.

Per C

D

¶ In accordance with another feature of my invention my improved cathode is used in conjunction with a non-carbonaceous reducing agent which is provided in the bulb, as for example, a highly oxidizable metal.

Per B

Insert B'

B' ~~Another feature of my invention comprises the combination with a thoriated cathode of a reducing agent having a materially lower vapor pressure than the alkali metals.~~ My invention will be pointed out with greater particularity in the accompanying claims and described fully in conjunction with the accompanying drawing which shows somewhat diagrammatically ~~the~~ an apparatus used for carrying out the preparation of an incandescent cathode rectifier.

D

The rectifier shown in the figure is illustrative of one of the various forms of incandescent cathode devices. It consists of a bulb 1 containing a filamentary cathode 2 into which thoria has been introduced as described in my above mentioned prior patents, and an anode 3, consisting of tungsten, molybdenum or other suitable material. These electrodes are respectively connected to lead wires 4, 4' and 5 sealed into the walls of the bulb. The bulb is connected to the usual pumping system by means of a tubulature 6. The bulb also communicates with an elongated tube 7 adapted to be surrounded by a freezing mixture contained within a double-walled receptacle 8.

In carrying out my invention, the bulb 1 is first baked out as usual to remove water vapor and is then exhausted. Within the tube 7 is placed a substance adapted to give a low pressure of carbonaceous vapor, as for example, anthracene ($C_{14}H_{10}$) or naphthalene ($C_{10}H_8$).

When the vapor pressure of the substance employed is relatively high, I prefer to reduce the pressure of the hydrocarbon vapor in the bulb 1 by surrounding the tube with a freezing agent contained in ~~a~~ the receptacle 8. When employing naphthalene, which has a moderately high vapor pressure, ~~I~~ prefer to reduce the temperature of the containing tube ~~6~~ 7 to about -20 to -30°C. to reduce the vapor pressure to about 0.1 to 0.01 microns. The bulb 1 which communicates with the side tube 7, therefor, is filled with hydrocarbon vapor at approximately this pressure. The quantity of hydrocarbon may be controlled by one or more constrictions, such as 9, 10 which may regulate the pressure with or without a freezing agent.

The filament 2, which preferably consists of metallic tungsten, containing about 3/4% thoria, is heated to a temperature of about 2300°K. (2000°C.) for a few minutes, in contact with the hydrocarbon vapor. At this temperature the incandescent filament decomposes the hydrocarbon vapor which comes in contact with the incandescent surface of the tungsten and causes the chemical combination with the tungsten of the carbon set free from the naphthalene vapor, with the formation of tungsten

Per D

Per A

carbide (W_2C). The heating is continued for a length of time ~~and was~~ sufficient ~~[illegible]~~ to give an increase in resistance of about 15 to 25% of the tungsten filament when cold, or at room temperature. This change in resistance corresponds to the presence of about two-thirds per cent of carbon by weight in the filament.

The carbon content most beneficial will vary with the conditions. In the case of a thoriated tungsten cathode all of the metallic tungsten will be converted to brittle tungsten carbide (W_2C) with a carbon content as high as 3%. Ordinarily a carbon content as high as about 1% is as high as permissible without unduly weakening the cathode. Although the presence of even minute amounts of carbon is highly undesirable in an incandescent lamp, a ~~reasonably~~ commercially long life can be obtained in a thoriated cathode containing carbon, as the cathode need be operated only at a relatively low temperature, say at about the operating temperature of an ordinary carbon lamp, the electron emissivity of a thoriated cathode being so much greater than that of an ordinary pure tungsten cathode. The hydrocarbon vapor is removed from contact with the filament either by sealing off the tube 7 at the contraction 9 or cooling the side tube 7 by means of liquid air in the receptacle 8 to a temperature so low that the vapor pressure of the naphthalene is negligible, thereby removing the naphthalene vapor from the bulb 1.

Per B

In some cases carbon to a desired proportion may be combined with the cathode prior to the introduction of the cathode into the bulb 1. For example, a thoriated filament may be prepared by squirting tungsten and thoria with a carbonaceous binder in amounts adapted to leave a suitable restricted proportion of carbon in the finished product.

104

As the next step in the preparation of the device, the anode 3 is deprived of gases by the usual method of electron bombardment; that is, by passing a discharge between the cathode at ~~[illegible]~~ incandescence and the anode, the exhaust pump in the meantime being operated to remove the vapors and gases which are liberated. During this step some of the carbon is removed by oxidation and evaporation from the cathode but with an original carbon content of about 2/3 of one per cent, enough carbon remains subsequently to furnish a supply of active thorium material by reduction of the thoria.

Per D

D

D

Per B

Insert B²

Insert B³

(7) B² ~~As the next step in carrying out my invention,~~ a non-carbonaceous ~~reducing~~ material (8) B³ may be introduced into the bulb. In some cases this non-carbonaceous reducing agent may consist of alkali metal, such as sodium or potassium. Caesium may be used to advantage in some cases, especially when some positive ionization is desired in the electron discharge device. Caesium can be conveniently provided by adding a mixture of caesium halide and metallic calcium as a paste to some part of the bulb. (14) a'

Insert a'

When not desiring ionization of residual gases or vapors, I prefer for the reasons given above to introduce a reagent having a lower vapor pressure than the alkali metals, as for example, alkaline earth metal such as magnesium, calcium, strontium, or the like. Conveniently this is done by providing within the bulb a small heating coil 11, consisting of tungsten or other suitable refractory material, and containing a small quantity of the metal to be vaporized. Preferably I employ metallic magnesium. By ~~When~~ heating the tungsten filament 11 with ~~by~~ current conducted thru the lead wires 4, 12, some of the magnesium is volatilized and deposited on the inner surface ~~walls~~ of the bulb which is then sealed off at the contraction 10. As during the sealing off process there is a tendency

B

D

Per a

D

D

C

to drive out a small quantity of gas from the heated glass, I prefer to heat up the filament 11 the second time, to volatilize a small additional quantity of magnesium, or the like, in order to combine chemically with what little gas may have gotten into the bulb during the sealing off operation.

The film of magnesium, or other equivalent metal, on the walls of the bulb will combine with any water vapor or oxygen which may be given off by the bulb, or any other parts of the device during its operation, and thereby prevent an oxidization of the active thorium material upon the surface of the cathode. ~~Unlike the alkali metals, a material of low vapor pressure such as magnesium, does not come into contact as a vapor with the cathode and take part in the reduction of thoria.~~

The tungsten cathode 2 is ~~also~~ preferably heated for a very short time to about 2700°K. to volatilize any thorium oxide on its surface.

As a final step, the ~~a~~ cathode is "activated ~~formed~~", that is, brought into its highly active state by heating to a temperature of about 2200°K. for a few minutes. This results in the reduction of thoria by the carbon and causes the active thorium product to come to the surface of the cathode where it will be effective in increasing the electron emission during the operation of the device. The tube is then ready for operation.

As explained in my prior patents, a temperature materially higher than the activating ~~forming~~ temperature will result in the thorium being volatilized from the surface of the cathode. A fresh supply can be produced and caused to accumulate upon the surface by again activating or "forming" an electrode at about 2200°K. During normal operation, the cathode is heated to a temperature below about 2200°K. and as high as 2100°K. Under these conditions, the electron emission stays constant.

What I claim as new and desire to secure by Letters Patent of the United States, is:-

Cl. 1-2

Sub ~~B7~~ C2

1. A cathode for an electric discharge device comprising a refractory metal and containing carbon and thorium as elementary constituents.

Per C

2. A cathode adapted to emit electrons at incandescence comprising tungsten, thoria and less than ~~3%~~ three percent by weight of carbon.

Per B

3. A cathode adapted to emit electrons at incandescence comprising tungsten, about ~~3/4%~~ three-quarters percent thoria and about ~~2/3%~~ two-thirds percent by weight of carbon.

" B

" B

4. The method of increasing the electron emissivity of an electrode of the thoriated type ~~operable at incandescence and comprising a refractory metal and thoria~~ which consists in introducing carbon into said electrode in amounts insufficient to convert said metal to a carbide, ~~and thereupon~~ sealing said electrode into a space substantially free from carbonaceous/vapors and thereupon activating said electrode.

" C

" B. " C

" B

5. An electric discharge device comprising an evacuated envelope, electrodes therein one of which comprises a refractory metal, thorium oxide and carbon, I C3 and a non-carbonaceous reagent capable of combining with ~~oxygenous~~ deleterious gases in said envelope.

Insert C3

" C

Cl. 6

Sub C4

6. An electric discharge device comprising an envelope, electrodes therein one of which consists of a highly refractory conducting material containing an oxide of thorium and ~~carbon, and a quantity of highly oxidizable metal therein capable of combining with traces of oxygenous gases.~~ B5

Insert B5

Per B

862 Ü

B C5 D B

7. An electric discharge device having a cathode comprising metallic tungsten, and thorium oxide ~~containing~~ combined with said tungsten C5 carbon ~~and thorium as constituents, and a quantity of magnesium in said device.~~

Cl. 8-9

i.e. B

B

8. The method of increasing the electron emissivity of ~~testing~~ an electrode comprising a refractory metal and thoria which consists in introducing carbon into said electrode, ~~and thereupon heating said conductor in a non-carbonizing and non-oxidizing environment to a temperature at which~~ B6 ~~chemical interaction occurs accompanied by a marked increase of electron emissivity.~~

id B6?

i A

id B7

B

9. The method of increasing the electron-emissivity of an electrode comprising a refractory metal and thoria which consists in introducing carbon into said electrode and B7 thereupon heating said conductor to about 2200° K. in a non-oxidizing environment. ~~in the presence of a non-carbonaceous reducing material.~~

C

id C7

10. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating a conductor comprising refractory metal and thoria in a carbonaceous vapor to a temperature adapted to cause combination of carbon with said conductor, ~~there-~~upon removing said vapor, E7 and heating said conductor in a non-oxidizing environment to a temperature at which electron emissivity is markedly increased.

id C8

11. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating to incandescence a conductor comprising tungsten and thoria in a carbonaceous vapor until a marked increase in cold resistance occurs, C8 and heating said conductor in the absence of said vapor in a reducing environment to

produce a surface layer of thorium material having a markedly higher electron emissivity than the original conductor.

Cl. 12-14

Sub C9

12. An electrical discharge device comprising an enclosing envelope, a quantity of metal therein having a chemical affinity for water vapor and having a materially lower ~~higher~~ vapor pressure than the metals of the alkali group and electrodes therein, one of which contains thorium as a constituent.

Per A

13. An electrical discharge device comprising an enclosing envelope, a quantity of magnesium ~~therein~~ deposited on said envelope, and electrodes ~~therein~~, one of which contains thorium as a constituent.

..a

Insert a2

IN WITNESS WHEREOF, I have hereunto set my hand this 8th day of August, 1921.

WGG-LEJ.

Irving Langmuir

864

AFFIDAVIT

STATE OF NEW YORK
COUNTY OF SCHENECTADY } SS.:

IRVING LANGMUIR the above named petitioner, being duly sworn, deposes and says that he is a citizen of the UNITED STATES and resident of SCHENECTADY, in the County of SCHENECTADY, State of NEW YORK, and that he verily believes himself to be the original, first, and sole inventor of the improvements in ELECTRON EMITTING CATHODES AND METHODS OF PREPARATION

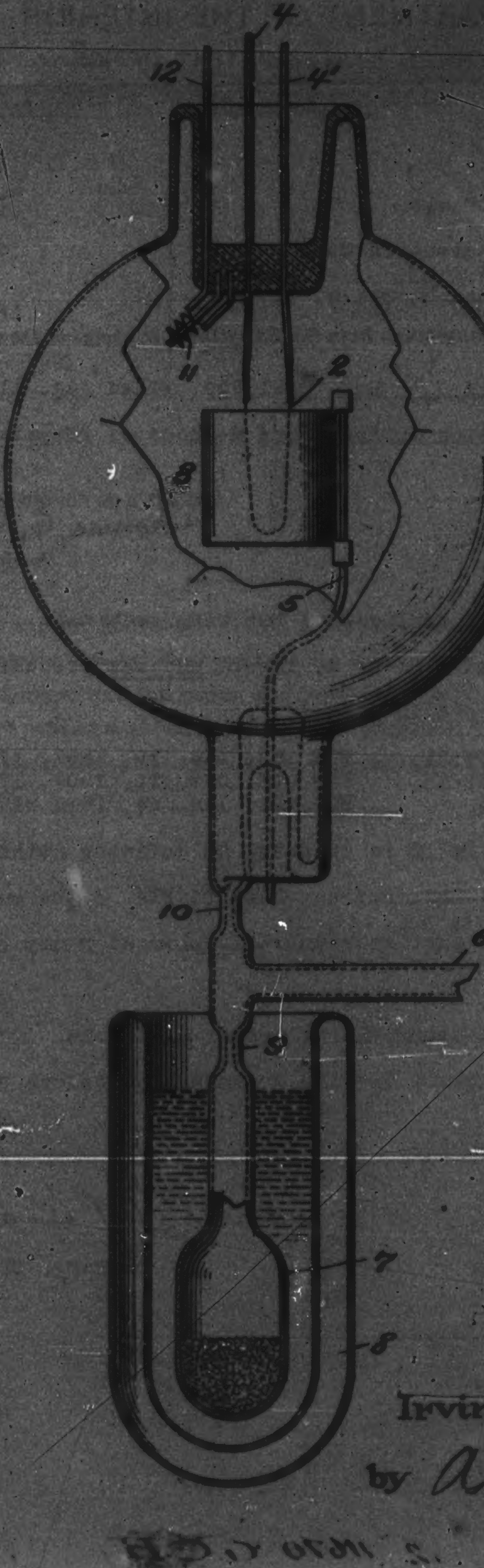
described and claimed in the annexed specification; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any country foreign to the United States.

Irving Langmuir

Sworn to and subscribed before me this 8th day of August, 1921

Helen Osgood
Notary Public

GO-181 500 1-18-21


4
12
4'
11
2
1
8
5
10
6
9
7
8

Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

866

Div. 16 Room 112 HHB:LBG 2—900

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name.

Paper No. 2

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON August 3, 1922

Mr. Albert G. Davis,
General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

Irving Langmuir, Ser. #491,634, filed Aug. 11, 1921.

Electron Emitting Cathodes and Methods of Preparation.

Thomas E. Robertson
Commissioner of Patents.

This application has been examined.

Page 4, line 2, insert and was preceding "formed".

Record is made of

DE LODYGUINE,	575,668,	Jan. 19, 1897,	176-130;
McQUAT ET AL,	869,012,	Oct. 22, 1907,	176-130;
THOWLESS,	982,751,	Jan. 24, 1911,	176-131.

Claim 13 is rejected as defining nothing patentable over THOWLESS, noting that, in Fig. 3 thereof, element F comprises in part thorium while element E may be made of magnesium.

All other claims appear allowable.

In claim 9, line 2, insert of before "electrode".

Exr., Div. 16.

HHB

25

#13

867

IN THE UNITED STATES PATENT OFFICE

16

In re application of
Irving Langmuir
Ser. No. 491,634
Filed August 11, 1921

Electron Emitting Cathodes and
Method of Preparation
Div.

HONORABLE COMMISSIONER OF PATENTS:

SIR,

I hereby appoint ALEXANDER D. LUNT, of Schenectady, New York, whose address is care of General Electric Company, Schenectady, New York, as my associate attorney, with full power of substitution and revocation, to prosecute the above entitled application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

Respectfully,

Albert G. Davis

Schenectady, N. Y.
September 11, 1922

Attorney for Applicant

AMENDMENT a

IN THE UNITED STATES PATENT OFFICE

~~In re Application of~~ :
IRVING LANGMUIR, :
Serial No. 491,634, : ELECTRON EMITTING CATHODES AND METHODS OF PREPARATION
Filed August 11, 1921, :
Div. 16, Room 112 :

a

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of August 3, 1923, please amend the above-entitled case as follows:

Page 4, line 2, after "time" insert - and was-

Page 5, line 19, after "bulb" change the period to a comma and add - this method of introducing an alkali metal being claimed in an application, Serial No. 608,311, December 21, 1922, by Ernest E. Charlton.

1a'

Line 23, before "magnesium" insert - and alkaline earth metal such as -

Page 6, line 18, cancel "formed" and substitute - activated -

Lines 26 and 27, cancel "forming" and substitute - activating -

Claim 9, line 2, after "emissivity" insert -of-

Claim 12, line 4, cancel "higher" and substitute - lower -

Claim 13, line 3, cancel "therein" and substitute - deposited on said envelope -

Add the following claims:

Per B
2
a
B
Insert B8

14. A cathode ~~material~~ for electric discharge devices comprising a refractory metal, an oxide which is capable of cathode ~~increasing~~ the electron emissivity of said material, and a quantity of reducing agent

Ⓐ^{2}

Rei C

.. C

15. A cathode of the thoriated type ~~material~~ for electric discharge devices containing ~~comprising a refractory metal, an oxide which is capable of increasing the electron emissivity of said material, and~~ less than about three percent ~~3%~~ by weight of carbon.

Rei B

16. An electric discharge device comprising an envelope, electrodes therein one of which comprises a refractory metal, a material reducible by carbon to a state of higher electron emissivity than said reffactory metal at a given temperature, and a quantity of carbon in an amount insufficient to convert said metal completely to a carbide.

.. B

17. An electrical discharge device comprising a container, electrodes therein one of which contains ② B9 a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, ② B10 and a quantity of alkaline earth metal deposited in said container out of immediate contact with said electrodes.

Insert B9

Insert B10

18. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, ② B11 and a quantity of alkaline earth metal deposited as a film on the inner surface of said container.

Insert B11

.. C

19. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, ② B12 and a quantity

Insert B12

of magnesium deposited ~~in~~ as a film on the inner surface of said container out of immediate contact with said electrodes.

Per C

20. An electrical discharge device comprising a container, electrodes therein one of which consists largely of refractory metal and contains an oxide of a metal of high electron emissivity (2)/B13 ~~and~~ together with a reducing agent, and a quantity of alkaline earth metal, the latter being deposited as a film on the inner wall of said container.

Insert B13

..D

..C

21. An electrical discharge device comprising a glass bulb, electrodes therein one of which consists largely of refractory metal and contains a material capable when activated of substantially increasing the electron emission of the electrode with which it is associated but which is deteriorated by oxidation and positive bombardment, and a film of magnesium coating the inner surface of said bulb.

Per B

..B

22. An electrical discharge device comprising a container, electrodes therein, one of which contains as a constituent a material capable of higher electron emission than the main constituent of said electrode but which is sensitive to water (2)/B14 vapor under operating conditions, and a film of metal deposited from the vapor state in a vacuum on the wall of said container which metal has a high chemical affinity for water vapor and has a materially lower vapor pressure at the operating temperature of said device than the alkali metals.

Insert B14

..C

..D

..B

23. The method of increasing the electron emissivity of a metallic electrode containing a compound capable upon reduction of materially in-

creasing the electron emissivity of said electrode which consists in introducing carbon into said electrode in an amount insufficient to convert the metal constituting said electrode completely to a carbide and heating said electrode in a non-oxidising, and non-carbonising environment to a temperature sufficiently high to activate said electrode. ④ 15

Ser B

Insert B15

24. An electrode material for an electrical discharge device consisting of a metal capable of stable operation at an elevated temperature, a compound of a material capable in a reduced state of higher electron emission than said metal, and carbon in a quantity insufficient to deleteriously affect the strength of said material. ④ 16

Insert B16

25. A cathode material for electrical discharge devices consisting largely of a metal capable of operation at an elevated temperature, a reducible compound of a material of high electron emissivity and less than about one per cent of carbon.

Ang.

REMARKS

The references cited relate to the manufacture of filaments or glowers for lighting purposes whereas applicant's invention relates to the manufacture of an efficient electron emitter. The former is operated at the highest incandescence consistent with a fair commercial life. The latter is operated at the lowest temperature consistent with efficient operation of the electron tube.

872

D 119

McQuat & Lorenz patent 959,012 describes a process of making a carbon incandescent filament provided with a coating of carbon and metal. DeLodyguine describes a flashing process of making a composite metal filament and Thowless patent 962,751 describes a method of making incandescent glowers which entail the use of magnesium only as a temporary element which is removed before use of the filament. If the magnesium were removed by volatilization in the lamp bulb an inoperative lamp would result due to the opaque magnesium "mirror" deposited on the bulb. In subject matter and in terms of the claims, this case relates to an art which has very few points of contact with the lamp art. Even if a filament useful for lighting were found useful unchanged as an electron emitter this discovery probably would involve a patentable invention. Claim 13 specifically calls for an "electrical discharge device" and electrodes are specified as part of the combination. These are not found in the Thowless lamp. The claim has been further amended to distinguish clearly over this reference. However, to protect applicant's invention a number of more generic claims are submitted herewith.

An allowance is solicited.

Respectfully submitted,

Alexander S. Lunt

Attorney for Langmuir.

Schenectady, N.Y.
May 28, 1923.

WCG/GAL

Div. 16 Room 112

Address only
"The Commissioner of Patents,
Washington, D. C."
and not any official by name.

Paper No. 5

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

FJH:LBG

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON

February 13, 1924

Mr. Alexander D. Lunt,
General Electric Co.,
Schenectady, N. Y

Please find below a communication from the EXAMINER in charge of the application of

Irving Lnagmuir, Ser. #491,634, filed Aug. 11, 1921.

Electron Emitting Cathodes and Methods of Preparation.

Thomas E. Robertson
Commissioner of Patents.

This action is responsive to amendment filed May 29, 1923.

A claim is a formal definition of the invention, and the numerical percent abbreviations should be expanded in the first few claims.

Page 5, line 23 is objected to as misdescriptive in that "magnesium" is not "an alkaline earth metal". Obviously, applicant intended the insertion of the amendment after "magnesium".

Applicant should observe proper line of demarcation between this application and his patents.

Cancelation of claims in the amendment such as 17, specific to the use of "alkaline earth metals" is required since applicant has elected to claim the magnesium species.

Claim 13 is rejected as aggregative since the magnesium getter apparently does not patentably cooperate with the cathode, but merely acts on the gas content of the tube as in the lamp art. It is old to use magnesium as a getter, as shown by

WHITE, 1,159,307, Nov. 2, 1915, 250-27; or
MACKAY, 1,208,597, Dec. 12, 1916, 250-27.

It is obvious that, after the getter has been vaporized within the tube, the excess would condense on the walls. However, this makes no difference patentably so long as it is exposed to the gases and positioned somewhere within the enclosure, e.g. on the leads as shown by Mackay. As to water vapor, see line 32, page 1 of Mackay. The patent to LEDERER, 1,461,360, July 10, 1923, 176-122; shows it old to coat the walls of a tube with a getter. It is old to use thorium in an electrode as shown by

LANGMUIR, 1,244,216, Oct. 23, 1917, 250-27x;
LANGMUIR, 1,244,217, Oct. 23, 1917, 250-27x.

Upon reconsideration, all claims such as 5, 6, 7, etc., formerly allowed, are rejected as aggregative for the same reasons given in the rejection of claim 13. In claim 10, the last step is merely the ordinary step in the subsequent operation of any tube. In the event of a traverse of this rejection, these claims will be rejected as unpatentable over LANGMUIR in view of MACKAY or LEDERER, cited.

Attention is directed to page 2, lines 111 to 123, of LANGMUIR, 1,244,216, which states that a certain amount of carbon increases the emission and that too much would form a carbide. In view of this and the state of the art as above exemplified, it appears that applicant is entitled to nothing but specific claims to the use of carbon within the cathode as a reducing agent, and the nature of the invention in view of the art will not permit of such an excessive number of claims as now exists. Claims such as 14 are indefinite as to the materials used and as to their proportions.

Attention is called to LANGMUIR, 1,244,217, page 1, lines 64, 65, and page 2, lines 8, 34 to 37.

In view of page 4, lines 27 to 33, attention is called to lines 45 to 48 of patent to

COOLIDGE, 1,010,866, Dec. 5, 1911, 250-27.

Coolidge shows a combination of ingredients which may be used as "cathode material". It appears that some of the carbon would remain and reduce some of the thoria in a manner set forth by applicant.

It is noted that the patent to

VON RECKLINGHAUSEN, 946,068, Jan. 11, 1910, 250-27x;

uses magnesium as a getter and confines it - lines 71 to 79, page 1, - to the element 5, hence preventing its escape to other parts of the tube where it is not wanted. On the other hand, see lines 80 to 87.

Attention is called to page 2, lines 14 to 37, of

BLAU, 674,754, May 21, 1901, 250-27x;

disclosing a process of adding carbon to a filament by means of a carbonaceous vapor.

Exr., Div. 16.

JOH

876

[illegible] No. 6 B

[illegible]

IN THE UNITED STATES PATENT OFFICE

In re Application of :

IRVING LANGMUIR :

Serial No. 491,634 : ELECTRON EMITTING CATHODES AND METHODS OF PREPARATION

Filed August 11, 1921 :

Div. 16, Room 112 :

B

Honorable Commissioner of Patents.

Sir:

In response to the Office Action of February 13, 1924, please amend the above entitled case as follows:

Page 1, line 13, after "containing" insert -distributed throughout its mass-

Page 2, line 14, after "agent" insert -which is provided-

Page 2, lines 16-19, cancel the sentence beginning with "Another" and ending with "metals" and substitute the following:

B' ita

-A thoriated cathode may be deleteriously affected by positive ion bombardment, that is, when voltages materially higher than the ionization voltages are impressed between a thoriated cathode and a positive electrode in the presence of ionizable gas, then the beneficial effect of the thorium may be largely or entirely destroyed by positive ion bombardment. Although the alkali metals are entirely satisfactory as agents to remove deleterious gases when the operating temperature of the bulb is only moderately above room temperature, as in the case of radio receiving tubes, these alkali metals have a sufficiently high vapor pressure at the operating temperature of power devices in which cathodes of the thoriated type are used to become ionized at

D

higher voltages and to cause removal of the active film of thorium from the cathode by bombardment. I have found that it is advantageous in many cases to provide a device containing a cathode of the thoriated type with a material having an affinity for gases, such as magnesium, for example, which at the operating temperature of the device, has substantially no vapor pressure.

Page 4, line 15, cancel "reasonably" and substitute -commercially-

Page 5, line 9, after "enough" insert -carbon-

Line 11, cancel "As the next step in carrying out my invention" and substitute -After the cathode has been provided with a content of reducing agent-

B2

Line 12, cancel "reducing" ; same line after "material" insert -capable of combining with water vapor and other deleterious gases-

B3

Line 21, after "introduce" insert -for the reasons given above-

Page 6, lines 12 to 15, cancel the sentence beginning with "Unlike" and ending with "thoria."

Line 15, indicate that sentence beginning with "The tungsten" should constitute a new paragraph.

Line 16, cancel "also."

Cancel Claim 1, and rewrite as follows:

B4

Sub. C 2

~~1. A cathode body for an electric discharge device comprising a refractory metal, containing thorium as an elementary constituent, and having carbon combined therewith, said body being characterised by a higher electrical resistance than a body~~

uncombined with carbon but which otherwise is similar, and being less sensitive to the deleterious effect of gases than a cathode body unprovided with carbon.

Claim 2, line 3, cancel "3%" and insert - three percent -.

Claim 3, line 2, cancel "3/4%" and insert - three-quarters percent -.

Line 3, cancel "2/3%" and insert - two-thirds percent -.

Claim 4, line 5, place a comma after "carbide" and cancel "thereupon."

Line 7, after "vapors" add - and thereupon activating said electrode -

Claim 6, line 4, cancel "carbon and a quantity of" and substitute" - a non-volatile material which is capable of reducing said oxide of thorium. -

B5 Rec C

Cancel lines 5 and 6.

Claim 7, line 2, after "tungsten" place a comma and insert - thorium oxide -.

Lines 3 and 4, cancel the matter beginning with "and thorium" and ending with "device", and substitute - combined with said tungsten -.

Claim 8, line 1, cancel "treating" and substitute - increasing the electron emissivity of -.

Line 3, place a comma after "electrode" and cancel "and thereupon".

Lines 5 to 7, cancel the matter beginning with "chemical" and ending with "emissivity" and substitute - a carbide of said metal is formed, activating said electrode by heating to about 2200° K. and operating the same under such conditions that bombardment of the electrode by positive ions is inappreciable -.

B6 Rec C

Claim 9, line 4, after "electrode" insert - in

B7 Rec

sufficient quantity to form an appreciable amount of carbide -.

Line 5, after "environment" place a period and cancel the rest of the claim.

Claim 14, line 1, after "cathode" cancel "material".

Incomplete & inaccurate?

Line 3, cancel "increasing" and substitute - cathode -; line 4, after "agent" insert the following: - contained in said cathode which is capable of forming a supply of said material of high emissivity during the life of said cathode, the amount of said agent being restricted to a proportion which will permit said cathode to be operated with a commercially long life. -

B8

Per C

Claim 15, line 4, cancel "3%" and substitute - three percent -.

Claim 16, line 7, before "to carbide" insert - completely -.

Claim 17, line 3, after "contains" insert - less than three percent of carbon combined therewith and -.

√ B9

Line 5, before "and" insert - but being sensitive to positive ion bombardment -.

√ B10

Claim 18, line 5, before "and" insert - but being sensitive to positive ion bombardment -.

√ B11

Claim 19, line 5, before "and" insert - but being sensitive to positive ion bombardment -.

√ B12

Claim 20, line 4, after "emissivity" insert - which when rendered active is sensitive to ion bombardment -.

√ B13

Claim 21, line 4, after "capable" insert - when activated -.

Line 7, after "oxidation" insert - and positive bombardment -.

Claim 22, line 5, before "water" insert

B14 -positive ion bombardment, and to the chemical effect of-

Line 9, after "pressure" insert -at the operating temperature of said device-

Claim 23, line 7, after "electrode" insert -completely-

Line 10, after "electrode" change the period to a comma, and add -and thereupon operating

15 said electrode under conditions which render the effect of positive ion bombardment of said electrode inappreciable-.

Claim 24, line 7, after "material" change the period to a comma and add the following -but being

16 capable of reducing a sufficient amount of said compound to enable said electrode to be more readily activated during use than would be the case in the absence of said carbon-.

REMARKS

The formal changes required by the Examiner in the first few claims have been made.

Reconsideration is requested of the Examiner's objection to the inclusion of magnesium with the alkaline earth metals. It is possible that some chemical writers have not included magnesium with the alkaline earths, but nevertheless according to the Century Dictionary and Webster's new International Dictionary, lime, magnesium, baryta and strontia are included in the alkaline earths, even though Webster states that properties of these metals fall between the true alkalies and the earths proper.

According to a more scientific chemical classification on the basis of Periodic System, magnesium is included in subgroup 1 of group 2, together with calcium, strontium, barium and magnesium; see for example, "Abegg's Handbuch der Anorganischen Chemie II, 2, and Smithsonian Physical Tables by Fowle, 7th edition, Page 410.

The claims in this case are rejected on eight different references, some of which are used in combination, and some singly. The invention constitutes an important improvement in a broad vacuum tube invention described in certain prior patents of the present inventor, Dr. Irving Langmuir; namely, 1,244,216, and 1,244,217, which were filed in 1914. The single fact that the production of radio tubes embodying the invention have run into the millions, is a sufficient indication of the commercial importance of the invention. The fact that the improvements herein claimed are in regular commercial use in the manufacture of vacuum tubes containing thoriated cathodes, speaks for itself and leaves no doubt as to the practical utility of the improvements.

The Examiner's reasoning in combining the references has not been stated very fully, but apparently he is of the opinion that the nature and constitution of the thoriated cathode is sufficiently described in the prior patents to render obvious the new features claimed herein.

A closer examination will show that this is not the case. It is true that by following the specifications of these patents good vacuum tubes can be made in which the high electron emissivity of thorium is utilized.

The present improvements extend the range of conditions under which the invention can be used, and increase the certainty of getting uniformly good results from day to day under manufacturing conditions. These improvements which are described [illegible] detail in the specification may be summarized briefly, as

First - The carburization of the thoriated filament, and

Second - The introduction of metallic magnesium into the evacuated bulb.

In prior patent 1,244,216 it is stated in lines 111 to 118, that the admission of a trace of hydrocarbon vapor to a tube containing a thoriated cathode is followed by a rise in electron emission, but the patent goes on to say that the electron emission drops to a low value when the carbon is in excess. The second patent 1,244,217 covers the addition of alkali metals such as potassium to a thoriated cathode tube, and states that in some cases, carbonaceous compounds can be used in place of alkali metal.

Mackay patent 1,208,597 describes an incandescent cathode arc device containing a filling of argon or similar gas at a pressure of about 5 to 12 c.m. Calcium or magnesium is placed in proximity to and receives the heat of the arc, thereby decreasing the drop of potential in the arc. The function of the magnesium, calcium, or the like, the patentee states, appears to be a combination with water vapor, hydrogen, or nitrogen.

It is always difficult after an improvement has been made to place oneself in the position of the person who is supposed to have been skilled in the art prior or at the time the invention was made. Such a person, in this case might be assumed to be the skilled manufacturer of vacuum tubes, who is familiar with the Langmuir patents, as well as the Mackay patents cited by the Examiner.

Suppose the electron emissivity of a thoriated cathode device containing an alkali metal was found to become impaired or destroyed under certain conditions, say, for power transmission.

Why should a person familiar with the prior patents, cited by the Examiner, conclude that if he were to substitute an alkaline earth metal for the alkali metal, the trouble would disappear. He would know that the conditions in the thoriated cathode tube device are utterly unlike the conditions of an arc tube, such as described in Mackay patent 1,208,597. In the arc device magnesium operates at comparatively high temperature in the presence of active positive ionization and its beneficial effect is to lower the arc drop (by the removal of gas producing inelastic collisions). From the prior Langmuir patent 1,244,217, he would know that he must remove water vapor and other deleterious gases to an unusual degree. He would know from the White patent 1,159,307 that magnesium or calcium vapor is one means of producing high vacua but as other methods of evacuation had already been used when preparing the tubes, why choose this particular agent, especially as the problem is not merely to produce a high vacuum, but to maintain a high vacuum. He would know that the alkaline earth metals are less chemically active than the alkali metals, and what is most significant, he would know that the former have substantially no vapor pressure at the operating temperature range of hot cathode tubes. Why should the alkaline earth metals work at all to combine with gases during the operation of the devices at temperatures way below the vaporizing temperatures of these metals. There was no such problem in the Mackay device which had an ordinary tungsten filament. The ordinary tungsten filament works all right in vacuum tubes without any getter, such as potassium or magnesium.

No reason was apparent for introducing a considerable amount of carbon into the filament. The prior patent 1,244,216 stated that electron emission drops to a low value when carbon is present in excess.

An intensive investigation of the whole subject, which was not within the range of the ordinary workers skilled in the art, finally showed that the difficulty encountered in thoriated cathode devices carrying large currents of considerable voltages, was due to the incidental increase of the pressure of potassium vapor by reason of the higher temperature of the operation until sufficient positive ionization occurred to lower or destroy the electron emissivity due to thorium. It was also found that metals such as magnesium, calcium, or the like, which had too low a vapor pressure to be vaporized appreciably by the heating of the bulb incidental to normal operation nevertheless will protect the sensitive thoriated filament, which operates by virtue of a surface film of the inconceivable thinness of about one hundred millionth of an inch. When one of these metals is vaporized upon the inner surface of the bulb, the surface exposed is so much greater than the filament surface that some adsorption phenomenon appears to come into play. Whatever may be the reason, there is no doubt that the alkaline earth metals do the trick, not only in power tubes, but also in small low temperature tubes, such as radio detectors. The ease with which they may be introduced without at the same time introducing oxides, hydrates, etc., make them superior to the alkali metals.

D

It was also found that the limitation which had existed in the use of hydrocarbons was due to the decomposition of the hydrocarbon leaving hydrogen in the bulb, which caused positive ionization, and cathode bombardment with its deleterious effect. It was found in the course of this investigation that when carbon was introduced into the cathode without the incidental liberation of hydrogen or if the hydrogen was removed before operation, that the carbon in some way modified the cathode to produce a condition favorable to steady high electron emission during operation. As a result, the functioning of the cathode became more reproducible under the unavoidable variations in conditions imposed by large scale manufacturers. This effect is even now not understood. The beneficial effect of carbon upon a thoriated cathode is well observed even when carbon seems to have disappeared (for example by combination with oxides) during the manufacture of the cathode wire. Under the new conditions, the formation of a carbide instead of being harmful, became a benefit.

It was certainly not obvious from the prior patents that carbon and alkaline metal getters could be used conjointly. Even though conjoint use of these two additions is not clearly understood, it is clear that they cooperate to produce high electron emissions. Both carbon and magnesium protect the thorium film from the effect of gases. Both coact to produce a favorable condition upon the surface of the cathode for the formation of an effective thorium film upon the cathode surface. The carbon appears to act upon the impurities in the tungsten which otherwise would accumulate on the surface and interfere with the formation of the film, and the magnesium, calcium, or the like, appear to combine with water vapor and other gases which would act deleteriously upon the surface from the outside. In one sense both the carbon and alkaline earth metal are "getters." Instead of one getter as recommended in patent 1,244,217 there are two getters, neither of which are identical with the getters of patent 1,244,217.

It certainly was not obvious from the lower vapor pressure of magnesium, that magnesium would thus act in small capacity radio tubes which operate at a temperature only slightly above room temperature. The vapor pressures of the alkaline earth metals are extremely low at a range of temperatures above room temperature. Applicant's attorney has been unable to find in a reference work a determination of the vapor pressures of these metals. Their melting points as compared with the alkali metals are an indication of the low value of the vapor pressures. A few melting point values from Laudolt-Börnstein Tabellen are instructive:

		Melting Point:
Caesium	about	25 - 26° C.
Potassium	"	62 - 63° C.
Sodium	"	97 - 98° C.
Magnesium	"	650° C.
Calcium	"	803 - 806° C.
Barium	"	850°C.

The applicant hesitates to lengthen this argument unduly, by detailed discussion of the patents cited as reference, which either merely show that magnesium had been used as a chemical agent for combining with gases to produce a vacuum, or show that carbon has been an accidental impurity in a lighting filament in which thoria constitutes a core, or show that it is known to introduce carbon into a filament by heating the same in a carbonaceous vapor. Not any of these steps are claimed broadly by themselves.

It is hoped that in view of the amendment to the claims, and the above discussion, it is not necessary to take up these remote references in detail.

The Examiner's criticism as to the number of the claims has been given earnest consideration. In view of the fact that three aspects of the invention are presented, namely:

(a) a new cathode material capable of manufacture and sale independently of the device,

(b) a new electric discharge device containing this new cathode together with a new getter, and

(c) a new method of producing this device without the disadvantages of destroying the operativeness of the cathode by the formation of by-products,

it is believed that the number of claims is not excessive.

In view of the practical importance of this invention applicant should not be obliged to jeopardize his rights by the danger of being charged with estoppels in some future litigation, due to his having cancelled claims. The claims are believed to be patentable over the references cited. In view of the difficulty of fully protecting these improvements over applicant's own prior patents by a few claims, the Examiner is earnestly requested to favorably consider the claims in their present form.

Reconsideration and allowance are respectfully requested.

Respectfully submitted,

ATTORNEY FOR LANGMUIR.

WGG/HH

Schenectady, N.Y.
April 25, 1924.

Div. 51 Room 240-Annex

Address only
"The Commissioner of Patents,
Washington, D. C."
and not any official by name.

Paper No. 7

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

FJH/tr

WASHINGTON December 12, 1924.

Alexander D. Lunt,
C/o General Electric Co.,
Schenectady, New York.

PATENT OFFICE
DEC 12 1924
MAILED

Please find below a communication from the EXAMINER in charge of the application of

Irving Langmuir, Ser. No. 491,634, Filed August 11, 1921
ELECTRIC EMITTING CATHODES AND METHODS OF PREPARATION.

Thomas E. Robertson
Commissioner of Patents.

Responsive to amendment filed April 26, 1924.

Record is made of

HEANY 872,936 Dec. 3, 1907 250-27

Claim 14, line 3, the insertion is incomplete.

Page 11 of applicants remarks paragraph b, states as one advantage that he gets a new cathode plus a new getter. The art shows, and applicant's statement admit, that magnesium is not a "new getter". The invention lies in the form or condition of the magnesium in the tube.

Claims such as 17 are rejected as broader than the invention and as not properly defining the invention. The claim should be limited to the form, nature and source of the magnesium deposit on the inner walls of the tube. The same applies to all other claims on magnesium as a getter.

All claims such as 5 are rejected as broader than the invention. Applicant has shown that only a certain maximum of carbon content will perform the invention.

Claims such as 1 are rejected as misdescriptive in view of lines 3 and 4 "thorium-----carbon". Thoriated cathode is suggested.

What is the cooperative relation between the thoriated cathode and the magnesium film? Does the magnesium act as a general getter agent, or more specifically as a getter for deleterious gases for example gaseous by-products from the reduction, or does it do both.

Attention is called to Heany cited, page 2 lines 122-124, and page 3, lines 100-105.

Applicant is urged to respond promptly in view of the long pendency of the case.

C. D. B

Examiner, Div. 51.

F.J.H.

PAPER NO. 8
AMENDMENT C

IN THE UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 491,634, : ELECTRON EMITTING CATHODES AND
Filed August 11, 1921, : METHODS OF PREPARATION.
Div. 51, Room 240-Annex. :

PATENT OFFICE
DEC 30 1924
DIV. 51 FILED

C

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of December 12, 1924, please amend the above-entitled application as follows:

Page 1, line 9, after "cathode" insert - of the type -.

Line 16, after "an addition of" insert ~~a~~ - a material capable of increasing the electron emissivity of the cathode, such for example as ~~a~~

√C¹ copied √

Page 2, line 1, cancel "thoriated" and insert after "cathode" - of the thoriated type -.

Page 5, line 30, cancel "walls" and substitute - inner surface -.

Page 6, line 25, Indicate that the matter beginning with "As explained.." should form a new paragraph.

Cancel claims 1 and 2 and rewrite as follows:

Pers C²

1. In an electron discharge device, a ~~A~~ cathode body of the thoriated type containing carbon in an amount insufficient to convert all of the metallic constituents of said cathode to a carbide but sufficient to render said cathode less sensitive to the deleterious effect of gases than a cathode body unprovided with carbon.

2. In an electron discharge device, a ~~A~~ tungsten cathode of the thoriated type adapted to emit electrons when heated, containing carbon in an appreciable amount~~s~~ but less than three per

cent by weight.

Claim 4, line 2, after "electrode" insert -- of the thoriated type --.

Lines 2 and 3, cancel "operable at incandescence and comprising a refractory metal and thoria".

Line 5, after "carbide" cancel "and".

Claim 5, line 4, cancel the comma after "carbon" and insert -- in an amount insufficient to convert said metal to a carbide, --

C3

Line 5, cancel "oxygenous" and substitute -- deleterious --.

Cancel claim 6, and rewrite as follows:

4 6. An electric discharge device comprising an envelope, an anode and a cathode of the thoriated type and a non-volatile material, which is capable of reducing thorium oxide, contained in said cathode in such small amounts that the durability of said cathode is not appreciably decreased.

Claim 7, line 3, after "tungsten" cancel the period and add the following -- in an amount materially less than required to convert all the tungsten to a carbide. --

5

Cancel claims 8 and 9 and rewrite as follows:

6 8. The method of increasing the electron emissivity of a cathode of the thoriated type which consists in introducing carbon into said cathode in an amount less than about one per cent by weight, heating said cathode in a non-carbonising and non-oxidising environment to a temperature at which a carbide of said metal is formed, activating said electrode by heating to about 2200° K. and operating the same under such conditions that bombardment of the electrode by positive ions is inappreciable.

(over)

9. The method of increasing the electron-emissivity of a cathode of the thoriated type which consists in introducing carbon into said electrode in an amount less than one per cent by weight, mounting said electrode in a bulb, evacuating the same, volatilizing magnesium in said bulb after evacuation, and activating said cathode by heating to an elevated temperature. cf. 10 [illegible]

Claim 10, lines 5 and 6, cancel "thereupon".

Line 5 after "vapor" remove the comma and

C7 insert / before the amount of carbon introduced into the filament exceeds one per cent /.

Claim 11, line 5, after "occurs," insert / by the

C8 introduction of carbon, discontinuing the heating before the tungsten has been largely converted to a carbide /.

Cancel claims 12, 13, and 14 and rewrite as follows:

C9 12. An electrical discharge device comprising a sealed envelope, electrodes therein which include a cathode of the thoriated type and a substance, having a marked chemical affinity for water vapor, deposited as a film of extensive surface upon the inside of said envelope ~~exposed to said cathode~~, said substance having a materially lower vapor pressure than the alkali metals.

13. An electrical discharge device comprising a sealed envelope, electrodes therein one of which is of the thoriated type and a film of magnesium deposited on the inner surface of said envelope.

14. An electron discharge device containing a cathode of the thoriated type, said cathode being provided with a reducing agent sufficient in quantity to promote ~~secure~~ activation of said cathode ~~during use~~, but restricted to an amount which will permit operation

D/136

of said cathode at a temperature of effective electron-emission with a commercially long life. Cl. 15-25

Claim 15, line 1, cancel "material" and substitute - of the thoriated type -.

Line 2, after "devices" insert - containing -; cancel the matter beginning with "comprising" and ending with "said material, and".

Claim 18, line 6, after "deposited" insert - as a film -.

Claim 19, line 6, after "deposited" insert - as a film on the inner surface of -; cancel "in".

Claim 20, line 6, after "deposited" insert - as a film -.

Claim 22, line 7, after "metal" insert - deposited from the vapor state in a vacuum -.

REMARKS.

The claims have been amended along the lines indicated by the Examiner. When magnesium has been used heretofore to combine with gases, it has acted in the vapor state. In the present case a film of solid magnesium (or its equivalent) guards against deterioration of a cathode extraordinarily sensitive to gases even at the extremely low pressure to be found in electron discharge devices in which ionization is absent. Even when a thoriated cathode is used in a discharge tube which has been baked out and highly evacuated, provision must be made to protect the film of thorium one atom deep on the cathode from minute amounts of gas given off during the operation of the device. It certainly is not obvious that a film of non-volatile metal will do this. Magnesium at room temperature has no appreciable vapor pressure but nevertheless is effective by reason of the large surface of the film.

Carbon in the cathode in some way also acts to give the cathode a commercially long life. It is difficult to determine exactly what the carbon does in the cathode. Its benefits are real but the conditions are such that the modus operandi is obscure.

Rather than resort to speculation applicant must say that he can not say whether or not coaction occurs between the carbon and the magnesium or other getter film. Both kinds of getter (if this term is permissible) act to preserve and render efficient the cathode as a low temperature electron emitter. Each may do so in its own way. As the Examiner no doubt is aware this invention has gone into extensive use in radio receiver tubes. It is being utilized also in power transmission devices.

An allowance is solicited.

Respectfully submitted,

Alexander D. Lunt
Attorney for Langmuir.

Schenectady, N.Y.,
WDG:RH December 27, 1924.

896

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

2—138

Serial No. 491,634

Gr
Div. 51

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE

WASHINGTON February 5, 1925.

Irving Langmuir, Assor. to General Electric Company, a corp of New York.

Sir: Your APPLICATION for a patent for an IMPROVEMENT in ELECTRON EMITTING CATHODES AND METHODS OF PREPARATION filed August 11, 1921 , has been examined and ALLOWED.(25 claims)

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $20, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of TEN CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully.

Thomas E. Robertson

Commissioner of Patents.

Alexander D. Lunt
C/o General Electric Co.,
Schenectady, New York.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED ORDERS WILL NOT BE ACCEPTED.

S-673

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON

Feb. 20, 1925

Petition under **RULE 78:**

Application of __________

Serial No. __________

Invention: __________

This petition is referred to Examiner in charge of Division 51 in accordance with Order No. 2698; Order No. 2901, 308 O. G., 447, and Notice of August 11, 1922.

Thomas E. Robertson
Commissioner.

898

PAPER NO. 9
AMENDMENT D

ISSUE DIVISION
FEB 10 1925
U. S. PATENT OFFICE

(R.78)

IN THE UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR :
Serial No. 491,634 : ELECTRON EMITTING CATHODES AND
Filed August 11, 1921. : METHODS OF PREPARATION.
Div. 51, Room 240-Annex :

D

AMENDMENT UNDER RULE 78

Honorable Commissioner of Patents,
Washington, D. C.

Sir:

It is requested that the following changes shall be made in the above application without withdrawing the same from issue.

Page 1, line 6, and wherever it appears in the title of application, change the word "CATHODE" in the title to--DEVICE--.

Line 29, before "admission" insert--beneficial results obtained by the--.

Page 2, line 12, indicate that the sentence beginning with, "In accordance" constitutes a paragraph.

In line 2 of the paragraph inserted line 16, page 2, place a comma (,) after "is".

Page 2, line 22, before "apparatus" cancel "the" and substitute,--an--.

Page 3, line 13, before "receptacle" cancel "a" and insert --the--.

Line 16, change "6" to--7--.

Page 4, line 2, cancel "and was found" and insert--sufficient--.

Page 5, line 4, cancel "method" and substitute--cathode at--.

Line 5, before "vapors" insert--the--.

Page 5, line 8, cancel the sign " % " and substitute--of one per cent,--.

Line 23, after "example" change "and" to read--an--.

Line 28, cancel "When" and substitute--By--.

Line 29, cancel "by" and substitute--with--.

Page 6, line 2, before "volatilize" insert--to--.

Line 9, place a comma (,) after "bulb".

Line 10, place a comma (,) after "operation".

Line 18, before "cathode" change "a" to--the--.

Line 21, before "carbon" insert--the--.

Line 30, before "forming" insert, --activating or--and place quotation marks before and after "forming".

Claim 1, line 1, cancel "A" and insert, --In an electron discharge device, a--.

Claim 2, line 1, cancel "A" and insert, --In an electron discharge device, a--.

Line 3, after "in" insert, --an--; same line change "amounts" to--amount--.

Claim 7, line 2, cancel "containing".

Claim 12, line 3, place a comma (,) after "substance".

Line 4, place a comma (,) after "vapor".

Line 6, cancel "exposed to said cathode".

Claim 14, line 4, cancel "permit" and substitute,--promote--; same line cancel "during use".

Claim 20, line 5, cancel "and" and substitute--together with--; same line place a comma (,) after "agent".

Line 6, place a comma after "metal" and insert--the latter being--.

Claim 22, line 7, after "which" insert--metal--.

REMARKS

The above changes are requested to correct minor errors in language and to render clear possible obscurities in terminology. None of the changes or additions involve new matter.

Respectfully submitted,

Alexander D. Lunt

Attorney for Langmuir.

February 10, 1925.

WGG/TRM

ENTRY RECOMMENDED
UNDER RULE 78

EXAMINER

Karl Fenning

901

Div. 51 Room 240-Annex

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

2 261-a

Paper No. 10

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON

February 11, 1925

Alexander D. Lunt,
C/o General Elec. Co.,
Schenectady, New York.

In the application of Irving Langmuir, Ser. No. 491,634,
Filed August 11, 1921 - Allowed February 5, 1925
ELECTRON EMITTING DEVICES AND METHODS OF PREPARATION

The amendment filed Feb. 10, 1925 has been entered under Rule 78.

Thomas E. Robertson
Commissioner of Patents.

902

FEB 13 1925 U.S. PATENT OFFICE

IN THE UNITED STATES PATENT OFFICE

In re Application of	
Irving Langmuir,	
Serial No. 491,634,	ELECTRON EMITTING CATHODES
Filed August 11, 1921,	& METHODS OF PREPARATION
Allowed February 5, 1925.	

THE HONORABLE COMMISSIONER OF PATENTS:

Sir:-

It is respectfully requested that the attached Supplemental Oath be filed in the above case.

Fee Feb 11
Iss Mar 10

Respectfully submitted,

Attorney for Langmuir

Schenectady, New York,
Feb. 12 ,1925.

BBK:MK

IN THE UNITED STATES PATENT OFFICE

In re Application of :
Irving Langmuir, :
Serial No. 491,654, : ELECTRON EMITTING CATHODES &
Filed August 11, 1921, : METHODS OF PREPARATION
Allowed February 5, 1925. :

SUPPLEMENTAL OATH

State of New York :
: ss:
County of Schenectady :

Irving Langmuir, whose application for Letters Patent for an improvement in Electron Emitting Cathodes and Methods of Preparation, Serial No. 491,654, was filed in the United States Patent Office on or about the 11th day of August, 1921, being duly sworn, deposes and says that the subject matter of the claims, as they now stand amended, was part of his invention, was invented before he filed his original application, above identified, was not known or used before his invention, was not patented or described in a printed publication in any country more than two years before his application, was not patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to his application, was not in public use or on sale in this country for more than two years before the date of his application, and has not been abandoned.

Irving Langmuir

Sworn to and subscribed before me this 12th day of February, 1925.

Benjamin B. Hull
Notary Public.

904

MAR
1925

12

B

Letters Patent

IN THE UNITED STATES PATENT OFFICE.

In re Letters Patent of
Irving Langmuir,
No. 1,529,597,
March 10, 1925.

ELECTRON-EMITTING DEVICES AND METHODS OF PREPARATION.

Hon. Commissioner of Patents,

Sir:-

On March 10, 1925, Letters Patent No. 1,529,597 for Electron-Emitting Devices and Methods of Preparation were granted to General Electric Company as assignee of Irving Langmuir on an application filed August 11, 1921, Serial No. 491,634. A comparison of the specification of the Letters Patent with the application file in the archives of the Patent Office shows that a certain mistake was made by said Office in printing the specification. The following correction is necessary to make the specification correspond with the file of said application:

Page 1, line 99, "what diagrammatically. An apparatus used" should be changed to read – what diagrammatically, an apparatus used –.

In accordance with the provisions of Rule 170 of Office Practice, it is respectfully requested that a certificate setting forth the above correction be duly endorsed upon the Letters Patent, and recorded in the records of patents, and a printed copy thereof attached to each printed copy of the specification and drawings.

Letters Patent No. 1,529,597 are transmitted herewith.

Respectfully submitted,

Alexander

Attorney for Langmuir.

Schenectady, N. Y.,
March 23, 1925.

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

905 /3

Letter No. 56200

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON, D.C.

March 27, 1925.

In the matter of
Letters Patent No.1,529,597,
Irving Langmuir, Assor.,
March 10, 1925,
Albert G. Davis, attorney.

REPORT OF THE CHIEF OF THE ISSUE AND GAZETTE DIVISION.

Associate attorneys return Letters Patent with a request that a certificate be issued correcting the following error:

Page 1, line 99, "what diagrammatically. An apparatus used" should read--what diagrammatically, an apparatus used--

Examination of the record discloses that the error is chargeable to the Printer.

Respectfully,

John Haw

Chief of the Issue Division.

To Commissioner of Patents.

14 J.R.S.

906

ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON, D.C.

U. S. PATENT OFFICE
COMMISSIONER'S OFFICE
APR 4 1925
COPY MAILED

April 4, 1925.

In re Patent No. 1,529,597, :
Irving Langmuir, Assor., :
March 10, 1925, :
Electron Emitting Devices etc. :

Request for Certificate of Correction.

It is regretted that the error mentioned has occurred but the meaning is perfectly obvious and the error, therefore, is not deemed to be of sufficient importance to affect the validity of the patent or warrant the issuance of a certificate of correction therefor.

However, the letter of March 23, 1925, will be placed in the official file and become a matter of record in the case.

The patent is returned herewith.

THOMAS E. ROBERTSON,
Commissioner.

By T. A. Hostetler
Solicitor.

Mr. Alexander D. Lunt,
c/o General Electric Co.,
Schenectady, N. Y.

20

ECD FEB 11 1925 PATENT OFFICE

907

MEMORANDUM

OF

FEE PAID AT UNITED STATES PATENT OFFICE.

(Be careful to give correct Serial No.)

Serial No. 491,634 , 191

INVENTOR:

Irving Langmuir

PATENT TO BE ISSUED TO

General Electric Company

NAME OF INVENTION, AS ALLOWED:

Electron Emitting Cathodes and Methods of Preparation

DATE OF PAYMENT:

Feb. 12, 1925

FEE:

$20.00 (final)

DATE OF FILING:

Aug. 11, 1921

DATE OF CIRCULAR OF ALLOWANCE:

Feb. 5, 1925

The Commissioner of Patents will please apply the accompanying fee as indicated above.

A. D. Lunt

Attorney.

SEND PATENT TO

Alexander D. Lunt,

General Electric Company,

Schenectady, New York.

908

United States District Court

#15

Eastern District of New York

HONORABLE COMMISSIONER OF PATENTS,
Washington, D. C.

SIR:

In compliance with the Act of February 18, 1922 (42 Stat. L. ______), you are advised that there was filed on the 25th day of April, 1925, in this court an action, suit, or proceeding No. 2152, entitled:

Name General Electric Co, Plaintiff,
Address New York City, New York

versus

Name De Forest Radio Co & Ltd a Philbin Radio Electric Corp, Defendant,
Address Jamaica, New York

brought upon the following patents:

PATENT NO.	DATE OF PATENT	PATENTEE
1. 1529577	March 10, 1925	Plaintiff as Assignee
2.		
3.		
4.		
5.		

In the above-entitled case, on the ______ day of ______, 192__, the following patents have been included by ______ (insert amendment, answer, cross bill, or other pleading):

PATENT NO.	DATE OF PATENT	PATENTEE
1.		
2.		
3.		
4.		
5.		

In the above-entitled case the following decision has been rendered or decree issued:

In witness whereof I have affixed my hand this 15th day of May, 1925, at Brooklyn New York

Percy G. B. Gilkes
Clerk of said Court.

$10

United States District Court

Southern District of New York

Honorable Commissioner of Patents,
Washington, D. C.

Sir:

In compliance with the Act of February 18, 1922 (42 Stat. L. ____), you are advised that there was filed on the 1st day of June, 1925, in this court an action, suit, or proceeding No. [illegible]-187, entitled:

Name General Electric Co., Plaintiff,

Address Schenectady N.Y.

versus

Name Alexander [illegible], [illegible] individually & [illegible] [illegible] Defendant,

Address New York N.Y.

brought upon the following patents:

PATENT NO.	DATE OF PATENT	PATENTEE
1. 1244216	Oct 23/17	General Electric Co.
2. 1244217	" 23/17	" "
3. 1527597	Mch 10/25	" "
4.		
5.		

In the above-entitled case, on the ____ day of ____, 192__, the following patents have been included by ____ (insert amendment, answer, cross bill, or other pleading):

PATENT NO.	DATE OF PATENT	PATENTEE
1.		
2.		
3.		
4.		
5.		

In the above-entitled case the following decision has been rendered or decree issued:

____

____

In witness whereof I have affixed my hand this 2nd day of June, 1925, at N.Y. N.Y.

Alex Gilchrist Jr
Clerk of said Court.

United States District Court

#V

Eastern District of New York

HONORABLE COMMISSIONER OF PATENTS,
Washington, D. C.

SIR: –

In compliance with the Act of February 18, 1922 (42 Stat. L. ______), you are advised that there was filed on the 1st day of June, 1925, in this court an action, suit, or proceeding No. E 12-188, entitled:

Name General Electric Co., Plaintiff,
Address Schenectady N.Y.

versus

Name Filament Export Corp. – Sigmund Mendel, Defendant,
Address N.Y. N.Y.

brought upon the following patents:

PATENT NO.	DATE OF PATENT	PATENTEE
1. 1244 216	Oct 23/17	General Electric Co
2. 1244 217	" " "	" " "
3. 1529597	Mch 10/25	" " "
4.		
5.		

In the above-entitled case, on the ______ day of ______, 192__, the following patents have been included by ______ (insert amendment, answer, cross bill, or other pleading):

PATENT NO.	DATE OF PATENT	PATENTEE
1.		
2.		
3.		
4.		
5.		

In the above-entitled case the following decision has been rendered or decree issued:

In witness whereof I have affixed my hand this 2nd day of June, 1925, at N.Y. N.Y.

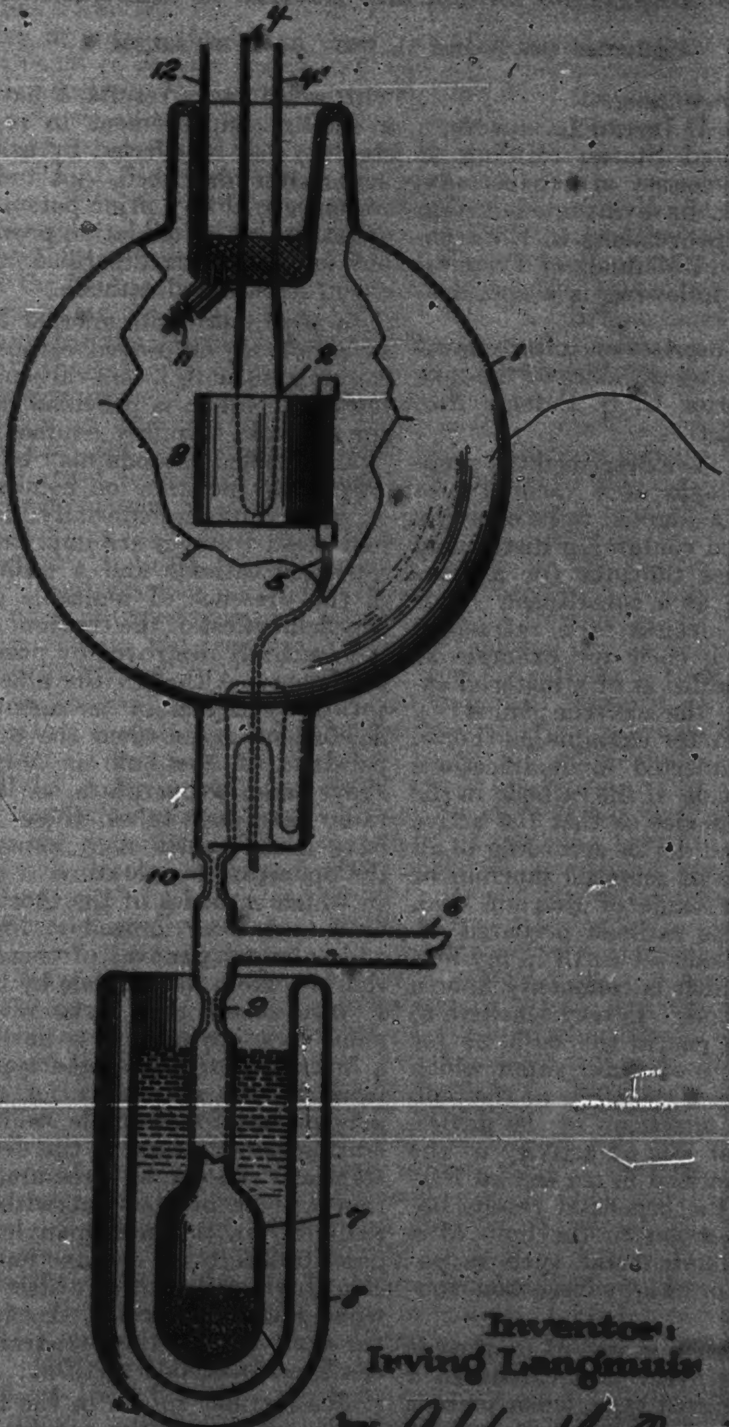
A. L. Gilchrist Jr.
Clerk of said Court.

March 10, 1925. 1,529,597

I. LANGMUIR

ELECTRON EMITTING DEVICE AND METHOD OF PREPARATION

Filed Aug. 11, 1921


4
12
4'
11
2
1
3
5
10
6
9
7
8

Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

Patented Mar. 10, 1925. **1,529,597**

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-EMITTING DEVICE AND METHOD OF PREPARATION.

Application filed August 11, 1921. Serial No. 491,604.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Emitting Devices and Methods of Preparation, of which the following is a specification.

This invention comprises an improvement in the electron emitting cathodes of the type described in my prior U. S. Patents Nos. 1,244,216 and 1,244,217.

In these patents I have described the preparation and advantages of a vacuum tube containing a cathode adapted to be operated at incandescence and containing distributed throughout its mass thorium (or a compound of thorium) as a constituent. This type of electrode consists of a refractory conducting material, such for example as tungsten, with an addition of a material capable of increasing the electron emissivity of the cathode, such for example as thoria, the latter being subjected to modifications during the preparation of the cathode in the electron discharge device so that the active material in a finished device according to all indications, consists of metallic thorium or at least of a lower oxide of thorium than thoria (ThO_2). The cathode prepared according to the methods set forth in my first Patent 1,244,216 which is commonly known as a "thoriated cathode", is very sensitive to traces of oxidizing gas in the bulb, as for example, small traces of water vapor which may be given off from the walls of the bulb during the normal operation of the device. In order to prevent loss of activity of the cathode, I have described in my second Patent No. 1,244,217, the beneficial results obtained by the admission to the bulb of a small amount of alkali metal, such as potassium or sodium, or of a hydrocarbon compound.

My present invention in one of its aspects is based on the discovery that carbon in a cathode of the thoriated type, when present in a definitely limited amount, will prevent not only reoxidation of active thorium material but what is more important, will act beneficially to reduce thoria to the active state. Although the thoriated cathodes described in my prior patents can be used with satisfactory results, I have found that a further improvement in regularity and stability can be effected by using carbon as hereinafter described, not only as in accordance with my prior patent in restricted quantities, as an oxidation preventing agent, but, as hereinafter described, as an ingredient of a thoriated cathode.

In accordance with another feature of my invention my improved cathode is used in conjunction with a non-carbonaceous reducing agent which is provided in the bulb, as for example, a highly oxidizable metal.

A thoriated cathode may be deleteriously affected by positive ion bombardment, that is, when voltages materially higher than the ionization voltages are impressed between a thoriated cathode and a positive electrode in the presence of ionizable gas, then the beneficial effect of the thorium may be largely or entirely destroyed by positive ion bombardment. Although the alkali metals are entirely satisfactory as agents to remove deleterious gases when the operating temperature of the bulb is only moderately above room temperature, as in the case of radio receiving tubes, these alkali metals have a sufficiently high vapor pressure at the operating temperature of power devices in which cathodes of the thoriated type are used to become ionized at higher voltages and to cause removal of the active film of thorium from the cathode by bombardment. I have found that it is advantageous in many cases to provide a device containing a cathode of the thoriated type with a material having an affinity for gases, such as magnesium, for example, which at the operating temperature of the device has substantially no vapor pressure. My invention will be pointed out with greater particularity in the accompanying claims and described fully in conjunction with the accompanying drawing which shows somewhat diagrammatically. An apparatus used for carrying out the preparation of an incandescent cathode rectifier.

The rectifier shown in the figure is illustrative of one of the various forms of incandescent cathode devices. It consists of a bulb 1 containing a filamentary cathode 2 into which thoria has been introduced as described in my above mentioned prior patents, and an anode 3, consisting of tungsten, molybdenum or other suitable material. These electrodes are respectively connected to lead wires 4, 4′ and 5 sealed into the walls of the bulb. The bulb is connected to the usual pumping system by means of a tubulature 6. The bulb also communicates with an elongated tube 7 adapted to be surrounded by a freezing mixture contained within a double-walled receptacle 8.

In carrying out my invention, the bulb 1 is first baked out as usual to remove water vapor and is then exhausted. Within the tube 7 is placed a substance adapted to give a low pressure of carbonaceous vapor, as for example, anthracene ($C_{14}H_{10}$) or naphthalene ($C_{10}H_8$).

When the vapor pressure of the substance employed is relatively high, I prefer to reduce the pressure of the hydrocarbon vapor in the bulb 1 by surrounding the tube with a freezing agent contained in the receptacle 8. When employing naphthalene, which has a moderately high vapor pressure, I prefer to reduce the temperature of the containing tube 7 to about −20 to −30° C. to reduce the vapor pressure to about 0.1 to 0.01 microns. The bulb 1 which communicates with the side tube 7, therefore, is filled with hydrocarbon vapor at approximately this pressure. The quantity of hydrocarbon may be controlled by one or more constrictions, such as 9, 10 which may regulate the pressure with or without a freezing agent.

The filament 2, which preferably consists of metallic tungsten, containing about ¾% thoria, is heated to a temperature of about 2300° K. (2000° C.) for a few minutes, in contact with the hydrocarbon vapor. At this temperature the incandescent filament decomposes the hydrocarbon vapor which comes in contact with the incandescent surface of the tungsten and causes the chemical combination with the tungsten of the carbon set free from the naphthalene vapor, with the formation of tungsten carbide (W_2C). The heating is continued for a length of time sufficient to give an increase in resistance of about 15 to 25% of the tungsten filament when cold, or at room temperature. This change in resistance corresponds to the presence of about two-thirds per cent of carbon by weight in the filament.

The carbon content most beneficial will vary with the conditions. In the case of a thoriated tungsten cathode all of the metallic tungsten will be converted to brittle tungsten carbide (W_2C) with a carbon content as high as 3%. Ordinarily a carbon content as high as about 1% is as high as permissible without unduly weakening the cathode. Although the presence of even minute amounts of carbon is highly undesirable in an incandescent lamp, a commercially long life can be obtained in a thoriated cathode containing carbon, as the cathode need be operated only at a relatively low temperature, say at about the operating temperature of an ordinary carbon lamp, the electron emissivity of a thoriated cathode being so much greater than that of an ordinary pure tungsten cathode. The hydrocarbon vapor is removed from contact with the filament either by sealing off the tube 7 at the contraction 9 or cooling the side tube 7 by means of liquid air in the receptacle 8 to a temperature so low that the vapor pressure of the naphthalene is negligible, thereby removing the naphthalene vapor from the bulb 1.

In some cases carbon to a desired proportion may be combined with the cathode prior to the introduction of the cathode into the bulb 1. For example, a thoriated filament may be prepared by squirting tungsten and thoria with a carbonaceous binder in amounts adapted to leave a suitable restricted proportion of carbon in the finished product.

As the next step in the preparation of the device, the anode 3 is deprived of gases by the usual method of electron bombardment; that is, by passing a discharge between the cathode at incandescence and the anode, the exhaust pump in the meantime being operated to remove the vapors and gases which are liberated. During this step some of the carbon is removed by oxidation and evaporation from the cathode but with an original carbon content of about ⅔ of one per cent enough carbon remains subsequently to furnish a supply of active thorium material by reduction of the thoria.

After the cathode has been provided with a content of reducing agent a non-carbonaceous material capable of combining with water vapor and other deleterious gases may be introduced into the bulb. In some cases this non-carbonaceous reducing agent may consist of alkali metal, such as sodium or potassium. Cæsium may be used to advantage in some cases, especially when some positive ionization is desired in the electron discharge device. Cæsium can be conveniently provided by adding a mixture of cæsium halide and metallic calcium as a paste to some part of the bulb, this method of introducing an alkali metal being claimed in an application, Serial No. 608,311, December 21, 1922, by Ernest E. Charlton.

When not desiring ionization of residual gases or vapors, I prefer to introduce for the reasons given above a reagent having a lower vapor pressure than the alkali metals, as for example, an alkaline earth metal such as magnesium, calcium, strontium, or the like. Conveniently this is done by providing within the bulb a small heating coil 11, consisting of tungsten or other suitable refractory material, and containing a small quantity of the metal to be vaporized. Preferably I employ metallic magnesium. By heating the tungsten filament 11 with current conducted thru the lead wires 4, 12, some of the magnesium is volatilized and deposited on the inner surface of the bulb which is then sealed off at the contraction 10. As during the sealing off process there is a tendency to drive out a small quantity of gas from the heated glass, I prefer to heat up the filament 11 the second time, to volatilize a small additional quantity of magnesium, or the like, in order to combine chemically with what little gas may have gotten into the bulb during the sealing off operation.

The film of magnesium, or other equivalent metal, on the walls of the bulb will combine with any water vapor or oxygen which may be given off by the bulb, or any other parts of the device during its operation, and thereby prevent an oxidization of the active thorium material upon the surface of the cathode.

The tungsten cathode 2 is preferably heated for a very short time to about 2700° K. to volatilize any thorium oxide on its surface.

As a final step, the cathode is "activated", that is, brought into its highly active state by heating to a temperature of about 2200° K. for a few minutes. This results in the reduction of thoria by the carbon and causes the active thorium product to come to the surface of the cathode where it will be effective in increasing the electron emission during the operation of the device. The tube is then ready for operation.

As explained in my prior patents, a temperature materially higher than the activating temperature will result in the thorium being volatilized from the surface of the cathode. A fresh supply can be produced and caused to accumulate upon the surface by again activating or "forming" an electrode at about 2200° K. During normal operation, the cathode is heated to a temperature below about 2200° K. and as high as 2100° K. Under these conditions, the electron emission stays constant.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In an electron discharge device, a cathode body of the thoriated type containing carbon in an amount insufficient to convert all of the metallic constituents of said cathode to a carbide but sufficient to render said cathode less sensitive to the deleterious effect of gases than a cathode body unprovided with carbon.

2. In an electron discharge device, a tungsten cathode of the thoriated type adapted to emit electrons when heated, containing carbon in an appreciable amount but less than three per cent by weight.

3. A cathode adapted to emit electrons at incandescence comprising tungsten, about three-quarters per cent thoria and about two-thirds per cent by weight of carbon.

4. The method of increasing the electron emissivity of an electrode of the thoriated type which consists in introducing carbon into said electrode in amounts insufficient to convert said metal to a carbide, sealing said electrode into a space substantially free from carbonaceous vapors and thereupon activating said electrode.

5. An electric discharge device comprising an evacuated envelope, electrodes therein one of which comprises a refractory metal, thorium oxide and carbon in an amount insufficient to convert said metal to a carbide, and a non-carbonaceous reagent capable of combining with deleterious gases in said envelope.

6. An electric discharge device comprising an envelope, an anode and a cathode of the thoriated type and a non-volatile material, which is capable of reducing thorium oxide, contained in said cathode in such small amounts that the durability of said cathode is not appreciably decreased.

7. An electric discharge device having a cathode comprising metallic tungsten, thorium oxide and carbon combined with said tungsten in an amount materially less than required to convert all the tungsten to a carbide.

8. The method of increasing the electron emissivity of a cathode of the thoriated type which consists in introducing carbon into said cathode in an amount less than about one per cent by weight, heating said cathode in a non-carbonizing and non-oxidizing environment to a temperature at which a carbide of said metal is formed, activating said electrode by heating to about 2200° K. and operating the same under such conditions that bombardment of the electrode by positive ions is inappreciable.

9. The method of increasing the electron-emissivity of a cathode of the thoriated type which consists in introducing carbon into said electrode in an amount less than one per cent by weight, mounting said electrode in a bulb, evacuating the same, volatilizing magnesium in said bulb after evacuation, and activating said cathode by heating to an elevated temperature.

10. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating a conductor comprising refractory metal and thoria in a carbonaceous vapor to a temperature adapted to cause combination of carbon with said conductor, removing said vapor before the amount of carbon introduced into the filament exceeds one per cent, and heating said conductor in a non-oxidizing environment to a temperature at which electron emissivity is markedly increased.

11. The method of preparing an electrode adapted to emit electrons at incandescence which consists in heating to incandescence a conductor comprising tungsten and thoria in a carbonaceous vapor until a marked increase in cold resistance occurs by the introduction of carbon, discontinuing the heating before the tungsten has been largely converted to a carbide, and heating said conductor in the absence of said vapor in a reducing environment to produce a surface layer of thorium material having a markedly higher electron emissivity than the original conductor.

12. An electrical discharge device comprising a sealed envelope, electrodes therein which include a cathode of the thoriated type and a substance, having a marked chemical affinity for water vapor, deposited as a film of extensive surface upon the inside of said envelope, said substance having a materially lower vapor pressure than the alkali metals.

13. An electrical discharge device comprising a sealed envelope, electrodes therein one of which is of the thoriated type and a film of magnesium deposited on the inner surface of said envelope.

14. An electron discharge device containing a cathode of the thoriated type, said cathode being provided with a reducing agent sufficient in quantity to promote activation of said cathode, but restricted to an amount which will permit operation of said cathode at a temperature of effective electron emission with a commercially long life.

15. A cathode of the thoriated type for electric discharge devices containing less than about three per cent by weight of carbon.

16. An electric discharge device comprising an envelope, electrodes therein one of which comprises a refractory metal, a material reducible by carbon to a state of higher electron emissivity than said refractory metal at a given temperature, and a quantity of carbon in an amount insufficient to convert said metal completely to a carbide.

17. An electrical discharge device comprising a container, electrodes therein one of which contains less than three per cent of carbon combined therewith and a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of alkaline earth metal deposited in said container out of immediate contact with said electrodes.

18. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of alkaline earth metal deposited as a film on the inner surface of said container.

19. An electrical discharge device comprising a container, electrodes therein one of which contains a material capable of materially higher electron emissivity at a given temperature than the main constituent of said electrode, but being sensitive to positive ion bombardment, and a quantity of magnesium deposited as a film on the inner surface of said container out of immediate contact with said electrodes.

20. An electrical discharge device comprising a container, electrodes therein one of which consists largely of refractory metal and contains an oxide of a metal of high electron emissivity which when rendered active is sensitive to ion bombardment together with a reducing agent, and a quantity of alkaline earth metal, the latter being deposited as a film on the inner wall of said container.

21. An electrical discharge device comprising a glass bulb, electrodes therein one of which consists largely of refractory metal and contains a material capable when activated of substantially increasing the electron emission of the electrode with which it is associated but which is deteriorated by oxidation and positive bombardment, and a film of magnesium coating the inner surface of said bulb.

22. An electrical discharge device comprising a container, electrodes therein, one of which contains as a constituent a material capable of higher electron emission than the main constituent of said electrode but which is sensitive to positive ion bombardment, and to the chemical effect of water vapor under operating conditions, and a film of metal deposited from the vapor state in a vacuum on the wall of said container which metal has a high chemical affinity for water vapor and has a materially lower vapor pressure at the operating temperature of said device than the alkali metals.

23. The method of increasing the electron emissivity of a metallic electrode containing a compound capable upon reduction of materially increasing the electron emissivity of said electrode which consists in introducing carbon into said electrode in an amount insufficient to convert the metal constituting said electrode completely to a carbide and heating said electrode in a non-oxidizing and non-carbonizing environment to a temperature sufficiently high to activate said electrode, and thereupon operating said electrode under conditions which render the effect of positive ion bombardment of said electrode inappreciable.

24. An electrode material for an electrical discharge device consisting of a metal capable of stable operation at an elevated tem-

perature, a compound of a material capable in a reduced state of higher electron emission than said metal, and carbon in a quantity insufficient to deleteriously affect the strength of said material, but being capable of reducing a sufficient amount of said compound to enable said electrode to be more readily activated during use than would be the case in the absence of said carbon.

25. A cathode material for electrical discharge devices consisting largely of a metal capable of operation at an elevated temperature, a reducible compound of a material of high electron emissivity and less than about one per cent of carbon.

In witness whereof, I have hereunto set my hand this 8th day of August, 1921.

IRVING LANGMUIR.

3—431

917

1921

CONTENTS:

1. Application ... papers O. K.
2. Rej. Aug 3-1922
3. Ack'n Powers Sep 7-1922
4. Amendt A May 29-1923
5. Rej. Feb 13-1924
6. Amendt B Apr 26-1924
7. Rej. Dec 12, 1924
8. Amendt C Dec 29-1924
9. Amdt D (R. 78) Feb 10-1925
10. Notice of Entry Feb 11, 1925
11. Oath Feb 13, 1925
12. Request for by [illegible] 3/25
13. Report by Div. B Mar 27/25
14. Commissioner's letter
15. Notice of Suit May 26-1925
16(a) June 19-1925
16. Notice of Suit June 5-1925
17(a) Aug 7-1925
17. Notice of Suit July 5-1925
18. Notice of Suit May 3-1926
19\.
20\.
21\.
22\.
23\.
24\.
25\.
26\.
27\.
28\.
29\.
30\.
31\.
32\.
33\.
34\.
35\.
36\.
37\.
38\.
39\.
40\.
41\.
42\.
43\.
44\.
45\.
46\.
47\.
48\.
49\.
50\.

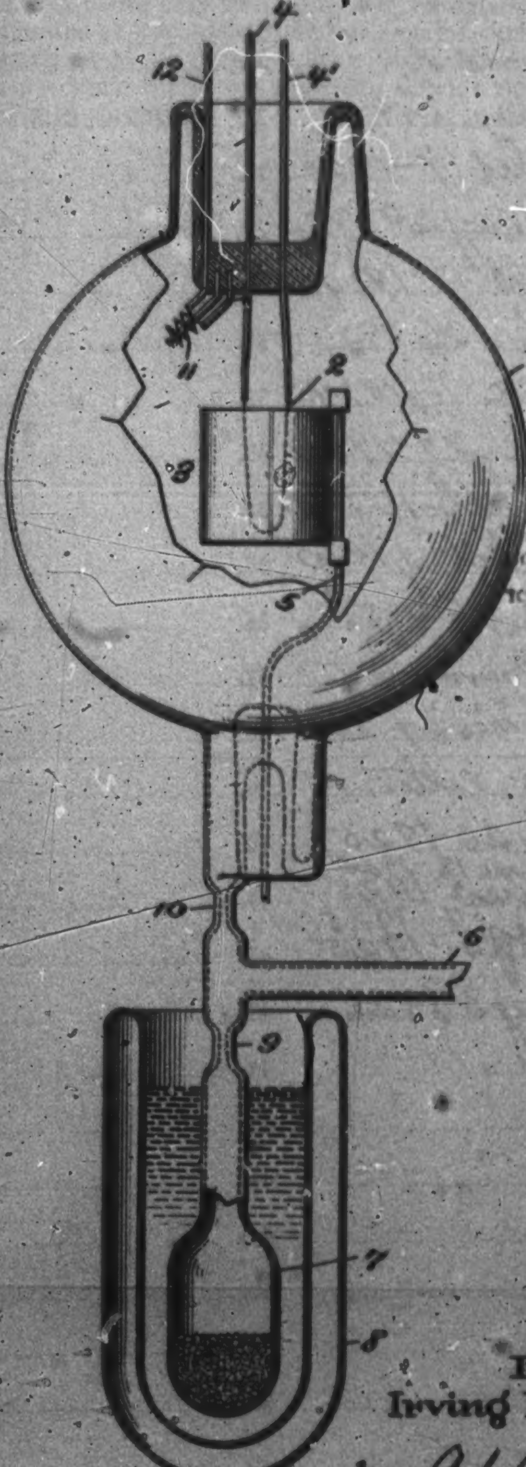
March 10, 1925. 1,529,597

I. LANGMUIR

ELECTRON EMITTING DEVICE AND METHOD OF PREPARATION

Filed Aug. 11, 1921

103
4
1


4
12
4'
11
2
1
3
5
10
6
9
7
8

Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

DEFENDANT'S EXHIBIT No. 66.

Coolidge Article in "Physical Review" of December, 1913, "A Powerful Rontgen Ray Tube With a Pure Electron Discharge."

Second Series *December, 1913* *Vol. II, No. 6*

THE

PHYSICAL REVIEW.

A POWERFUL RÖNTGEN RAY TUBE WITH A PURE ELECTRON DISCHARGE.

By W. D. Coolidge.

§ 1. Introduction.

In an earlier publication attention has been called[1] to the use of wrought tungsten for the anticathode, or target, of a Röntgen tube of the ordinary type. In the development of this target many different designs were made and mounted in tubes, and these tubes were operated on what was then the most powerful Röntgen apparatus on the market, a 10 K.W. transformer coupled to a mechanical rectifying device. The operation of tubes in this manner, to see how much energy it took to ruin the target, gave perhaps an unusual viewpoint. When, as a result of these experiments, a satisfactory form of target had been developed, the writer became interested in studying the remaining limitations in the tube. Some of these limitations are the following:

1. With low discharge currents the vacuum gradually improves, with a consequent increase in the penetrating power of the rays produced.

2. With high discharge currents there are very rapid vacuum changes, sometimes in one direction and sometimes in the other.

3. If a heavy discharge current is continued for more than a few seconds the target is heated to redness and then gives off so much gas that the tube may have to be reëxhausted.

4. If the temperature of the standard copper-backed target is allowed to get up to bright redness, a rapid deposition of metallic copper begins to take place on the bulb, continuing for some time after the cutting off of the current, owing to the very slow rate of cooling from such temperatures in the evacuated space.

5. Of the tubes tested, very many have failed from cracking of the

---

[1] Coolidge, Trans. Am. Inst. E. E., June, 1912, pp. 870–872.

glass, and this, with one exception, always at the same point; that is, in the zone around the cathode. In many cases there has first been chipping-out of the glass from the inner surface of the tube at this point.

6. The focal spot on the target in many tubes wanders about very rapidly.[1] In many cases where it does not show a tendency to wander, it will be found after a heavy discharge to have permanently changed its location.

7. While it is relatively easy to lower the tube resistance by means of the various gas regulators, it is a relatively slow matter to raise it much.

8. With very heavy discharges, the central portion of the usual massive aluminum cathode melts, and the molten globules so formed are shot right across the tube, flattening themselves out on the glass and sticking to it. When the melted area is small, no harm is done except that the curvature of the cathode at this point may be changed, and the focal spot may, in consequence, be moved.

9. No two tubes are exactly alike in their electrical characteristics.

10. The characteristics are in general far from ideal, in that the penetrating power of the Röntgen rays produced, changes with the magnitude of the discharge current.

11. When operated on a periodically intermittent current, even though it be of constant potential, the tube, of necessity, gives a very heterogeneous bundle of primary Röntgen rays, for the reason that the breakdown voltage of the tube is much higher than the running voltage.[2]

It was found that limitations 3 and 4 could be removed by the use of a massive all-tungsten (in place of the usual copper-backed) target. Such a target can be run continuously at intense white heat. Aside from eliminating the troubles incident to the use of copper, the all-tungsten target does not change the general characteristics of the tube.

An attempt was made to remove limitation 8, imposed by the low melting point of aluminium, by substituting for it a tungsten cathode of the same dimensions. Tubes made up in this way showed a behavior entirely different from that of the ordinary tube. They would have been absolutely hopeless from the standpoint of a practical radiographer. They were like the ordinary Röntgen tube which is in the condition which the radiographer describes as "cranky." Upon passing a discharge current of any magnitude through the tube, the resistance would quickly rise to a point where, even with an impressed potential difference of 100,000 volts, no further discharge would pass. The tube could be restored to its original condition by the liberation of gas from the vacuum

---

[1] In radiographic work, movement of the focal spot during an exposure is of course detrimental to good definition.

[2] See F. Dessauer, Phys. Zeitschr., 14, pp. 246–247 (1913).

regulator. The phenomena would repeat themselves as often as one cared to make the experiment. Continuous operation for even a few seconds seemed out of the question. It finally developed, however, that with the adoption of the following expedient, the situation changed. Gas was admitted from the regulator and a discharge passed through the tube. As soon as the resistance had risen, more gas was admitted and the tube was again excited. These operations were repeated as rapidly as possible. With each excitation of the tube, the cathode became hotter. There was evidently the same focusing of the positive ions bombarding the cathode as there was of the electrons at the anticathode, for there was a similar localization of heat at the two electrodes. A little conical depression which formed at the center of the cathode showed that, with the vacuum range employed, the positive ion bombardment was, at least mainly, confined to an area only about 2 mm. in diameter. As soon as the cathode had become heated to bright incandescence,[1] the behavior of the tube changed, and it could then be operated continuously for at least several minutes. Upon interrupting the discharge for a short time, and so allowing the cathode to cool, the "cranky" condition returned, and the tube could again be operated continuously only after repeating the procedure outlined above.

Tubes like the above with tungsten cathodes showed, upon operation, a rapid blackening of the bulb. The deposit proved to be metallic tungsten. The conical depression which invariably formed at the center of the cathode seemed to indicate that this was the source of the deposit, the disintegration of the metal at this point being doubtless due to the mechanical action of the positive ions which bombard it.

The extreme instability of vacuum attendant upon the use of a tungsten cathode in what was otherwise a standard Röntgen tube, called attention very forcibly to the part which is played by gases in the ordinary aluminum cathode. (The tungsten cathodes used must have been, from their method of manufacture, relatively very free from gas.)

A consideration of the above-mentioned limitations showed that they were for the most part incident to the use of gas and that they could therefore be made to disappear if a tube could be operated with a very much higher vacuum. In this case the electrons would have to be supplied in some other way than by bombardment of the cathode by positive ions.

---

[1] The magnitude of the heating effect at the cathode was much greater with tungsten than it is with aluminum cathodes. In one case the cathode and the anode, which functioned also as anticathode, were both made of tungsten, exactly alike in size and shape and symmetrically placed in the tube (concave faces towards each other). On continuous operation, both ran at white heat, and, as nearly as the eye could judge, at the same temperature. Where aluminum is used as the cathode material, much less heat is developed in the cathode than in the target. Willey (Vernon J. Willey, Archives of the Roentgen Ray, XII., p. 250, 1908) finds in tubes of the ordinary type that 75 to 85 per cent. of the total heat evolution in the tube, inclusive of the glass walls, takes place at the target.

Richardson[1] and others had shown that electrons might be produced by simply heating the cathode. But the values of the thermionic currents obtained by different observers had varied between wide limits, so much so as to suggest that a Röntgen tube based upon this principle might be as unstable in resistance as is the standard tube. Moreover, the fact that the substances usually worked with, platinum and carbon, are so difficult to completely free from gas, suggested strongly that with the cleaner conditions (greater freedom from gas) that could be realized by the use of tungsten, the thermionic currents might cease altogether.[2] Some experiments of Dr. Irving Langmuir,[3] however, on the thermionic currents between two tungsten filaments in a highly evacuated space, were very reassuring. According to his observations, after a certain high degree of exhaustion had been reached, the thermionic currents increased, up to a certain limiting value, as the tube became freer and freer from gas.

The idea of using a hot cathode in a Röntgen tube was not new, but, so far as the writer could learn, the principle had never been successfully applied in a vacuum good enough so that positive ions did not play an essential rôle.

Wehnelt and Trenkle[4] had used a hot lime cathode for the production of very soft Röntgen rays, working with voltages from 400 to 1,000. Wehnelt, in another article, describes the use of his lime cathode in a Braun tube, and here he says that it is not advisible to employ more than 1,000 volts, as otherwise cathode rays come off from that part of the platinum which is bare, giving bad disintegration.

The Röntgen rays produced by voltages as low as 1,000 are of course too "soft" for the ordinary applications.

Lilienfeld and Rosenthal[5] had described a Röntgen tube whose penetrating power is, they say, independent of vacuum. Their main aluminum cathode and their platinum anticathode are shaped and located like the electrodes in the ordinary Röntgen tube. Besides these they have an anode and an auxiliary hot cathode. Current from a low voltage source passes from the hot cathode to the anode and this current furnishes the positive ions which by their bombardment of the main cathode liberate electrons from it. Their tube is dependent for its operation on the presence of positive ions, for without these there is no means provided for getting electrons out from the main, aluminum, cathode. Lillienfeld concludes from his extended experiments in tube exhaustion that the complete removal of all gas from tube and electrodes would not do away with positive ions. There would according to this view be no such thing as a pure electron discharge. Lilienfeld's work in exhausting the gas from the tube itself and from the glass seems to have been excellent, but according to the experience of the writer, his electrodes were not sufficiently freed from gas to justify the conclusions drawn. Working even with tungsten electrodes in a tube so designed that the electrodes could be heated in place to very high temperatures, the writer has had the positive ion effects persist for hours, disappearing completely however as the electrodes become sufficiently freed from gas.

---

[1] Proc. Camb. Phil. Soc., XI., 286 (1902); Proc. Roy. Soc., LXXI, pp. 415–418 (1903).

[2] See Goldstein, Ann. der Physik, 24, p. 91, 1885. He finds that platinum must be heated almost to its melting point to give an appreciable thermionic current. Also see H. A. Wilson, Proc. Roy. Soc., 72, pp. 272–276 (1903). He concludes with the following statement: "It is probable that a pure platinum wire heated in a perfect vacuum would not discharge any electricity at all, either positive or negative, to an extent appreciable on a galvanometer."

[3] This work is just being published.

[4] A. Wehnelt and W. Trenkle, Sitzungsber. d. Phys.-Medic. Soc. in Erlangen, 37, 312–315 (1905).

[5] J. E. Lilienfeld and W. J. Rosenthal, Fortschritte auf dem Gebiete der Röntgenstrahlen, 18, 256–263 (1912).

The work of Dr. Langmuir had shown that a hot tungsten cathode in a very high vacuum could be made to continuously yield a supply of electrons at a rate determined by the temperature.

Further work showed that very high voltages, up to at least 100,000, in no wise affect this rate of emission. For application to the fields of radiography and fluoroscopy, it was necessary to develop a satisfactory method of focusing. And, finally, the large amounts of energy transformed into heat in a Röntgen tube render imperative the use of a very heavy target, and this made it necessary to develop methods for sufficiently freeing from gas large masses of metal.

The result of efforts in this direction has been entirely successful, and tubes have been made, based upon this principle, which are free from all of the above-mentioned limitations. This is of particular physical interest because it brings all of the peculiarities of the Röntgen ray tube into accord with the modern conception of electronic conduction and gas molecule decomposition. In the following, it will be sufficient to describe one type (a focusing tube) and its characteristics, leaving for later papers the description of other types.

§ 2. GENERAL DESCRIPTION OF THE NEW TYPE OF TUBE.

The structural features of the new tube which differ from those of the ordinary type are the following:

The pressure, instead of being, as in the ordinary tube, a few microns, is as low as it has been possible to make it, that is, not more than a few hundredths of a micron.

The cathode consists of a body which can be electrically heated (such as a tungsten or tantalum filament) and, suitably located with reference to this portion, an electrically conducting ring or cylinder, consisting preferably of molybdenum or tungsten or other refractory metal. The ring or cylinder is connected either to the heated portion of the cathode, or to an external source of current by means of which its potential may be brought to any desired value with respect to the heated portion. The heated portion of the cathode serves as the source of electrons, while the ring or cylinder assists in so shaping the electrical field in the neighborhood of the cathode that the desired degree of focusing of the cathode-ray stream upon the target shall result.

The anticathode, or target, functions at the same time as anode.

The operation is satisfactory only when the vacuum is exceedingly high, so high that the ordinary tube would carry no current even on 100,000 volts.

§ 3. THEORY OF OPERATION.

As will be seen from the characteristics of the tube, in § 5, it gives, in operation, no evidence of positive ions. This makes the theory of its operation exceedingly simple.

The discharge appears to be purely thermionic in character.

The rate of emission of electrons from the filament appears to be in accord with Richardson's Law, which says that the maximum thermionic current, which can be drawn from a hot filament is

$$i = a\sqrt{T}e^{-\frac{b}{T}}$$

where T is the absolute temperature, e is the base of the natural system of logarithms, and a and b are constants.

In the particular tube described in detail in this paper, over the range of temperatures and voltages included in the data of Table I., this simple law accounts perfectly for the conductivity of the tube. With still higher temperatures, however, the discharge currents would be found to increase at a much slower rate than that required by the above law. And the same applies, even in the temperature range of Table I., to a different tube design in which the distance between cathode and anode is greater. In these cases the failure to follow Richardson's Law at the higher temperatures has been accounted for by Dr. Langmuir[1] by the spacial density of negative electricity in the neighborhood of the cathode.

§ 4. DETAILED DESCRIPTION OF TUBE NO. 147.

This description relates to tube No. 147, which was used in getting the data for the following tables. Fig. 1 shows a complete assembly, while Fig. 2 shows an enlarged detail of the cathode and of the front end of the target.

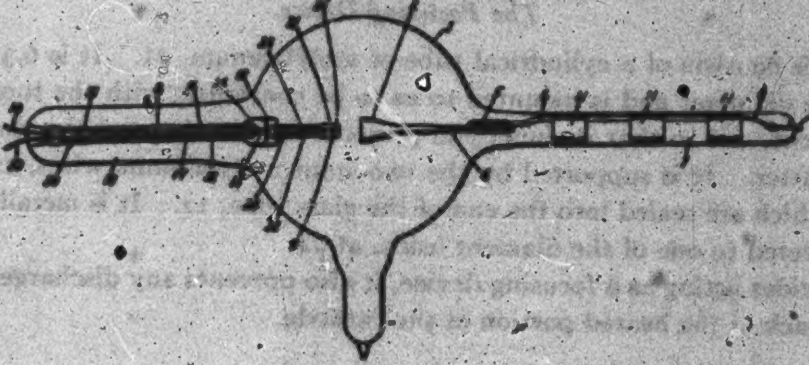


Fig. 1.

The Cathode.

In the diagrams, 25 is a tungsten filament in the shape of a flat, closely wound spiral. It consists of a wire 0.216 mm. in diameter and 33.4 mm. long with 5½ convolutions, the outermost of which has a diameter of 3.5 mm. It is electrically welded to the ends of two heavy molybdenum wires 14 and 15, to the other extremities of which are welded the two copper wires 16 and 17. These in turn are welded to the platinum wires 18 and 19. The molybdenum wires are sealed directly into a piece of special glass, 12, which has essentially the same temperature coefficient of expansion as molybdenum. This first seal is simply to insure a rigid support for the hot filament, the outer seal being the one relied upon for vacuum tightness. The outer end, 13, of the support tube is of German glass like the bulb itself, and it is therefore necessary to interpose at *S* a series of intermediate glasses to take care of the difference in expansion coefficients between 12 and 13. The small glass tube, 20, prevents short-circuiting of the copper wires, 16 and 17.

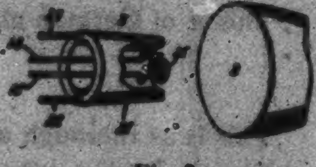


Fig. 2.

The filament is heated by current from a small storage battery which is, electrically, well insulated from the ground.

In the circuit are placed an ammeter and an adjustable rheostat and, by means of the latter, the filament current can be regulated, by very fine steps, from 3 to 5 amperes. Over this current range, the potential drop through the filament varies from 1.8 to 4.6 volts and the filament temperature from 1890 to 2540 degrees absolute.

The Focusing Device.

This consists of a cylindrical tube of molybdenum, 21. It is 6.3 mm. inside diameter and is mounted so as to be concentric with the tungsten filament, and so that its inner end projects 1.0 mm. beyond the plane of the latter. It is supported by the two stout molybdenum wires, 22 and 23, which are sealed into the end of the glass tube, 12. It is metallically connected to one of the filament leads, at 24.

Besides acting as a focusing device, it also prevents any discharge from the back of the heated portion of the cathode.

The Anticathode or Target.

The anticathode or target, 2, which also serves as anode, consists of a single piece of wrought tungsten, having at the end facing the cathode a diameter of 1.9 cm. (Its weight is about 100 gm.) By means of a molybdenum wire, 5, it is firmly bound to the molybdenum support, 6. This support is made up of a rectangular strip and, riveted to this, three split rings, 11, 11, 11, all of molybdenum. The split rings fit snugly in the glass anode arm, 7. They serve the double purpose of properly supporting the anode and of conducting heat away from the rectangular strip and so preventing too much heat flow to the seal of the lead-in-wire, 9.

The Bulb.

This is of German glass and about 18 cm. in diameter.

The Exhaust.

This is as thorough as possible.

For the earlier tubes, mercury pumps were used, with a liquid-air trap between tube and pump to eliminate mercury vapor. The whole tube, while connected to the pump, was in an oven and was heated at intervals to 470° C. Between heating operations the tube was operated with as heavy discharge currents as the condition of its vacuum would permit. For hours the tube would show the characteristics of an ordinary Röntgen tube, and in many cases a several days' application of the above treatment was required to entirely eliminate these characteristics and to realize an essentially pure electron discharge.

The exhaust time has been greatly reduced in two ways. The massive tungsten anode is given a preliminary firing to a very high temperature in a tungsten-tube vacuum furnace.[1] The molybdenum support is also fired, to a somewhat lower temperature, in the same manner. In the second place, a Gaede molecular pump has been substituted for the mercury pumps and, at the same time, a very large and short connection has been adopted between tube and pump.

In the later stages of the exhaust a very heavy discharge current is maintained continuously on the tube for perhaps an hour, the temperature of the bulb being kept from rising too high by the use of a fan.

The pressure in the finished tube is very low, certainly not more than a few hundredths of a micron and probably much less than this.

Connections and Method of Operating.

The tube was connected as shown in the diagram, Fig. 3, in which, *T* is the tube; *B* is a small storage battery; *A* is an ammeter; *R* is an adjustable rheostat which can be controlled from behind the lead screen which shields the operator from the Röntgen rays; *S* is an adjustable spark gap with pointed electrodes, which can also be operated from behind

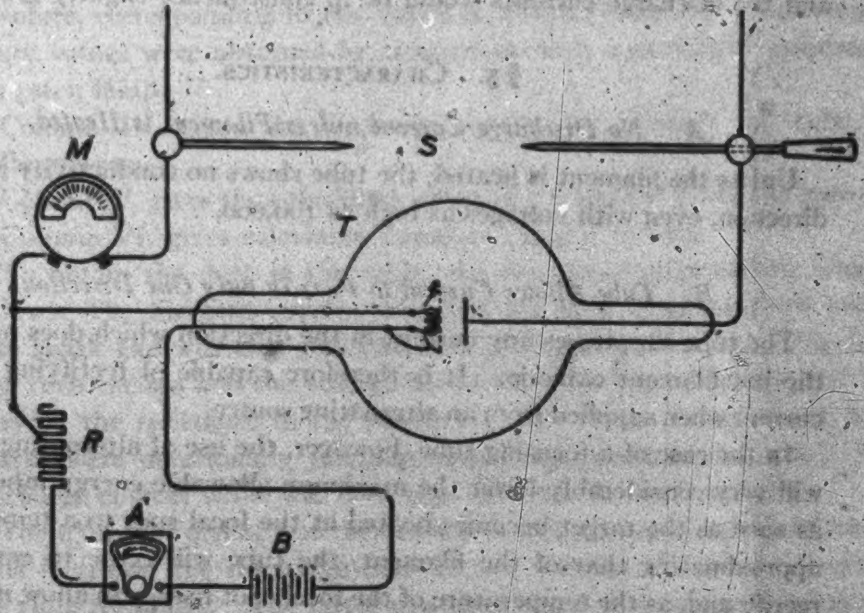


Fig. 3.

---

[1] A description of this furnace will be published in the near future. The heating element consists of a tungsten tube 2.5 cm. inside diameter and 30 cm. long. This is fastened in an upright position and, by means of suitable terminals, is connected to a 100 K.W. transformer. The heating element is placed in a water-cooled metal cylinder and the space within connected to a pump which maintains, with the furnace at its highest temperature, a vacuum of a few microns.

the lead screen; and *M* is a milliampere-meter which can be read from behind the screen.

As the high potential is connected to the battery circuit it is necessary that the latter shall be thoroughly insulated from the ground.

As a high potential source, a 10 K.W. Snook machine, made by the Röntgen Apparatus Co., was used. This consists of a rotary converter driven from the direct current end and delivering alternating current at 130 volts and 60 cycles per second to a closed magnetic circuit step-up transformer with oil insulation. From the secondary of this transformer the high voltage current is passed through a mechanical rectifying switch (which is direct-connected to the shaft of the rotary) and the milliampere-meter, *M*, to the tube. The output of the transformer is controlled by a variable resistance in the primary.

Throughout these experiments a fan was kept blowing on the tube. Without this fan, the gas pressures in the tube would be slightly higher, and the discharge currents would be in consequence slightly lower.

§ 5. CHARACTERISTICS.

A. *No Discharge Current unless Filament is Heated.*

Unless the filament is heated, the tube shows no conductivity in either direction, even with voltages as high as 100,000.

B. *Tube Allows Current to Pass in only One Direction.*

The tube suppresses any current in the direction which does not make the hot filament cathode. It is therefore capable of rectifying its own current when supplied from an alternating source.

In the case of a focusing tube, however, the use of alternating current will very considerably lower the maximum allowable energy input. For as soon as the target becomes heated at the focal spot to a temperature approximating that of the filament, the tube will cease to completely rectify and, as the temperature of the focal spot rises, will allow more and more current to pass in the wrong direction. This, to be sure, will not cause either a harmful vacuum change or a metallic deposit on the bulb, as it would in the case of the ordinary tube; but it will give rise to needless heating of the bulb where it is bombarded by the cathode rays from the target, and to disturbing Röntgen rays emanating from the glass at this point. In the case of a tube which does not focus, but in which the cathode rays bombard the entire surface of the anode, the allowable energy input which the tube will completely rectify can be increased to any desired amount by simply increasing the surface of the anode.

C. *Discharge Current Determined Primarily by Filament Temperature.*

With a given design, the amount of discharge current which can be passed through the tube is determined primarily by the temperature of the filament, and responds instantly to changes in the same in either direction.

The effect of both temperature and voltage on the discharge current, in the case of tube No. 147, illustrated in Fig. 1, may be seen by referring to Table I., which gives the data on the finished tube after it had been sealed off from the pump. The focal spot was 3 mm. in diameter.

In the table, Column I. gives the length in centimeters of the equivalent spark gap.

Column II. gives the heating current (*C*) in the filament, expressed in amperes.

Column III. gives the filament temperature (*T*), expressed in degrees absolute, corresponding to the values of *C* in Column II. The temperature values were obtained by comparison with a previously calibrated tungsten lamp.

Column IV. gives the discharge current (*i*) through the tube, in milliamperes.

Column V. gives the calculated values of $(-\log i/\sqrt{T})$ to the base 10.

Column VI. gives calculated values of $(.434/T \times 10^5)$.

To obtain the data in the table, the experimental procedure was as follows: The filament current was first set at a predetermined point. The spark gap was next set, also at a predetermined point. The tube was then excited and the voltage across the tube terminals adjusted (by varying the resistance in the primary circuit of the transformer) until sparks were occasionally jumping across the parallel spark gap. The discharge current value was then read off from the milliammeter.

The filament current was then raised to a second predetermined value. This increased the discharge current and lowered the potential across the tube terminals. The latter was then raised to its original value and and the new discharge current reading was obtained.

In this way the discharge current value, for a given voltage, was brought up by steps to the point where the tube finally began to show signs of instability. The temperature-current series was then repeated with a different voltage.

The values of discharge current and temperature, for each voltage, are plotted in Fig. 4. The different curves are seen to lie very close together, showing that over the range of voltages employed, the magnitude of the discharge current is practically independent of voltage.

This shows that the current in these experiments was always the saturation value.[1]

According to Richardson, the relation between the saturation current flowing from a hot filament and the absolute temperature of the filament, is expressed by the equation $i = a\sqrt{T}e^{-\frac{b}{T}}$, in which i is the current, T is the temperature, and a and b are constants of which the first has to do with the concentration of electrons within the hot body, and the second represents the amount of work required to get the electron through the surface of the metal. e is the base of the Naperian system of logarithms.

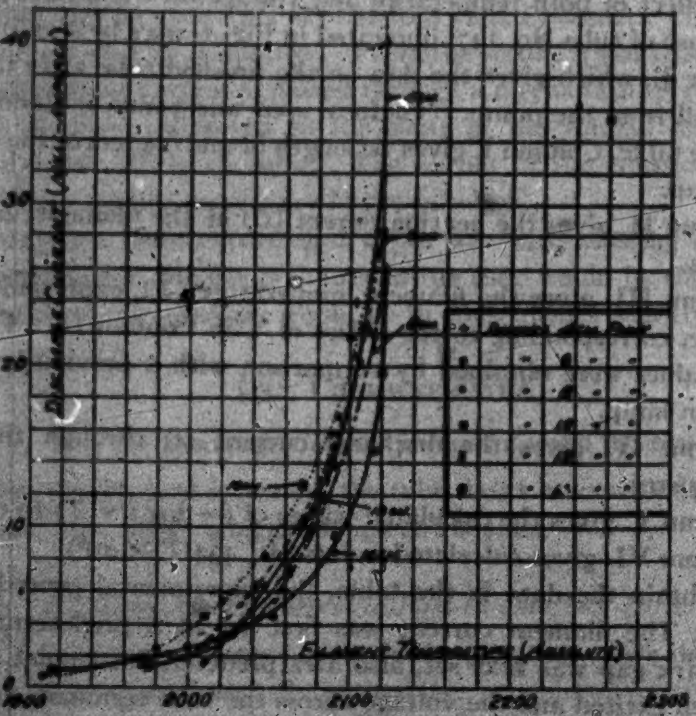


Fig. 4.

Richardson[2] applies this equation to his data by first taking the logarithm, to the base 10, of both sides of the equation, which gives

$$\log i = \log a + \tfrac{1}{2}\log T - \frac{b}{T}(.434)$$

or

$$-\log\frac{i}{\sqrt{T}} = b\,\frac{.434}{T} - \log a,$$

which is the equation of a straight line.

[1] The two points to the extreme right of the curves correspond to an unstable condition of the tube. The instability disappears instantly upon lowering the filament temperature.

[2] O. W. Richardson, Proc. Camb. Phil. Soc., 11, p. 293 (1901).

TABLE I.

I. Equivalent Spark Gap (Cm.).	II. Filament Current C (Amps.).	III. Filament Temp. T (Degs. Abs.).	IV. Discharge Current i (Milliamps.).	V. $-\text{Log}\,\frac{i}{\sqrt{T}}$	VI. $\frac{434}{T} \times 10^3$
4	3.40	2010	1.7	1.4212	216.1
	3.45	2028	3.5	1.1094	214.1
	3.51	2049	6.4	.4985	212.0
	3.60	2077	11.3	.6056	209.1
	3.66	2088	15.8	.4611	208.0
	3.67	2104	24.0	.2813	206.4
	3.71	2116	27.0	.2313	205.3
	3.73	2121	40.0	.0611	204.8
6	3.29	1976	1.6	1.4438	219.8
	3.43	2020	3.3	1.1341	215.0
	3.52	2053	6.5	.8433	211.5
	3.59	2074	10.6	.6331	209.4
	3.64	2090	15.3	.4753	207.8
	3.70	2110	22.3	.3138	205.8
	3.72	2120	28.3	.2113	204.9
8	3.27	1970	1.6	1.4431	220.4
	3.43	2020	2.9	1.1902	215.0
	3.53	2055	5.7	.9005	211.3
	3.59	2074	9.7	.6716	209.4
	3.64	2090	13.8	.5201	207.8
	3.71	2116	21.8	.3242	205.3
	3.73	2121	26.2	.2449	204.8
	4.07	2240	36.2	.1164	193.9
10	3.09	1909	0.6	1.8411	227.5
	3.31	1980	2.5	1.2504	219.4
	3.40	2010	4.4	1.0081	216.1
	3.50	2046	8.2	.7416	212.3
	3.57	2070	12.6	.5576	209.8
	3.67	2104	20.7	.3455	206.4
	3.65	2096	21.8	.3222	207.2
	3.71	2116	27.0	.2313	205.2
	4.13	2259	35.4	.1279	192.3
12	3.28	1973	1.7	1.4171	220.2
	3.44	2023	3.4	1.1215	214.7
	3.55	2061	7.3	.7937	210.7
	3.57	2070	10.1	.6537	209.8
	3.65	2093	16.9	.4325	207.5
	3.68	2107	22.4	.3116	206.1
	3.68	2107	20.1	.3586	206.1
14	3.11	1917	1.0	1.6413	226.6
	3.36	1998	2.5	1.2624	217.4
	3.52	2053	4.5	1.0030	211.5
	3.64	2090	8.6	.7255	207.8
	3.71	2116	14.7	.4954	205.3
	3.72	2120	19.6	.3708	204.9
	3.73	2121	26.0	.2482	204.8

If then the values of Columns IV. and V. are plotted, they should lie along straight lines, provided conduction in the tube, between the voltage limits used, follows Richardson's Law.

Reference to the plots, Figs. 5 and 6, will show that the points are closely represented by straight lines. By reading off the tangents of the angles which the lines make with the horizontal axis we get the following values of the constant *b*:

Voltage Corresponding to Spark Gap of	Value of *b*.
4 cm.	115,000
6 cm.	93,000
8 cm.	94,000
10 cm.	71,000
12 cm.	76,000
14 cm.	60,000
Average	85,000

These values of *b* are interesting in that they all fall within the range of the values which are just being published by Dr. Langmuir. His

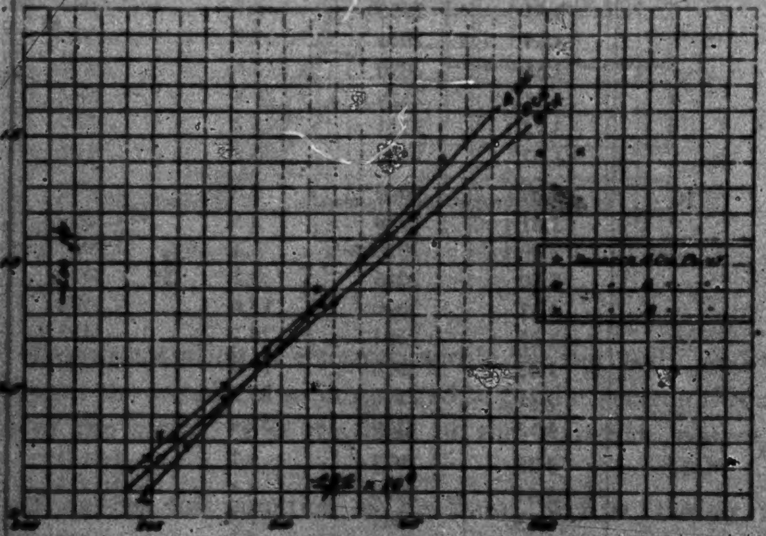


Fig. 5.

values were obtained from an apparatus in which the electrodes were fine tungsten filaments having a total mass perhaps 1/100,000 of that of the target in the above tube. His results show the enormous effect of gas on the value of *b*, and the conclusion can, therefore, be drawn, that very large tungsten masses can be used in a tube without, to any appreciable extent, impairing the vacuum, even though these masses may be heated close to their melting point.

If the temperature of the filament is low, only a small number of electrons escape from it and, consequently, only a small discharge current (the saturation current) can be sent through the tube. Increasing the impressed voltage above that needed for this current value causes no further increase in current. It simply increases the velocity of the cathode rays and hence the penetrating power of the Röntgen rays.

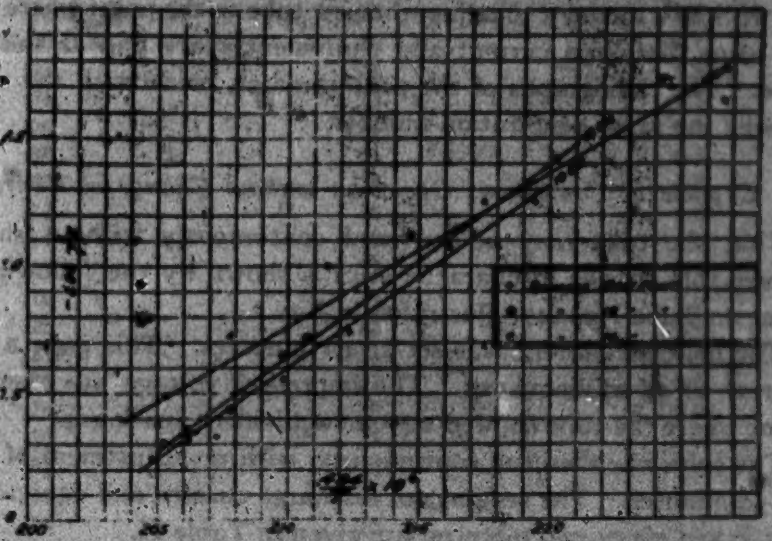


Fig. 6.

At higher filament temperatures there is a current-limiting factor, other than the number of electrons emitted by the hot filament, which plays a dominating part. This factor is the spacial density of negative electricity in front of the cathode, which amounts, in effect, to a back electromotive force. This factor would play a very important rôle at lower voltages; but in the case of the Röntgen ray tube the voltages involved are so high that, in case a suitable design is used, its influence can be entirely avoided, as is shown by the data of Table I.

D. *Penetrating Power of Röntgen Rays Determined by Voltage across Tube Terminals.*

The penetrating power of the Röntgen rays coming from the tube increases with the potential difference between tube terminals.

With the tube excited from a variable potential source, such as the transformer, it did not seem safe to predict that, with the same equivalent spark gap, the rays would show, photographically, the same penetrating power as those from a standard tube. But upon making the experiment, using a Benoist penetrometer,[1] it was found that they did.

---

[1] M. L. Benoist, C. R., 134, 225 (1902).

The experiment was interesting from another point of view in that it showed how readily the new tube could be adapted to a given set of conditions.

An exposure was made first with a standard tube of the ordinary type, and the discharge current and equivalent spark gap were noted. A tube of the new type was then set up in place of the standard. It was but the work of a moment to adjust the new tube to the point where it showed the same discharge current and equivalent spark gap as the standard tube. The radiographs of the penetrometer, made with the two tubes, showed the same penetration number.

E. Capable of Continuous Operation without Change of Characteristics.

That the tube may be operated continuously without showing an appreciable change in characteristics is shown by the following experiment on Tube No. 147, illustrated in Fig. 1.

The filament current was set at 4.1 amperes. This gave a discharge current of 25 milliamperes. The impressed voltage was then set at a point where the tube showed a 7 cm. equivalent spark gap.

The tube was then run continuously, with no adjustment of any kind, for 50 minutes. The readings of discharge current and equivalent spark gap, taken every two minutes, are given in Table II.

F. Sharpness of Focus.

Sharpness of focus is determined mainly by the design of the tube. If the filament temperature is such that, with the voltage employed, the discharge current does not represent the saturation value, the size of the focal spot will vary with the impressed voltage. But in the tube shown in Fig. 1, over the range of voltages corresponding to an equivalent spark gap ranging from 4 to 14 cm., the focal spot does not vary appreciably in size.

The tube may be made to focus more sharply by increasing the distance between the filament and the front (end facing the target) of the molybdenum tube. This change in design will also affect the temperature-current characteristics of the tube in the direction that a higher filament temperature will be needed for a given discharge current value.

Similarly it may be made to focus less sharply by decreasing the distance between the filament and the front of the focusing device.

All of the observations made are consistent with the idea that focusing is determined by the shape of the equipotential surfaces which may be drawn in the space between cathode and anode, and that the surfaces close to the cathode have the strongly preponderating influence.

TABLE II.

Time.	Discharge Current (Milliamps.).	Equivalent Spark Gap (Cm.).
11:48 A.M.	25	7.0
:50	25	7.0
:52	25	6.9
:54	25	6.5
:56	25	6.6
12:00 P.M.	25	6.7
:02	25	6.9
:04	25	6.5
:06	24	6.4
:08	24	6.3
:10	24	6.5
:12	23	6.6
:14	25	7.0
:16	25	6.8
:18	24	6.8
:20	25	6.9
:23	23	6.7
:26	23	6.9
:28	25	6.9
:30	25	6.9
:32	25	7.0
:34	24	6.9
:36	25	7.0
:38	24	7.1

Near the cathode, the velocity of the electrons is relatively small, and the direction of their motion will therefore conform closely to the direction of the strong electric force. Near the anode, on the other hand, the velocity of the electrons is so high that the same force acting over the same length of path will produce but little deflection.

G. *Fixity of Position of Focal Spot.*

The focal spot on the anode does not wander, but remains perfectly fixed in position. This is in sharp contrast to the ordinary Röntgen tube in which the focal spot does move about, and often so rapidly as to be noticeable even during the shortest radiographic exposures.[1] The effect of movement of the focal spot is, of course, to cause in the radiograph or on the screen, a blurring of all lines except those parallel to the direction of motion. In the earlier stages of exhaustion, while the new tube is being operated with a relatively poor vacuum, the focal spot may dance about, but as the electrodes and the glass become freer from gas the mobility of the focal spot decreases and finally disappears completely. Its disappearance goes hand in hand with the disappearance of fluorescence of the glass, discussed in section *J*. Movement of the focal spot appears to be due to the action of positive ions in disturbing the distribution of static charge on the glass walls of the tube.

---

[1] See Dr. Pfahler, Fortschritte auf dem Gebiete der Röntgen[illegible], 18, pp. 340-343 (1911-1912).

H. Tube not Sensitive to Considerable Changes in Gas Pressure.

The gas-pressure within the tube is so low that it can increase severalfold, and apparently decrease without limit, without appreciably affecting the other characteristics.

The slight effect of pressure change may be seen from the following experiment:

While one of the tubes was being continuously operated on the pump, the pressure, as indicated by a McLeod gage, decreased from 0.113 to 0.035 micron.[1] The discharge current passing through the tube remained constant at 3.1 milliamperes, while the parallel spark gap backed up by the tube changed only from 7.9 to 8.6 cm. A corresponding pressure change in the case of an ordinary Röntgen tube would bring about an enormous change in current and voltage.

I. Capable of Continuous Operation with High Energy Input.

Owing to the fact that the tungsten target can run at such a high temperature, large amounts of energy can be continuously radiated.

J. No Fluorescence of Glass.

When operating properly the tube shows no fluorescence of the glass at any point. Corresponding to this, there is an absence of the usual strong local heating of the anterior hemisphere. The absence of fluorescence and of local heating seem to point to the fact that there is no bombardment of the glass by secondary cathode rays sent out from the target. This is in striking contradistinction to what takes place in an ordinary Röntgen tube, where, in the case of a platinum target, it has been found that there are about three-fourths as many electrons leaving the target, and going to the glass, as secondary cathode rays, as there are bombarding it, in the form of primary cathode rays. This elimination of secondary cathode ray bombardment prevents the production of a large part of the useless and disturbing Röntgen rays which emanate from the glass in the case of the ordinary tube.

The absence of bombardment of the glass is of interest both theoretically and practically. Other explanations of the lack of fluorescence suggested themselves at first. A plausible hypothesis was that bombardment took place, but that the surface of the glass was much freer from gas than it is in the ordinary tube and that this accounted for the lack of fluorescence. But the fact that fluorescence appears so suddenly when a trace of gas is evolved, coupled with the fact that such fluorescence may appear in streaks and that these may rapidly change their location, seems to disprove the hypothesis. It also seemed possible at first that the fluorescence might be there, but that it could not be seen because of the strong light emission from both filament and target. But this hypothesis is disproved by the fact that with filament and target at their highest temperatures, fluorescence becomes suddenly strongly visible whenever gas is liberated.

---

[1] In the light of later experiments it seems doubtful whether a further pressure decrease, no matter how great, would have appreciably affected the tube characteristics.

The simple explanation appears to be based upon the fact that the large number of positive ions present in an ordinary Röntgen tube is here lacking. The inner surface of the glass becomes strongly negatively charged, when the tube is first operated, and, not being able to attract an appreciable number of positive ions, remains so. The presence of this negative charge upon the glass prevents further electrons, either in the shape of primary or secondary cathode rays, from going there.

K. *Identity of Starting and Running Voltage.*

The starting, or break-down, voltage of the tube is the same as the running voltage. This is very different from the state of affairs in the ordinary tube in which the break-down voltage is much higher than the running voltage.[1] The difference is to be explained as follows: In the ordinary tube the number of ions present when the circuit is closed is exceedingly small, being only that due to natural ionization causes, such as radioactive matter in the surroundings. After the discharge circuit is closed, the number of ions increases, by collision, very rapidly, and the voltage across the tube terminals falls in consequence. In the case of the new tube, on the other hand, the full supply of electrons is there the instant the discharge circuit is closed, and even before this, and the available number is not changed by the discharge current.

L. *Permits of Realization of Homogeneous Bundle of Primary Röntgen Rays.*

The tube must permit of the realization of a strong homogeneous bundle of primary Röntgen rays of any desired penetrating power. For this purpose it should clearly be excited from a source of constant potential. The result should be attained even though the discharge is intermittent.[1]

---

[1] See Dessauer, l. c.

M. No Heating of Cathode by Discharge Current and no Evidence of Cathodic Disintegration.

An earlier experiment showed that when a tube is made up with two similar concave tungsten electrodes, symmetrically located in the tube, and operated on direct current at an ordinary Röntgen tube vacuum, the heating effect at the cathode is as strong as that at the anode. Furthermore, the heat evolution at the cathode is as strongly localized as it is at the anode. In fact, it is impossible, when the tube is operating, to tell, by looking at it, which of the white hot electrodes is functioning as anode and which as cathode. There is a very rapid blackening of the bulb in such a tube, the material of the deposit coming evidently from the cathode, which shows a deep and sharply defined cavity at the point of local heating. The simple explanation seems to be that the cathode is bombarded by positive ions and that the emission of the electrons which constitute the cathode ray stream is due to this bombardment. So, also, the heating effect and the cathodic disintegration.

At the higher vacuum and with the relatively gas-free electrodes of the new tube there is no evidence of any bombardment of the cathode. In the earlier stages of gas removal, when a discharge can be made to pass through the tube without the heating current in the filament, the latter is seen to be strongly locally heated by the discharge current, as from bombardment by positive ions. But when the exhaustion has been completed and the tube is operated with the cathode hot, a voltmeter and ammeter in the filament circuit show no change even when a very heavy discharge is sent through the tube. Positive ion bombardment, if it existed to an appreciable extent, would raise the temperature and, hence, the resistance of the tungsten filament and would therefore be indicated by the instruments. If it were very local and considerable, it would be further indicated by a melting through of the filament at the point in question. The resistance change and local disintegration of the filament have been observed in only those cases where the vacuum, as shown by other effects, such as fluorescence of the glass, has been poor.

Disintegration of the cathode would also manifest itself in blackening of the bulb. Even after running for several hours, the deposit on the bulb is very slight, and what there is may well be entirely accounted for by vaporization of tungsten at the focal spot on the target.

---

[1] For fluoroscopic work with the ordinary tube, it seems preferable to use an interrupted discharge so as to reduce heating of the tube and danger to patient and operator. The phosphorescence of the fluoroscopic screen makes possible frequent interruptions without appreciable loss of light.

N. *The Target the Factor Limiting Allowable Energy Input.*

There is one limitation with the new tube. With a sharp focusing tube and above a certain energy input the tube resistance is unstable, dropping suddenly to perhaps a small fraction of its original value, returning instantly to the old value however upon stopping the discharge or upon lowering it to the limiting value. The cause of this phenomenon appears to be as follows:

With a very high energy input and sharp focusing, the surface of the target melts at the focal spot and volatilizes. Owing to the fact that this tungsten vapor is produced at the focal spot, all of the primary cathode rays pass through it and, by collision, ionize it. This of course decreases the tube resistance. The larger the focal spot the greater is the limiting current. The design of the target also has a great deal to do with the limiting current value, as the face of a thin target is vaporized with a much lower energy input than a relatively thick one. For very short excitation of the tube, the limiting energy input is somewhat larger than for longer periods; but an input which can be carried for a few seconds can be carried indefinitely.

The effect of substituting any other single refractory metal for the tungsten of the target will be to lower the maximum allowable energy input. For the essential properties of a target material are: high density, high melting point, high heat conductivity, and low vapor pressure. Tungsten has a higher melting point and lower vapor pressure than any other metal. Its nearest competitor in point of refractoriness, tantalum, has only about one third of the heat conductivity. Molybdenum and iridium have vapor pressures altogether too high to entitle them to consideration, even if their melting points made them otherwise competitors. Osmium has only about one half of the heat conductivity of tungsten.

The ordinary copper-backed tungsten target would be very difficult to exhaust sufficiently. Otherwise its use might be desirable for certain classes of work, as it would raise the maximum allowable instantaneous energy input.

§ 6. DANGER CONNECTED WITH USE OF TUBE.

There has been in the old tube a certain element of safety in that it could not be run continuously with a very heavy energy input. The new tube, even when focusing sharply, can be operated, for example, on a 7 cm. parallel spark gap with currents as high as 25 milliamperes for hours at a time, and without the slightest attention.

For most purposes, other than diagnostic or radiographic work, there is no advantage in having the tube focus. In case it does not, the above-

DEFENDANT'S EXHIBIT No. 67.

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper and Contents, in the matter of the

Letters Patent of

William D. Coolidge, Assignor to
General Electric Company,

Number 1,203,495, Granted October 31, 1916,

for

Improvement in Vacuum Tubes.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-sixth day of October in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

ATTEST:
Chief of Division.

Thomas E. Robertson
Commissioner of Patents.

941

842

DIV. 37 16

1913

(EX'R'S BOOK) 268-10

NUMBER (Series of 1900).

766549

PATENT No. 1203495

Name William D. Coolidge,
Assignor to General Electric Company
a corp of N. Y.

of Schenectady,
County of
State of New York.
Invention Vacuum Tube.

Division of App. No. ______ filed ______ 191__

PARTS OF APPLICATION FILED.

	ORIGINAL	RENEWED
Petition	May 9, 1913,	191
Affidavit	" " 1913,	191
Specification	" " 1913.	191
Drawing	" " 1913	191
Photo Copy	May 27, 1913.	191
First Fee Cash	$15 May 9, 1913.	191
" " Cert.	191	191
Appl. filed complete	May 9, 1913	191

Examined and passed for Issue Apr. 17 1916

[illegible] Ex'r. Div. 16

Notice of Allowance APR 18 1916

Final Fee Cash $20 Oct. 3 1916

" " Cert. 191

Patented OCT 31 1916

Attorney Albert G. Davis, Gen'l Electric Co.,
Schenectady, N. Y.

Associate Attorney

No. of Claims Allowed 33, Title as Allowed Vacuum-Tube

2.60 - 3.50

PETITION

To the Honorable Commissioner of Patents:

Your petitioner William D. Coolidge,

a citizen of the United States, residing at Schenectady,

in the County of Schenectady State of State of New York,

whose Post Office address is c/o General Electric Co., Schenectady, N.Y.

prays that Letters Patent may be granted him for the improvement in

VACUUM TUBES

(Docket No. 17,390),

set forth in the accompanying specification.

And he further prays that you will recognize Mr. Albert G. Davis, of Schenectady, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

William D. Coolidge

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN, that I, William D. Coolidge, a citizen of the United States, residing at Schenectady, in the County of Schenectady, and State of New York, have invented certain new and useful improvements in Vacuum-Tubes, of which the following is a specification.

My invention relates to vacuum tubes and more especially to tubes operated for the purpose of producing Röntgen or X-rays. The tube which I have produced differs so radically from the tubes of the prior art used for producing Röntgen or X-rays as to amount not so much to an improvement on prior tubes as to an entirely new variety of tube differing both in its principles of operation and in its operating characteristics.

In the Röntgen tube of the prior art, it was necessary that there be at least some free gas in the tube, the reason for which may be explained as follows: The number of ions present in the tube was exceedingly small until a high potential was impressed upon its terminals. The effect of this high potential was to accelerate the motion of the small number of ions originally present, thus causing them, by their collision with gas molecules to produce more ions, and, further, to so ~~direct~~ attract the positive ions that they would bombard the cathode and so cause it to emit electrons. These electrons, directed by the electric forces in the tube, move towards the anti-cathode and in their movement constitute the so-called cathode rays. Upon colliding with the anti-cathode these undergo a sudden change in velocity and so give rise to the Roentgen or X-rays. As the emission of electrons from the cathode was due solely to bombardment by positive ions, and as these positive ions owed their existence to the presence of gas in the tube, it is seen at once that the

Par B

X-ray tube of the prior art was absolutely dependent for operativeness upon a proper amount of gas. Without the presence of sufficient gas to permit a discharge to take place between the electrodes the cathode would not be bombarded by positive ions and so no resulting production of X-rays would occur. The presence of this gas, heretofore considered a necessity in the operation of such a tube, gave rise to certain features of operation of the tube which are obviously very disadvantageous but which have heretofore been accepted by workers in the art as unavoidable evils. I will not here attempt to point out all of the troubles which may be traced to the presence of this gas, but will mention a few of the attendant difficulties.

(a) The pressure of the gas in such a tube is exceedingly variable, and any change in gas pressure is accompanied by a corresponding change in the resistance of the tube and in the penetrating power of the Roentgen rays.

(b) A sufficiently exact adjustment of pressure, to give the desired penetrating power of the Roentgen rays, calls for a great deal of manipulative skill and long experience on the part of the operator.

(c) Besides the slow changes in gas pressure, which can be corrected by the operator, there are other very rapid pressure changes which go on even during a very short radiographic exposure. These cannot be corrected and, as a result, the exposure or fluoroscopic examination is made, not with Roentgen rays of the quality desired, but with whatever approximation to that is allowed by the idiosyncrasies of the particular tube in question, in other words, with a mixture of rays differing perhaps very widely in penetrating power.

(d) The tendency to undergo rapid changes in gas pressure increases with use, until finally the tubes of the prior art show such instability of vacuum that they are no longer useful, even though they may be otherwise in perfect condition.

(e) Many of the positive ions instead of striking the cathode, strike the glass constituting the tube wall around it, and, by their excessive local heating, cause disintegration and cracking of the envelope at this point. This imposes a limitation on the permissible energy input in such a tube.

Per. Fr

(f) Many tubes of the prior art show variability in the location of the focal spot. As the focal spot is the source of the X-ray, its movement during a radiographic exposure, means a blurring of the picture ~~in this direction~~. It is my belief that sudden changes in gas pressure lead to movements of the focal spot.

(g) Some of the electrons coming from the cathode are impeded in their passage to the target by impact with intervening gas molecules and so do not have, upon reaching the target, the same velocity as those electrons which have passed through the entire potential drop from cathode to target without meeting an obstruction. The higher the gas pressure in the tube the greater will be the influence of this effect and, consequently the greater will be the lack of uniformity in the penetrating power of the resulting Roentgen rays.

(h) There is a strong bombardment of the glass, constituting the entire anterior hemisphere, of such a tube, by secondary cathode rays emitted from the anticathode. This causes excessive local heating of the glass and a vigorous emission of secondary X-rays from the bombarded glass. These secondary rays, unless prevented by the use of a proper diaphragm, cause a blurring effect in the radiograph and on the fluorescent screen.

(1) Any electromotive force in the source of current supply for such a tube, in a direction which would make the target function as cathode, must be carefully suppressed, as it otherwise leads to changes in gas pressure.

In order to overcome these troubles met with in the X-ray tubes of the prior art, I remove the cause of the trouble, namely, the gas in the tube, and produce the electrons from the cathode necessary to the production of the X-rays, not by a bombardment of the cathode by positive ions due to ionization of the gas by the voltage impressed upon the tube, but by heating the cathode to incandescence by energy from a suitable source. In tubes made according to my invention I eliminate the action of positive ions as far as it is possible to do so by evacuating the tube to the highest vacuum which can possibly be attained and by thoroughly freeing the electrodes from gas. In the tube of the prior art the pressure of gas was quite appreciable and varied from say one to ten microns (0.001 to 0.010 millimeters) of mercury. With a tube made according to my invention, the tube proper and the electrodes being thoroughly freed from gas as hereinafter described, the pressure of gas may be say five hundredths of a micron (0.00005 millimeter) or lower and in any event lower than that at which the tube would operate as an ordinary Roentgen ray tube. The upper limit of pressure may therefore be placed roughly at say about 0.6 of a micron or thereabout. With such a vacuum in a tube of the prior art so far as I am aware no current whatever would pass in the tube and no X-rays would be produced.

As a cathode I ordinarily use a tungsten filament and this may be conveniently heated by current from a storage battery or transformer with suitable regulating devices so that the temperature of the cathode or filament may be adjusted at will. I have found that electrons will be emitted from such a cathode, which electrons will traverse the space between the cathode and the target under the influence of the electromotive force impressed upon the tube, and by bombardment of the target, will give rise to X-rays. In this new type of tube positive ions appear to play no role whatsoever. The excessively low gas pressure must make their number exceedingly small. The fact that they do not play an appreciable rôle at the cathode is experimentally shown by the fact that the temperature of the heated cathode is not measurably raised by passing heavy discharges through the tube. In the same tube, with gas pressures approximating those used IN tubes of the prior art, the tungsten filament, functioning as cathode, is raised by these same discharges from room temperature to extreme incandescence, and may even be melted by the bombardment of the positive ions.

Gas pressure in the tube being thus eliminated to the highest possible degree, those features of instability in the tubes of the prior art which it can now be seen were due to the presence of the gas in the tube are likewise eliminated.

Furthermore, by static or electromagnetic means I cause the cathode rays or electrons to be focused on the anode or target and this focusing effect is steady and unwavering.

A tube made in accordance with my invention differs from the tubes of the prior art in the possession of most remarkable characteristics. Thus there are no marked changes in the operation of the tube during a considerable length of time, with the result that X-rays may be constantly generated of a much more uniform degree of penetrating power and much more constant in volume and in the location of their source-

or focal spot. The penetrability or in other words the "hardness" or "softness" of the X-rays may be adjusted at will by adjusting the temperature of the cathode. There is practically no fluorescence of the glass of the tube and this is important because it indicates that the glass is not bombarded by secondary cathode rays emanating from the target or anode and is therefore not being locally heated thereby. There is only a more or less negligible production of the secondary X-rays from the glass which form such a useless and disturbing factor in the ordinary Roentgen tube. The voltage consumed by the tube may in certain forms of embodiment of my invention be made to remain more or less constant even though the voltage of the source of current supply varies. The focusing effect is steady and the sharpness of definition of the X-ray photographs is increased. These and other features and advantages of my invention will be better understood by reference to the following description taken in connection with the accompanying drawings. The features of novelty I have endeavored to point out in the appended claims.

In the accompanying drawings, Fig. 1 is a sectional view of a complete tube equipped with one type of focusing device; Figs. 2 to 7 illustrate alternative forms of focusing devices, and Fig. 8 illustrates a modified tube having a constant voltage characteristic.

42

Referring to Fig. 1, showing one embodiment of my invention, the tube or envelop~~e~~ is indicated at 1, consisting as usual of glass, or other transparent material. In the tubular end 2 is sealed an anode 3 which in this case is plate-shaped. It is supported by a stem 4, both anode and stem consisting, preferably, of wrought tungsten. Opposite this anode, which serves also as target, is a cathode 5 adapted to be heated, in this case a filementary

Per F.

spiral of tungsten, tantalum, carbon or other highly refractory material. In this case the filament is wound non-inductively, though this is not essential. It is connected to leading-in wires 6, 7, sealed into a glass support 5, the wires being insulated from each other by little glass tubes 8 as clearly shown. The wires 6, 7 are connected to a source of current, such as a battery 9, or to a transformer, through a regulatable resistance 10. The battery, or transformer secondary, should be well insulated owing to the high potential used in operating the tube. Around the cathode proper is a hollow cylinder 11 consisting of tungsten, aluminum, iron, or other suitable conductive material held in position by springs 12, one of which engages with a little knob 13 on the glass. This cylinder or tube is preferably electrically connected to the cathode by means of wire 14, either inside the tube or brought outside of the tube as shown, and containing in circuit a switch 15. In normal operation the cylinder 11 performs the important function of modifying the static field to focus the cathode discharge, as will be explained.

Instead of being tubular the focusing device may assume various other shapes. It may be a perforated flat disc, as shown at 16, Fig. 2, or a perforated dished or concave disc 17, Fig. 3, or even a simple ring 18, Fig. 4. In fact, even a metallic deposit, such as a film of chemically deposited silver, on the walls of the globe, as shown in Fig. 5 at 19, will act as a static focusing means.

Magnetic focusing means may be used, instead of the static focusing devices, and as shown in Figs. 6 and 7. The magnetic focusing means may take the form of a solenoid, either inside the tube similarly to the static focusing ring, or outside the walls of the tube in the vicinity of the cathode, as diagrammatically indicated in Fig. 6, at 20, or the cathode itself is wound inductively, as shown by cathode 21 in Fig. 7.

In the preparation of the tube the glass is first freed from moisture and gas by heating and other approved methods and the electrodes preferably are freed from gas as by heating them to a high temperature in a vacuum. Exhaustion of the tube is preferably carried on by means of a pump which will remove vapors as well as gases, such as the Gaede molecular pump. For the removal of the last portions of gas from the electrodes and from the glass the tube is operated on the pump. The electrodes should be made of refractory metal such as tungsten so that they will withstand the very high temperatures attainable by operating the tube while connected to the pump, whereby gas may be effectively driven out. In case the usual constriction in the exhaust tube is employed, pumping is thereby greatly delayed. In some cases much time can be saved by omitting the constriction until the tube has been exhausted to [illegible] point where the operation is satisfactory. Carefully dried air can then be admitted and the constriction put in. Upon exhaustion of the dry air it will be found that the condition of the tube, even without further running on the pump, is essentially what it was before air was admitted.

Per L

When the electrodes have been sufficiently freed from gas, particularly the anode which is of large mass relative to the cathode and the tube has been exhausted to a vacuum of about .05 microns (0.00005 millimeters of mercury) or lower it is sealed off from the pump. It may be operated, in accordance with my invention, by closing the battery circuit through the resistance 10 so as to heat the filament 5 to incandescence. When a sufficiently elevated temperature has been reached electrons are emitted by the filament. When a sufficient potential is applied across the tube by completing connection to a suitable source 22, through conductors 23 and 24, current is transmitted, provided the negative terminal of the source is connected to the filament. ¶

L.H. The electrons soon charge the hollow cylinder 11 to a negative potential with respect to the cathode unless the cylinder and cathode are connected. Whether connected or not, the cylinder so modifies the nature of the static field within the tube that the electrons are directed upon a spot of small area upon the anode 3. ¶ In my opinion the focusing action is caused by the electrons tending to move perpendicularly to the equipotential surfaces which may be drawn in the space between cathode and anode. This manner of focusing the cathode discharge is especially effective as the speed of the electrons is relatively low near the cathode and therefore their movement is easily directed by the focusing devices. The focal spot on the anode remains fixed during the normal operation of the tube. This is in sharp contrast to the operation of the ordinary Roentgen tube in which the focal spot often moved about so rapidly as to produce blurring of all lines not parallel to the direction of motion, even during very short radiographic exposures.

E The operation of ~~tubes~~ X-ray devices made in accordance with my invention is markedly affected by the temperature to which the cathode is raised. If the temperature of the filament is low only a small number of electrons escape, and therefore the saturation current through the tube is relatively small. Increasing the impressed voltage on the tube will

B cause substantially no further increase in current. It will increase the velocity of the cathode rays and hence the penetrating power of the Roentgen rays. If the filament temperature on the other hand is very high, further increase of temperature

Pe B
Pei a
a

produces no appreciable effect on the tube characteristics, more electrons being emitted by the filament than can be carried by the voltages employed ~~be carried~~ from one electrode to the other. At higher filament temperatures, the space relations of the elements of the tube such as the distance between cathode and anode, the location of the focusing means relative to the cathode, the diameter of the opening in the focusing device, etc. constitutes a current limiting factor, as will be later explained.

Except for these limiting cases, an increase in impressed voltage will in general cause an increase in discharge current and in the potential drop in the tube, thus increasing the penetrability of the X-ray.

However, by giving the cathode its main extension in the direction of the axis of the tube, and also suitably proportioning and locating the focusing device, a most important new characteristic may be attained. Such a construction is shown in Fig. 8 in which a filament 25 extends nearly through the whole length of tube 26, being anchored at its tip by a support 27. With a low impressed voltage, only that part of the filament ~~26~~ 25 nearest the anode will furnish the electrons necessary to carry the discharge current. With higher impressed voltages, a progressively greater part of the filament will contribute electrons. The increase in the number of electrons thus rendered available by the increase of impressed voltage and the accompanying change in distribution in the static field, tends to reduce the tube resistance and thus counteract the tendency of the higher impressed voltage to increase the potential drop through the tube. A tube thus constructed, therefore, exhibits within certain limits an important new characteristic of operating with a substantially constant potential drop over a range of variable

B

impressed voltage. The advantages of this new characteristic of the tube are manifold. A most important advantage is gained in the homogeneity of the X-rays obtained when the tube is operated from a current source, in which the voltage varies periodically, as, for example, when a transformer, induction coil or a rectifying device such as a mechanical selector, are used which gives current impulses of variable voltage.

My novel apparatus, therefore, has the following valuable and striking characteristics. First, the resistance of the tube, and, hence the penetrating power of the Roentgen rays produced in the tube, may be controlled with certainty, and may be instantly increased or decreased at will, by raising or lowering of the temperature of the cathode; second, a much more homogeneous bundle of X-rays can be produced even though a several-fold increase, or decrease of gas pressure takes place in the tube, providing the pressure remains within the limits above indicated; third, as the discharge can pass through the tube only when the heated electrode is made the cathode, the tube may be operated on alternating current almost equally as well as on direct current; fourth, if desired, a tube may be proportioned to give over a predetermined range of impressed voltage X-rays of substantially uniform penetration.

E

The operator is thus enabled to determine, with a properly calibrated ~~tube~~ device, from a curve, or chart, just what current values and voltages he needs for a given purpose, and may be sure that when he has prepared his patient he can get exactly the service he requires from his tube without troublesome and dangerous experimentation.

One of the main causes for the uniformity of the penetrability of the X-rays is to be ascribed to the fact that the operation of the tube is not dependent upon positive ion bombardment of the cathode. Another cause is its complete independence of vacuum changes within the permissible range of pressure. It will also be noted that with the high vacuum existing in the tube, the mean free path between gas molecules is much greater than the distance between anode and cathode and, therefore, very few electrons can collide with gas molecules in passing from cathode to anode, therefore, practically all of the electrons reach the target with uniform velocity. Because of the low gas pressure the number of positive ions is so small that the filament is not heated at all by bombardment. Even when a very heavy discharge current is sent through the tube, a voltmeter and ammeter in the filament circuit indicate no change in the resistance and hence the temperature of the filament. Another observation, which has a similar significance, is that at low filament temperatures, where the electrons emitted by the cathode are all used in carrying current, a several-fold increase in voltage brings substantially no accompanying increase in the discharge current. This could hardly pertain, in case positive ions played an appreciable rôle, for increased voltage would mean higher velocities, and hence, a greater emission of electrons which, in turn, would mean an increase in the discharge current.

Per B

A

The wall of the tube exposed to the anode is not heated by secondary cathode rays from the anode, thereby removing the limitation formerly imposed by local tube heating. Tube fluorescence due to secondary cathode rays is likewise absent. Not only are current carrying limitations thus removed but it should also be noted that a marked gain of efficiency is secured in the tube. For example, in the former type of tube with a platinum target, about three-fourths of

A

many electrons left the target as "secondary cathode rays" as were received by it in the form of primary cathode rays. The elimination of secondary cathode rays also greatly improves the tube as the secondary X-rays produced by the secondary cathode rays striking the tube were a serious disturbing factor as already mentioned.

While I have described and illustrated specific forms of tubes embodying my invention, I wish it to be understood that various changes and modifications may be made in the tube within the scope of my invention. As already indicated the ~~specific~~ spacial relations of the elements of the tube affect its characteristics. For example, increasing the distance between the front of the focusing device and the incandescent cathode increases the resistance of the tube; decreasing the opening in the static focusing ring or tube increases the resistance of the tube. Decreasing the distance between cathode and anode lowers the resistance of the tube, but this effect is probably not to be ascribed to any considerable resistance change due to linear separation of the electrodes but to the fact that the glass walls of the tube are charged negatively during operation and thus act as though they represented an extension of the focusing device. Bringing the cathode nearer to the anode therefore, would have an effect similar to that caused by bringing it nearer to the front of the focusing tube or ring.

Insert "B"

⑨

What I desire to secure by Letters Patent of ~~the~~ United States, ~~is~~:-

Per B

1. In a device ~~tube~~ for the production of X-rays, the combination of a ~~the~~ tube ~~proper~~ provided with electrodes, the vacuum in the tube being so attenuated as practically to eliminate the production of positive ions, and means for generating electrons at the cathode or negative electrode substantially independently of the voltage impressed upon said electrodes.

C

C

Per A

Sub-B¹

~~2. A Roentgen ray ~~tube~~, comprising an envelope, and cooperating electrodes therein, at least part of one of which is adapted to be maintained at incandescence, said envelope having a vacuum more highly attenuated than the working vacuum of a Roentgen tube provided with an unheated cathode.~~

Cl'd

B

3. An electrical vacuum discharge tube, comprising an envelope, ~~and~~ cooperating electrodes ~~therein~~, at least part of one of which is adapted to be maintained at incandescence, the vacuum within said envelope being so high that ~~the cathode is not sensibly heated by a discharge current through the tube~~.

Insert B²

4. An electrical vacuum discharge tube, comprising an envelope, cooperating electrodes therein, one of which is adapted to be independently heated, and a conducting body surrounding said cathode, said body serving to modify electrostatic forces in the tube, to control the direction of ~~and direct~~ the cathode rays.

Per E

Insert B³

B

5. An X-ray device ~~tube~~ comprising electrodes consisting of tungsten freed thoroughly from gas, the negative electrode being adapted to be independently heated, at least in part, and an enclosing envelope so ~~more~~ highly evacuated ~~than the working vacuum of an X-ray tube provided with an unheated cathode~~.

B

Insert B⁴

Sub B

6. An electrical discharge tube comprising an evacuated envelope, electrodes therefor, the cathode being extended longitudinally and adapted to be heated independently and conductive means in part at least surrounding the space between said electrodes to control electrostatic forces in the tube.

Cl. 6-7

7. An electrical discharge tube, comprising an evacuated envelope, cooperating electrodes therein, the cathode being adapted to be independently heated, and static means near the cathode for focusing the cathode discharge upon the anode.

V. C. 4

8. A Röntgen ray tube, comprising an envelope evacuated to a pressure of less than about .6 micron, a cathode therein adapted to be heated independently of the operating current, a cooperating anode and means for focusing the cathode discharge upon the anode.

Cl. 9

Sub. B

9. The combination of an envelope, cooperating electrodes therein, said envelope being evacuated to such degree that the mean free path between the residual gas molecules is greater than the distance between the electrodes, a source of energy connected to said electrodes, and means for heating at least part of the negative electrode to incandescence.

5

D

Insert D'

C

C

Insert D

10. ③ A Röntgen apparatus comprising an ~~evacuated~~ envelope, D' electrodes therein, external means for independently heating the negative electrode, and means ~~for controlling~~ modifying the static field to focus the cathode discharge upon a spot of small area on the anode.

52

11. A Röntgen tube comprising an evacuated envelope main working electrodes therefor, one of which is of fila-

mentary character, means for heating said filamentary electrode, and an electrical conductor at least in part surrounding the space between said electrodes. ② C'

Insert C'

Per A

12. A Roentgen ray tube comprising an evacuated envelope, electrodes therein, the cathode being arranged to be heated independently, and a focusing device surrounding and electrically connected with said independently heated cathode.

B

13. The combination of a source of current alternating in potential, and a Roentgen-ray tube operatively connected therewith comprising co-operating electrodes at least part of one of which is adapted to independently generate electrons ~~be heated~~, and an envelope therefor evacuated to such high degree that manifestations of positive ions are absent.

B

a

14. A Roentgen ray tube comprising an envelope, cooperating electrodes therein, at least part of one of which may be independently heated to emit electrons, the space in said envelope being so highly evacuated that manifestations of positive ions are absent, means for producing a cathode discharge in said tube and means for controlling the static field in said tube to prevent electrons from striking the ~~glass~~ envelope.

E

Cl. 15

Sub E'

~~15. The combination of a source of current, an X-ray tube having main electrodes connected thereto, the cathode being adapted to be heated at least in part, an envelope surrounding said electrodes, evacuated to so low a pressure that manifestations of positive ions are absent, an independent source of energy for heating the cathode and means for adjusting the heating current to control the resistance of the tube.~~

Per E
E

16. In a ~~tube~~ device for the production of Roentgen rays, the combination of ~~the tube proper~~ a tube evacuated to such a degree that practically no current can pass due to ionizing action of the impressed voltage upon such gases as may remain in the tube, positive and negative electrodes in the tube provided with suitable leading-in conductors, and means for heating the cathode to a high temperature, said means being independent of the impressed voltage.

Insert B7

Insert B8

17. An electrical vacuum tube, comprising a (5) B7 cathode adapted to be heated to incandescence, a cooperating anode (6) B8 and means disposed about an axis passing through cathode and anode for directing the cathode discharge. Cl. 18

Per B
Sub. D3

~~18. An electrical ~~vacuum tube~~ discharge device, comprising an envelope, a cathode adapted to be heated, a cooperating anode, and conductive means surrounding, in part at least, the space between cathode and anode for modifying the static field to focus a cathode discharge.~~

Sub. B9

~~19. The method of producing Roentgen rays which consists in producing an electric discharge between an incandescent cathode and a cooperating anode in a vacuum more highly attenuated than the ordinary working vacuum of Roentgen tubes, and focusing the cathode rays by means of an electrical field.~~

Per B.

~~20. The method which consists in producing an electric discharge between an incandescent cathode and a cooperating anode in a very highly attenuated vacuum, directing the discharge upon a focal surface, and regulating at will, the penetrability of the rays by varying the voltage impressed upon said electrodes.~~

[illegible]

~~21. The method of regulating the penetrability of Roentgen rays produced by a discharge from an incandescent cathode in a very high vacuum, which consists in varying the temperature of said cathode.~~

20. ~~22.~~ The method of regulating the penetrability of Roentgen rays produced by a discharge from an incandescent cathode in a vacuum ~~more rarified than the ordinary Roentgen tube vacuum~~ ② B10 which consists in adjusting the cathode temperature and impressed voltage.

// Insert B10

21. ~~26.~~ The process of producing Roentgen rays by current from a source alternating in potential which consists in emitting electrons at a negative electrode, transmitting thereby a ray-producing current ~~wave~~ of one polarity, while preventing at the same time the formation of positive ions, and ~~thus~~ suppressing the other half wave of the alternating current.

// Per E
" " E

80

22. ~~24.~~ The process of producing X-rays which consists in impressing an alternating electromotive force upon electrodes of an X-ray tube and causing electrons to be emitted from one electrode only while preventing ~~without~~ any accompanying manifestations of positive ions, and projecting said electrons upon a target surface, whereby one-half wave of an alternating current is utilized and the opposite half wave suppressed.

80

// Per B

23. ~~25.~~ The method of operating a tube for the production of X-rays which consists in maintaining within the tube a vacuum so highly attenuated that practically no current can flow through the tube under the influence of the impressed voltage ~~impressed upon the tube~~ through the medium of ionisation of gas molecules in the tube, and rendering the tube unilaterally conducting by generating electrons at the cathode independently of the voltage impressed upon the tube.

// E

7V

24 ~~23.~~ The method of operating a tube for the production of X-rays which consists in maintaining within the tube a vacuum so highly attenuated that practically no current can flow ~~through the tube~~ under the influence of the voltage impressed upon the tube, through the medium of ionisation of gas molecules in the tube, and rendering the tube unilaterally conducting by generating electrons at the cathode by current independent of the voltage impressed upon the tube. Cls. 25-29

Per E

Insert D4

IN WITNESS WHEREOF, I have hereunto set my hand this 8th day of May, 1913.

WITNESSES:

Benjamin B. Hull

Helen Orford

William D. Coolidge

AFFIDAVIT

STATE OF NEW YORK } SS:
COUNTY OF SCHENECTADY

William D. Coolidge, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Schenectady, in the County of Schenectady, State of New York, and that he verily believes himself to be the original, first, and sole inventor of the improvements in

VACUUM TUBES

described and claimed in the annexed specification; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any foreign country on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any foreign country.

William D. Coolidge

Sworn to and subscribed before me this 8th day of May, 1913.

Benjamin B. Hull
Notary Public

Cert Affdv as filed 5800

964

Serial No 766,549 Application filed May 9/13

11380

Fig.1.

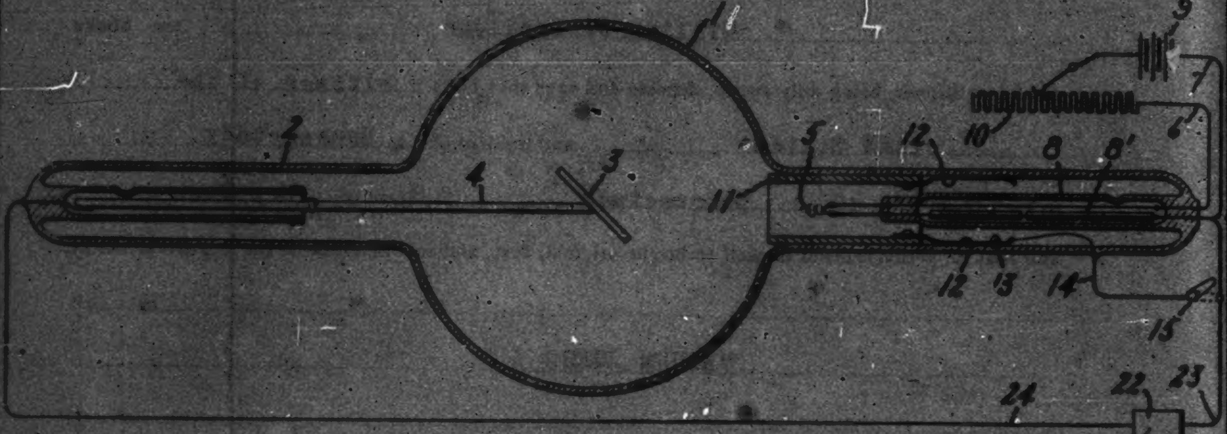

1
2
3
4
5
6
7
8
8'
9
10
11
12
12
13
14
15
22
23
24

Fig.2.

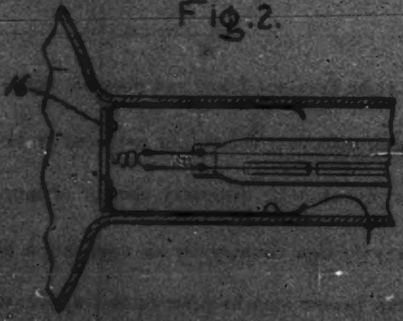


Fig.5.

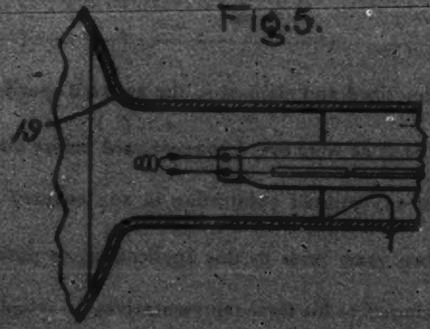


Fig.3.

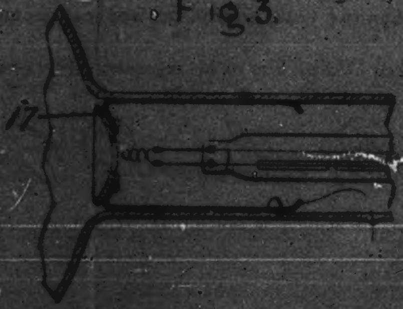


Fig.6.

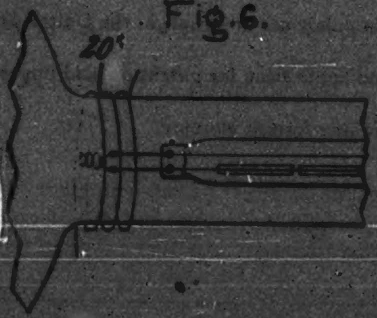


Fig.4.

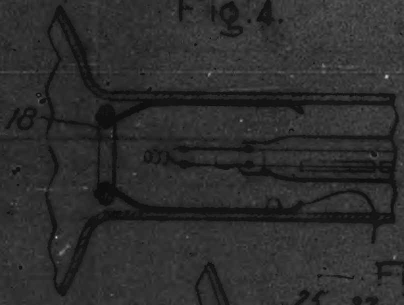


Fig.7.

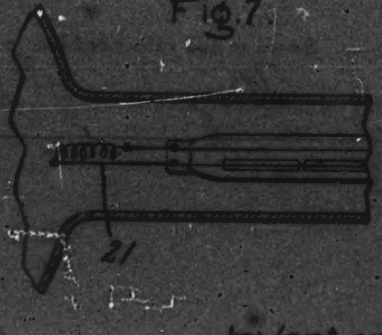


Fig.8

Witnesses

Inventor
William D Coolidge

Div. 16 Room 109

Address only
"The Commissioner of Patents,
Washington, D.C."

Paper No. 2

All communications respecting this application should give the serial number, date of filing, and title of invention.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON July 23, 1913.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER *in charge of the application of*

W. D. Coolidge, S. No. 766,549, filed May 9, 1913,

Vacuum Tubes.

E. B. Moore
Commissioner of Patents.

The following references are made of record:

"Conduction of Electricity Through Gases", second edition, by Thomson, Cambridge University Press,
"Practical Radiography", third edition, by Isenthal and Ward, published by Dawbarn and Ward, London,
"Annalen der Physik und Chemie", Vol. 14, 1904, page 425-468, Wehnelt,
"Annalen der Physik und Chemie", Vol. 20, 1883, page 705.

These references may be seen in Division 16 of this Office.

Page 7, line 6, "8" should be 8'.

Page 10, lines 2 and 3, respectively, a comma should be inserted after "can" and "employed".

The source of current 22 should be shown conventionally in Figure 1.

The state of the art is generally shown in the above references. The two references in Annalen der Physik und Chemie show that it is old to heat the cathode in a highly evacuated tube. Attention is particularly directed to Figures 12 and 13 of Volume 20 and the description pertaining thereto, page 133, Article 90. Also see Articles 91 and 92, Volume 21.

14380

Fig. 1.

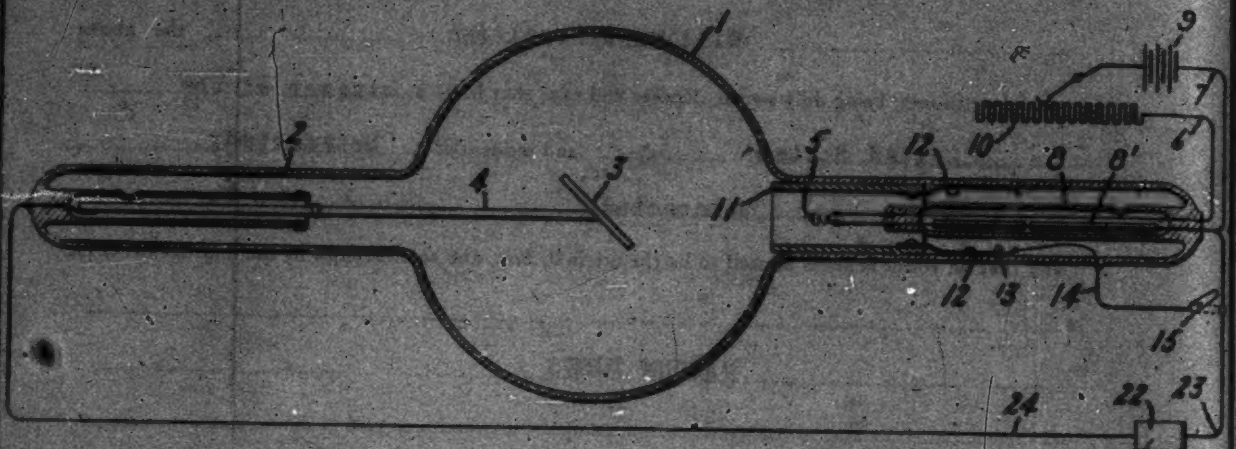

1
2
3
4
5
6
7
8
8'
9
10
11
12
12
13
14
15
22
23
24

Fig. 2.

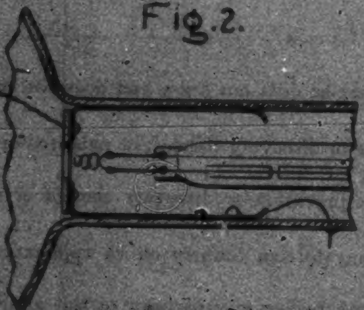


Fig. 5.

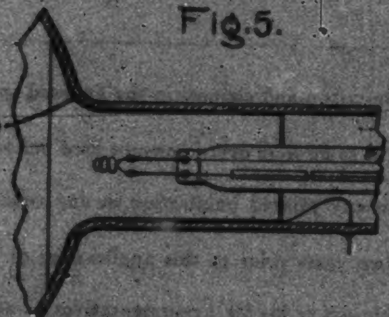


Fig. 3.

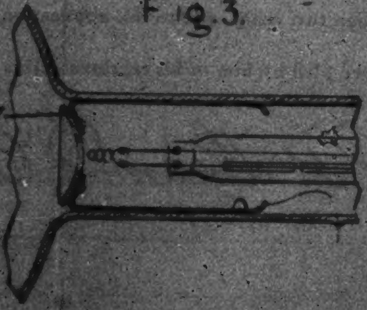


Fig. 6.

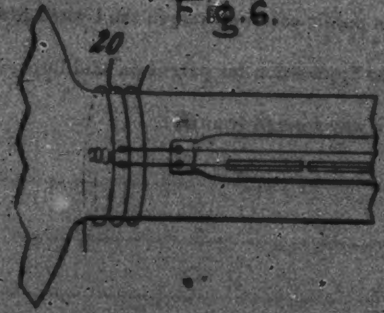


Fig. 4.

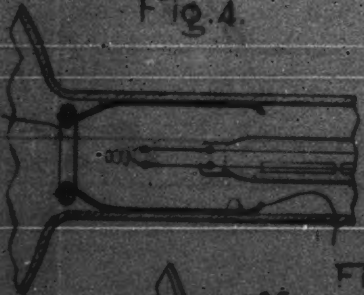


Fig. 7.

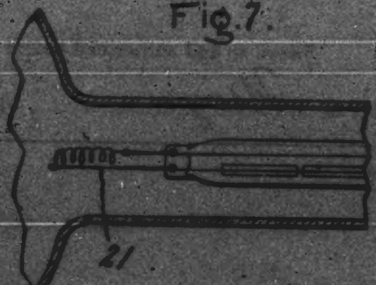
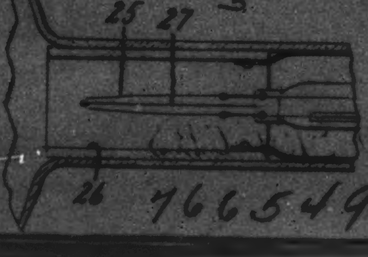


Fig. 8



Witnesses
Chas B Stikeo

Inventor
William D. Coolidge
by Albert G. Davis
His Attorney

766549-22

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON

July 23, 1913.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

W. D. Coolidge, S. No. 766,549, filed May 9, 1913,

Vacuum Tubes.

E. B. Moore

Commissioner of Patents.

The following references are made of record:

"Conduction of Electricity Through Gases", second edition, by Thomson, Cambridge University Press,
"Practical Radiography", third edition, by Isenthal and Ward, published by Dawbarn and Ward, London,
"Annalen der Physik und Chemie", Vol. 14, 1904, page 425-468, Wehnelt,
"Annalen der Physik und Chemie", Vol. 20, 1883, page 705.

These references may be seen in Division 16 of this Office.

Page 7, line 6, "8" should be 8'.

Page 10, lines 2 and 3, respectively, a comma should be inserted after "can" and "employed".

The source of current 22 should be shown conventionally in Figure 1.

The state of the art is generally shown in the above references. The two references in Annalen der Physik und Chemie show that it is old to heat the cathode in a highly evacuated tube. Attention is particularly directed to Figures 12 and 13 of Volume 20 and the description pertaining thereto, page 133, Article 90. Also see Articles 91 and 92, Volume 21.

Attention is directed to Chapter VIII in Thomson on "Ionization of Incandescent Solids" and particularly Articles 103 to 106 therein in which several experiments are described showing that the generation of electrons is independent of the voltage between certain limits (bottom page 193) and that "the negative electricity from the hot wire is carried by the same carriers as the cathode rays, i. e., by 'corpuscles', those small negatively electrified bodies of constant mass which in all the cases yet investigated act as the carriers of negative electricity in high vacua" (bottom page 197). Thus it is clear that the action involved in the references is identical with that which would be obtained with cathode rays in an x-ray tube.

Claims 1, 2, 3, 5, 8, 9, 11, 13, 15 and 16 are each rejected on Thomson or the Annalen der Physik und Chemie references for the reasons given.

Claims 4, 6, 7, 10, 12, 14, 17, 18 which include the electrostatic cathode-stream directing means are rejected on the same references and grounds, in view of Practical Radiography, cited, which discloses the idea of "coating the neck of the tube with a strip of tinfoil in the plane of the cathode edge, and connecting the tinfoil ring through a small gap with the cathode terminal". It is true that no suggestion is made in this reference of the use to which applicant has put his similar arrangement, but the discovery of a new function for an old construction is, of course, unpatentable. Furthermore, it is a well known fact that the cathode itself has a pronounced electrostatic effect in directing the cathode stream and this effect has been determined to a mathematical exactness. See Thomson, above cited, Articles 339 and 340 and incidentally see top page 120 and middle page 600. The effect of a conductor surrounding the cathode a short distance away and connected thereto, as in the reference cited, would of soufse be similar. The fact that a small gap exists in the connection between the tinfoil and the cathode in the reference is immaterial since sparks pass freely across the gap and maintain the tinfoil at the same potential as the cathode.

Claims 2, 9 and 15 are rejected on practically any reference in the art since the cathode is usually heated to the point of incandescence by the operation of the tube.

In connection with claim 11 it is noted that cathodes of filamentary character are well known in the art and the use thereof involves no invention.

Claims 19 to 26 are rejected as being purely functional since they do not recite a true method or process but merely the mode of operation of the apparatus disclosed. Furthermore, these claims are met by the references cited.

Examiner, Division XVI.

CSG

PAPER NO. 3
AMENDMENT. a

UNITED STATES PATENT OFFICE.

In re Application of :
WILLIAM D. COOLIDGE, :
Serial No. 766,549, : **VACUUM TUBE**
Filed May 9, 1913, :
Room No. 109. :

a

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of July 23, 1913, please amend the above-entitled application as follows:-

✓ Page 7, line 6, change "8" to - 8' -

✓ Page 10, line 2, after "can" insert - be carried, -

✓ Line 3, after "employ" place a comma and cancel "be carried"

✓ Claim 2, line 1, before "tube" insert - ray -

✓ Claim 12, line 1, before "tube" insert - ray -

✓ Claim 14, line 1, before "tube" insert - ray -

✓ Add the following claims:-

a'
2 C²

25. ~~27.~~ The method of depriving a metal body of occluded gas which consists in subjecting said metal body to electron bombardment in a maintained vacuum.

26. ~~28.~~ The method of removing gas from a metal which consists in operating said metal as anode to an electron discharge in a highly evacuated space and progressively removing gas from the space near said anode as liberated by said discharge.

~~29.~~ The method of preparing an anode for electron discharge apparatus which consists in subjecting the same to electron bombardment in a maintained vacuum.

28. ~~30.~~ ~~The method of preparing an electron-discharge device comprising a gas-tight envelope, an electron-emitting cathode and an anode, which consists in evacuating said envelope, then subjecting said anode to an electron-discharge while continuing the evacuation to completely free the same from gas, and finally sealing the envelope when the gas pressure is so low that the normal operating electron discharge cannot produce appreciable gas ionization.~~

29 ~~31.~~ ~~The method of preparing an electron-discharge device comprising a gas-tight envelope, an electron-emitting cathode and an anode, which consists in evacuating said envelope, then subjecting said anode to an electron-discharge with an energy input sufficient to heat the same to incandescence, continuing the evacuation until the residual gas present in the envelope is below the pressure at which appreciable ionization takes place at the normal operating electron current, and then sealing the envelope.~~

Insert B" Per B

~~32. An electron discharge apparatus comprising a gas-tight envelope, an electron-emitting cathode and an anode freed from gas ionizable by electron bombardment, said envelope being evacuated to below the pressure at which gas ionization by collision takes place at the working current and voltage of the apparatus.~~

~~33. An electrical discharge device comprising an envelope, and cooperating electrodes at least one of which has been deprived of gas disengagable~~

by electron bombardment, said envelope being evacuated to such low pressure that conduction of current can take place in the evacuated space independently of gas ionization.

34. An electrical discharge device comprising an evacuated envelope, an electron-emitting cathode, and an anode deprived of occluded gas by electron bombardment in a maintained vacuum, the gaseous pressure in said envelope being low enough to enable an electron discharge to take place without substantial gas ionization.

R E M A R K S

Applicant's attorney has carefully perused chapter 8 of Thomson's"Conduction of Electricity through Gases" (1906 edition). This chapter no doubt contains a very comprehensive study of the work of the investigation in the field of vacuum tubes provided with incandescent cathodes. It is true that investigators have for a great many years observed that there is a unilateral conductivity between a heated electrode and an unheated electrode in an evacuated space. It is a significant fact, however, that no one ever produced a useful X-ray tube provided with an incandescent cathode. The Examiner is no doubt aware that in order to produce X-rays of high enough penetrating power to even pass through the glass of the tube, very high voltages are necessary running in the large commercial X-ray tubes up to 100,000 or even 150,000 volts. The current also is considerable, as heavy anodes may be melted in a high-powered tube. By carefully perusing the article and referring to the original literature from which the observations were obtained, it at once becomes obvious that all the experiments were carried on at very low voltages and at extremely minute currents. For example, in the curves given on page 194 which illustrate the relation between the saturation current and the temperature expressed in degrees centigrade, it will be observed that the current values vary between zero and 200×10^{-9} amperes (.0000002 amperes maximum), and on page 195 a statement occurs that in one particular case the current amounted to about 4×10^{-4} at a temperature of 1500° C. By a perusal of the original literature it will be observed that the current had to be maintained at these extremely low values in order to prevent destructive gas ionization. Applicant's attorney has by diligent search extending not only through the literature cited, but through a wider field, not been able to find a single instance where a current of as much as a few milliamperes has been used in a device of the above character with a voltage of as much as, say, 200 volts.

In all the devices described in the literature anodes of such metals as platinum, carbon or even aluminum, have been used and it is impossible to free materials of this kind from ionizable gas by the methods used by the experimenters. An experiment is described on pages 192-193 of Thomson's book in which it is stated that the pressure is "reduced as low as possible, say to .001 mm. of mercury." The present applicant exhausts to a pressure of .00005 mm. of mercury, or even lower. The gas in the electrodes is even more harmful than the gas in the space in the tube. The early investigators either did not realise or did not have means available for completely removing gases from the anodes, in fact, actually believed that the presence of gas to be necessary for the discharge between the heated and unheated electrode.

The present applicant carefully frees the anode from occluded gases by operating the device on the pump for considerable time while continuing evacuation, as particularly described on page 8 of the specification. It is not merely a matter of heating the electrodes in a vacuum as this alone is not sufficient. In fact, applicant recommends preheating the electrodes in a vacuum but distinctly states that in addition to this heating it is necessary to subject them to the discharge incidental to the operation of the tube while continuing the pumping.

When the gases have not been completely removed from the electrodes or the space not sufficiently evacuated positive ionization takes place by collision of the electrons with the gas molecules which at first is made manifest by erratic readings on the measuring instruments and, if the impressed voltage is increased, by blue glow in the tube, electrical disintegration or "sputtering" of the cathode and also heating of the cathode by bombardment with positive ions. In applicant's device all these phenomena are absent even with currents many thousand times greater than the maximum currents possible in the devices described by Thomson and at voltages for which thus far no limit has been found. In the ordinary operation of the device described in the specification voltages up to 150,000 volts are in everyday use. The discharge current varies directly with the $\frac{3}{2}$ power of the impressed voltage and is independent of the vacuum.

This explanation has been carried to considerable length so as to make clear at the outset that there are remarkable differences between the present apparatus and the devices described in chapter 8 of Thomson's book.

The other articles in the Annalen der Physik und Chemie are mere cumulative references and anything that has been said above also applies to those articles.

In view of these facts it is not seen how claims 1, 2, 3, 5, 8, 9, 11, 13, 15, 16, can be considered to be met by the references cited. In no case could any of these prior devices have been used for the production of X-rays, in fact, it did not even occur to anyone as far as the references show to attempt to use them for this purpose. While applicant's invention includes more than an X-ray tube it undoubtedly does include an X-ray tube which produces a number of new and useful results and which operates in a different manner than any of the X-ray tubes heretofore produced. These new results have already been sufficiently set forth in the specification and therefore it should not be necessary to repeat them here.

The article in "Practical Radiography" appears to have no bearing whatever on the present case. The tinfoil coating on the neck of the tube is for the purpose of discharging static charges upon the glass and not for the purpose of focusing or in any way influencing the discharge itself. In fact, in an ordinary X-ray tube the cathode rays have an exceedingly high initial velocity and therefore while influenced by the curvature of the cathode would not be appreciably influenced by the static field near the cathode. In the present case the velocity of the electrons emitted by the hot cathode is low and therefore are influenced but little by the shape of the cathode but greatly influenced by the static field. Unless the Examiner can point out some reasons not obvious from a perusal of the article cited it is respectfully requested that the reference be withdrawn.

As to claim 11, it is believed that as the application of a filamentary cathode to an X-ray tube is new the combination is a new one notwithstanding the use of a filamentary cathode in some entirely different type of electrical device. Reconsideration of this claim is therefore requested.

Reconsideration of method claims 19 to 26 is also requested. These claims while including certain features of the apparatus include more than this, namely, positive acts to be performed in connection with the operation of the tube, such as the regulation of filament temperature, the impressed voltage, the generation of electrons at the cathode, etc. Applicant's invention includes more than a certain structure which is merely connected in circuit. He accomplishes in a positive, regular manner the control of the penetrability of the rays and the quantity of the rays which had to be left to chance in the former type of X-ray tubes.

Additional claims have been added to more completely cover such broad features of applicant's invention, as the removal of gas on the pump from the electrodes by an electron discharge, and in general, devices operable at high currents and voltages with a pure electron discharge, whether X-ray tubes, rectifiers, relays or any other type of discharge device.

Reconsideration of the Examiner's requirement to illustrate the source 22 conventionally is respectfully requested. This source furnishes either direct or alternating current and to this end may be a high potential synchronous rectifier or an ordinary transformer, or indeed, a source of unsymmetrical current such as an induction coil. It is not clear to applicant's attorney what conventional designation to use.

Favorable reconsideration is respectfully requested.

Respectfully submitted,

Albert G Davis

Attorney for Coolidge.

Schenectady, N. Y.
October 14, 1913.

WGC/GAL

976

Div. 15 Room 102
Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

B-240

F.H.

Paper No. 8
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON Jan. 7, 1914.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the **EXAMINER** *in charge of the application of*

W. D. Coolidge, S. No. 766,549, filed May 9, 1913,
Vacuum Tubes.

Thomas Ewing
Commissioner of Patents.

This is in response to amendment filed Oct. 16, 1913.

Page 10, line 21, "22" should be 25.

It is not understood how the positive ions are directed as described in line 23, page 1. This should be made clear.

The statements at the bottom of page 9 and top of page 10 are apparently too broad. As stated in the paragraph beginning line 10, page 10, an increase in voltage ordinarily produces an increase in discharge current and some increase in current, however small, would be produced in the two limiting cases described. It is suggested that the statements be modified by inserting the word substantially before "no" in line 29, page 9, and in inserting the word appreciable before "effect" in line 1, page 10.

In claim 1 the word "substantially" should be inserted at the beginning of the last line.

766,542 -- 2.

The following references are added to the record to show specific instances of independently heated cathodes in vacuum tubes:

VonLieben et al, 1,038,910, Sept. 17, 1912,
179 - 171,
German, 254,586 of 1912, 250 - 35,
Moore, 1,010,662, Dec. 5, 1912, 250 - 35, X.

The expression "more highly attenuated than the working vacuum of a Roentgen tube provided with an unheated cathode" in claims 2 and 5 is merely relative and is objected to as being indefinite.

Claim 2 is again rejected on the references of record on the ground that practically all cathodes in Roentgen tubes are heated to incandescence during operation.

Claim 3 is rejected and claim 2 is further rejected on the German patent 254,586, cited. In this reference the cathode is heated by a separate source to produce ionization instead of by bombardment of positive ions. Hence the cathode would not be sensibly heated by a discharge current. The tube in the German reference is not shown as a Roentgen tube, but it might be used as such by providing an ordinary target in lieu of the anode A. Claim 2 in no way distinguishes from the reference when so modified.

Claim 4 is rejected on the references and ground of record. As shown by the references of record and those cited it is old to heat the cathode independently in vacuum tubes. The tinfoil ring in the reference, Practical Radiography, while not provided as a means for directing the cathode rays would necessarily perform this function since the structure is substantially the same as that of applicant's Figure 5. The tin-foil ring is connected to the cathode thru a small spark-gap to collect the static charge so that it may be conducted away. The ring would consequently be charged at the same polarity as the cathode. If applicant's directing means operates differently from the reference it must be by virtue of some structural difference and the claims should distinguish by structure rather than by function.

Claim 5 is deemed allowable in substance, upon reconsideration, but is objectionable in form as noted above.

Claims 6 and 7 are rejected on the German patent on the ground that there would be no invention in providing a ring of tin-foil around the cathode as in the reference, Practical Radiography.

Claim 9 is rejected on the German patent 264,588, in view of Note 97, page 105, of the book "Notes on X-light", by William Rollins, published at Boston in 1904, which book may be seen in Room 109 of this Office. This note describes the method of exhausting an X-ray tube by continuing the exhaustion while sending a discharge current thru the tube. A vacuum equal to a millionth of an atmosphere is mentioned which is of substantially the same order as claimed by applicant and there would, of course, be no invention in merely continuing this method to ob-

tain an even higher vacuum. It is held that there would be no invention in applying this method of evacuation to an independently heated tube as shown, e. g., in the German patent. Also see Note 64 of Rollins.

Claim 13 is rejected on the German patent cited on the ground that the discharge tube shown therein could be used as a Roentgen tube by making the anode in the form of a target. Positive ions are comparatively absent (as in applicant's tube) in the German reference and the other references which employ an independently heated cathode.

Claims 17 and 18 are rejected on the references of record and on the ground more fully explained above.

Claim 19 is thought to be allowable in substance. One step in the method has been omitted from the claim, however, and it is suggested that line 2 be amended by inserting "independently producing incandescence of the cathode", after "in" and in changing "an" to the, same line.

Claims 20, 21 and 22 are rejected as merely reciting the method ordinarily employed in operating an x-ray tube in which the cathode is heated to incandescence by the bombardment of positive ions. As described on page 13 of the book by Thomson, of record, a stage is reached in the operation of all vacuum tubes where there is no appreciable increase of current when the potential difference is increased. At such stage increase of voltage would merely increase the velocity of the ions and hence the penetrability of the rays.

Claim 22 is indefinite in the relative expression "more rarified than the ordinary Roentgen tube vacuum".

Claim 24 is allowable in substance but objectionable in the negative limitation in line 4. This objection could be overcome by changing "without" to ", preventing" in line 4.

New claims 27 to 31 are rejected on the Note 37 in Rollins, above cited, which fully anticipates the method here recited.

Claims 32 to 34 are rejected on the same reference. The method disclosed in the reference being the same as employed by applicant, there is no apparent reason why the process could not be continued until the pressure is "low enough to enable an electron discharge to take place without substantial gas ionization".

Claims 8, 10, 11, 12, 14, 15, 16, 23 and 25 are allowable as at present advised.

Wm A Kinnan
Examiner, Division XVI.

AG

UNITED STATES PATENT OFFICE

In re Application of :
WILLIAM D. COOLIDGE, :
Serial No. 766,549, : **VACUUM TUBE**
Filed May 9, 1913, :
Div. 16, Room 109 :

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of January 7, 1914, please amend the above-entitled application as follows:-

Page 1, line 23, cancel "direct" and substitute - attract -

Page 9, line 29, after "cause" insert - substantially -

Page 10, line 1, before "effect" insert - appreciable -

Line 21, change "22" to read - 25 -

Page 12, line 19, after "brings" insert substantially -

Page 13, line 11, correct the spelling of "spacial"

Claim 1, line 1, cancel "tube" and substitute - device -

Cancel claim 2 and substitute the following claim:

B'

2. An X-ray device comprising a gas-tight envelope, the space within ~~said envelope~~ being exhausted to a pressure at which substantially no gas ionization occurs, a cathode, an anode, and means for generating electrons at the cathode, the current

transmitted by said device with a given cathode temperature being independant of the voltage over a range of impressed voltage values. Cls 3-5 fol

Claim 3, line 2, cancel "and"

Same line, cancel "therein"

Lines 5 and 6, cancel "the cathode is not sensibly heated by a discharge current through the tube" and substitute - evidences of positive

B2 ionization are substantially absent during operation and means for focusing the discharge -

Claim 4, line 6, after "rays" change the period to a comma and add - the residual gas in said envel-

B3 ope being insufficient to produce appreciable ionization by collision during the operation of the tube. -

Claim 5, line 1, cancel "tube" and substitute - device -

Line 4, cancel "more" and substitute - so -

Same line, cancel "than the"

Cancel lines 5 and 6, and substitute

B4 - that evidences of positive ionization are substantially absent during the operation of the device -

Cancel claims 6 and 7, and rewrite as follows:

B5 6. An electrical discharge device comprising an envelope, the space within said envelope being evacuated to a pressure below the value at which appreciable positive ionization can occur, electrodes therefor, the cathode being adapted to be heated independently of energy transmitted by said device and conductive means in part at least surrounding the space between said electrodes to control electrostatic forces in the tube.

7 11 7. An electrical discharge device comprising an evacuated envelope the residual gas in which is insufficient to conduct current between ordinary unheated electrodes, a cathode adapted to be independently heated, an anode from which gas is not disengagable during the operation of the device, and means near the cathode for maintaining a static field focusing a cathode discharge upon the anode. Cl. 8 fols

✓ Claim 8, line 1, before "tube" insert - ray -

✓ Cancel claim 9 and rewrite as follows:

B 6 9. A Röntgen ray device comprising the combination of an envelope evacuated to a pressure at which positive ionization is substantially absent during the operation of the device, an electron-emitting cathode, an anode and a source of energy connected to said electrodes having a voltage in excess of the minimum value at which the current is substantially independent of the voltage. Cls. 10-14 fol

✓ Claim 13, line 2, after "tube" insert - operatively connected therewith -

✓ Line 4, cancel "be heated" and substitute - independently generate electrons -

✓ Claim 17, line 1, after "comprising" insert -

B 7 an envelope the space in which is exhausted to below the pressure at which residual gas will conduct current,

Line 3, after "anode" insert -

B 8 substantially deprived of gas evolvable by electron bombardment, -

✓ Claim 18, line 1, cancel "vacuum tube" and substitute - discharge device -

Same line, after "comprising" insert - an envelope,

98

Cancel claim 19 and rewrite as follows:

~~19. The method of producing Roentgen rays which~~ consists in independently heating the cathode to incandescence, producing an electric discharge between the incandescent cathode and a coöperating anode in a vacuum so highly attenuated that evidences of positive ionization are substantially absent during the passage of current, and focusing the cathode rays by means of an electrical field. Cls. 20-24 fol

(B) Per C

Claim 22, lines 3 and 4, cancel "more rarefied than the ordinary Roentgen tube vacuum" and substitute so attenuated that electrical conductivity of the residual gas is substantially absent, [redacted]

(correct) B10

Claim 24, line 4, cancel "without" and substitute - while preventing -

Cancel claims 20, 21, 32, 33 and 34, renumber the remaining claims and add the following:-

Per L

B11

30. The process of operating an X-ray device comprising a gas-tight evacuated envelope, a cathode and an anode, which consists in generating electrons at the cathode independently of current passed by said device while preventing any accompanying manifestations of positive ions, ~~and~~ impressing on the electrodes a voltage at least as high as the value at which substantially all of the electrons are utilized, whereby the current becomes substantially independent of the impressed voltage., (4)

L

not L2

31. An X-ray device comprising a gas-tight envelope, an electron emitting cathode, and an anode deprived of ionizable gas, the space in said envelope being evacuated to a pressure at least as low as five hundredths of a micron of mercury pressure, the

current transmitted by said device with a given electron-emissivity of the cathode being substantially constant with an impressed voltage variable over a working range.

F 3 Cl. 33

REMARKS

In a previous amendment the nature of applicant's fundamental improvement in Roentgen tubes has been quite fully discussed and therefore will not be repeated at length. Attention, however, is directed once more to the fact that in applicant's tube all evidences of positive ionization such as luminescence of residual gas, conductivity in the space, glass fluorescence, variability of electrical characteristics and others are entirely absent. The term "ionization" has become well understood by scientists working in this field to imply some or all of these phenomena, depending upon the voltage, current and other conditions. For example, in a device such as described in Moore patent #1,0[illegible],568 the light emitted by the gas column is accepted evidence of positive ionization, and, in fact, the Moore patent distinctly states that gas is ionized and rendered luminous by the electric energy passing through the tube. In devices such as described in U. S. patent #1,038,910 and German patent #254,538, the presence of a blue glow or haze in the space within the tube and the electrical characteristics of the device indicate positive gas ionization. Altho these phenomena are not described in the patents these gas ionization tubes are well known in the art, and it is stated repeatedly in each patent that the operation is by virtue of a gas discharge.

The U. S. patent #1,038,910 mentions, lines 55-56 page 1, the "formation of an artificial dark space near the cathode and thus of a space where the number of ions is small". The German patent [illegible] states that an electropositive substance is introduced into the tube "whose vapor wholly or partly assumes the conduction of the current". The patent very clearly indicates that the object of the invention is to lower the discharge potential by the presence of metal vapors which are ionized.

The descriptive matter in a book "Notes on X-Light" by Rollins, referred to by the Examiner, merely discloses the well known fact that gas is "cleaned up", that is rendered inactive in some way by the passage of an electrical discharge in a highly evacuated space. This gas is not removed from the tube and it is stated by Rollins that if such a tube is

> "allowed to rest for a time, it will be found in sending a current through it that the resistance is less - - - - - - - - Gas has come to the surface from the interior, furnishing particles on which the charge rides the field between the terminals."

Rollins explains that under some conditions the vacuum may be reduced to a millionth of an atmosphere. This is about the lowest pressure at which current at the highest voltage will be conducted by residual gas and applicant operates well below this pressure. Rollins could not operate below this pressure while applicant is obliged to operate below this pressure to prevent destruction of the incandescent cathode by bombardment with positive ions.

Neither does Rollins disclose the method of depriving the anode of ionizable gas as set forth by claims 27 to 31. It is true that in the ordinary X-ray tube gas is disengaged from the anode, (in fact, the operation of the tube partly depends upon the evolution of gas from the anode) but the anode is never completely deprived of gas as the removal of gas from the envelope is not being continued. In other words, the anode is not being subjected to the [illegible] removing electron bombardment in a maintained vacuum. As described in the specification it is one of the essential steps in the preparation of applicant's tube to subject the electrode to electron bombardment while on the pump.

Most of the claims have been amended to more clearly distinguish over the references by stating that the vacuum is below the pressure at which conduction of current by gas can occur or, in other words, at a pressure at which positive ionization is absent and have been in other respects improved.

The present invention of Dr. Coolidge, the present applicant, has been commented on by many scientific publications. Space forbids reference to more than two.

In an article by Dr. Kerschbaum in Die Naturwissenschaften for July 3, 1914, page 654, the disadvantages of the old type of X-ray tubes are very fully described and it is pointed out that their operation depend upon positive ions caused by gas molecules by collision. He points out various disadvantages such as the variation of the hardness of the rays during a single current impulse, the vaporization of the electrodes, etc. He goes on to say:

> "All these disadvantages now appear to have been removed to a comprehensive extent in a new vacuum tube which has recently been constructed by W. D. Coolidge and now has been placed in trade by the General Electric Company. Coolidge recognized that the presence of gas was entirely responsible for the disadvantages of the formerly used X-ray tubes."

He goes on to describe the construction of the tube and the fact that a vacuum 100 to 1000 times better than that in the usual tubes is produced. After describing the functions of the hot cathode he states as follows:

> "By realizing simultaneously both of the above named conditions of construction a vacuum tube is produced in which a pure electron discharge can be initiated and maintained, a result which has not been realized by the constructions employed either by Wehnelt and Trenkle, nor by Lilienfeld and Rosenthal."

The various advantages of the Coolidge tube are fully described, and the article closes with the statement that a remarkable advance has been made in this field.

The Examiner is also respectfully referred to an article by Lewis Gregory Cole, M.D., one of the leading X-ray experts, in the Archives of the Roentgen Ray, March, 1914, entitled "Diagnostic & Therapeutic Value of the Coolidge Tube". The following paragraphs are quoted from this article:-

> "On December 27th last the author had the honour of introducing to an assembly of his American associates a man who has accomplished more for the advancement of this science than anyone except Roentgen himself.
>
> \- - - - - - - - - - - - -
>
> "He believed that if a tube could be devised which should be entirely free from gas many of the disadvantages of the ordinary tube would be removed. He introduced a cathode and anode of tungsten, supported by the sister metal molybdenum, which substances are more readily freed from gas than the metals used in the ordinary tube. In this way he was able to procure a vacuum 1,000 times more attenuated than that of the ordinary tube. Dr. Coolidge's associate, Dr. Langmuir, found that a tungsten cathode heated in a highly evacuated bulb, would emit a stream of negative electrons, and thus provided the foundation upon which Dr. Coolidge developed his subsequent work."
>
> \- - - - - - - - - - - - -
>
> "Its tremendous output, both for diagnostic and therapeutic purposes, is perhaps the most wonderful advantage of the tube, making it especially useful in the Roentgenkinematography of the stomach and heart and in radiotherapy of deep-seated cancers.
>
> The complete absence of indirect rays in the Coolidge tube is of great scientific interest and of practical value. The positive bodies in the ordinary tube are a useless and harmful by-product, and their elimination suppresses entirely both the intense heating of the tube and fluorescence of the glass walls. In the author's laboratory the tube is already being used for routine diagnostic and therapeutic work."

The various distinguishing features of the Coolidge X-ray tube have been more fully discussed with the Examiner in a personal interview and it is hoped upon reconsideration the claims will be found allowable.

Respectfully submitted,

Albert G. Davis

Attorney for Coolidge.

Schenectady, N. Y.
December 17, 1914.

sq. 4

WGC/GAL

990

Div. 215 Room 102

Address only
"The Commissioner of Patents,
Washington, D. C."
and not any official by name.

F.H.

Paper No. 5

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Jan. 12, 1915.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of
W. D. Coolidge, S. No. 766,549, filed May 9, 1913, Vacuum Tubes.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Dec. 19, 1914.

The following reference is added to the record:
Rankin, 838,273, Dec. 11, 1906, 250 - 36.

Claim 19, line 3, a comma should be inserted after "incandescence".

The word substantially should be inserted at the beginning of the last line of claim 1, as pointed out in the last Office action.

Claims 10, 11, 12 and 19 are rejected on the newly discovered patent to Rankin, which shows a vacuum discharge tube having a coil of wire surrounding the tube between the cathode and anode for focussing the cathode discharge. In regard to claim 11, which recites a "filamentary cathode", it is noted that the ordinary type of cathode shown in Rankin is the full equivalent of a filament cathode, the two being used interchangeably in vacuum discharge tubes. As clearly showing that either one or the other may be used, attention is directed to the British patent to Reiss; 2,111 of 1911, 1 sheet.

250 - 27, which shows various modifications in some of which is shown the ordinary type of cathode and one of which (Figure 5) shows a filament cathode adapted to be independently heated."

Claims 25 to 29, formerly 27 to 31, are again rejected on the reference and ground of record. As described in the note of Rollins, it is old to operate vacuum tubes by passing a current therethrough during the process of evacuating the tube. This method is held to be the same regardless of how far it is carried, that is, the method is the same whether the process is carried to the point where the anode is only partially deprived of gas or is carried to the point where the anode is completely deprived of gas. Furthermore, it is noted that this distinction which is relied upon in the argument is not brought out in the claims. However, as above indicated, the claims would not be considered allowable even if this distinction were brought out.

The remaining claims are allowed.

Wm A Kinnan
Examiner, Division XVI.

10761 C

UNITED STATES PATENT OFFICE

In re Application of :
WILLIAM D. COOLIDGE, :
Serial No. 766,549, : **VACUUM TUBE**
Filed May 9, 1913, :
Div. 16, Room 109. :

C

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of January 12, 1915, please amend the above-entitled application as follows:

Claim 1, line 2, before "tube" cancel "the" and substitute - a -; after "tube" cancel "proper"

Line 5, after "electrode" insert - substantially -

Claim 10, lines 3 and 4, cancel "controlling" and substitute - modifying -

Line 4, after "discharge" insert - upon a spot of small area on the anode -

Claim 11, line 5, after "electrodes" insert - for concentrating a discharge from said cathode upon a spot of small area on the anode -

C'

Claim 19, line 3, place a comma after "incandescence"

Cancel claims 25 to 29, inclusive, and substitute the following claims:-

C.2

Sub D4

25. The method of depriving a metal body of occluded gas which consists in subjecting the metal body to an electron discharge in an evacuated space, the generation of electrons constituting the origin of said discharge being independent of the voltage producing said discharge, and the residual gas being so attenuated that at the given voltage the gas will not conduct the discharge without the independent generation of electrons, and coincidentally removing gas evolved from said metal mass to maintain the gas pressure so low that at the given voltage a discharge will not occur without the independent generation of electrons.

26. The method of depriving a metal body of occluded gas which consists in operating the metal body as anode for a high voltage discharge originating at a cathode which generates electrons independently of the voltage producing said discharge in a vacuum too high to enable current to be passed at the given voltage without the independent generation of electrons, the energy of the discharge being sufficient to heat said metal body to incandescence, and coincidentally removing gas disengaged by said discharge.

27. The method of preparing an anode for an electrical discharge device which consists in subjecting said anode to a high voltage discharge originating at a cathode which generates electrons independently of said discharge in a vacuum so high that no energy can be passed at the voltage impressed between said electrodes without the independent generation of electrons at the cathode, removing gas liberated by said discharge, and finally sealing the envelope when the residual gas pressure is so low that the device can be operated without appreciable evidence of positive ionization.

28. The method of depriving a metal body of occluded gas which consists in passing between said body used as anode and a cathode heated to incandescence an electrical discharge in a vacuum so high that

~~with the given voltage no energy can be passed without the independent generation of electrons at the cathode, and removing from the evacuated space gas liberated from the anode by said discharge to maintain said high vacuum.~~

~~29. The method of preparing a discharge device comprising an anode of refractory material and a cathode which consists in passing a high voltage discharge between said electrodes, while the cathode is heated to incandescence, in a vacuum so high that with the given voltage no energy can be passed while the cathode is unheated, the energy input of said high voltage discharge being sufficient to heat the anode to incandescence, and removing from the evacuated space gas liberated from the anode by said discharge.~~

Add the following claim:

32. A Röntgen ray device comprising a sealed envelope, the space within which is evacuated to a pressure so low that evidences of positive ionization are substantially absent during the operation of said device, a cathode of refractory metal adapted to be heated substantially independently of a voltage impressed upon said electrodes and a cooperating anode.

Insert F3

REMARKS

cl. 33

The Rankin patent #838,273, and also the Examiner's remarks with respect to a substitution of a filamentary cathode for the cathode shown in the patent, have been carefully noted. Claims 10 and 18 rejected on this patent call for means for modifying the static field to focus a cathode discharge. Whatever may be said of this patent as a reference it certainly does not show a static focusing means. Claim 12 calls for an electrical connection between the focusing device and the independently heated cathode. This is not shown in the Rankin patent.

Claim 11 is expressed in broader language, and in connection with this claim it is pointed out that the Rankin patent shows in addition to the magnetic coil r a diaphragm n opaque to the cathode rays and pierced by a small central aperture whereby the desired small pencil of cathode rays is secured. Clearly it is not the function of the coil r to bring the rays to an actual focus on the anode else why the diaphragm? Claim 11 not only calls for a Roentgen tube and a filamentary cathode, the focusing properties of which were investigated for the first time by Dr. Coolidge the present applicant, but the claim has been amended to indicate that the focusing device actually concentrates the rays upon a spot of small area on the anode and in this manner distinguishes over the Rankin patent.

The Examiner's remarks with reference to claims 25 to 29 have been carefully noted. There appears to be one phase of the situation which the Examiner has not considered. Can a new process be considered a carrying forward of former process if the former process could not possibly be carried any further along the old lines? While gas is being eliminated from the anode by the Rollins process there must be sufficient ionisable gas in the space between the electrodes to spontaneously continue the discharge. As long as this gas is present the anode cannot be completely degasified. The difficulty is much like that of the man who tried to get rid of bugs by the aid of their natural bug enemies. We never quite got rid of bugs.

Others have attempted to get a "highest possible vacuum" in an X-ray tube, for example, in an article by Lilienfeld and Rosenthal in Vol. XVIII, page 256 of "Fortschritte auf dem Gebiete der Rontgenstrahlen" there is described a Roentgen tube which is said to be evacuated in which the metal is said to be freed from occluded gas as far as possible, but the authors themselves state that "negative electrons would serve for the transport of current and are accompanied by an equivalent number of positive charges", and state in the same publication in a later article, Vol. XXII, that "in case of overload gas is somewhat given off by electrodes and the tube temporarily loses its hardness". Whatever may have been the reasons why the authors did not secure the high vacuum at which operation without positive ionization is possible, can only be surmised, but applicant's attorney is willing to guess that one of the reasons was the fact that the electrodes still contained large amounts of occluded gases. The method of Rollins was open to them but even were a vacuum made as high as possible by this method the investigator would still have to stop at the threshold and could not enter the interesting range of high vacuum at which a discharge independent of positive ionization can be produced. This necessarily follows when the means of attaining high vacuum involves the utilization of positive ionization as is the case in the Rollins disclosure. The method set forth in present claims 25 to 29 could not be practiced by following the teaching of Rollins or any other method which involved spontaneous generation of electrons depending upon the discharge itself. It is hoped that upon reconsideration these claims as well as the rejected claims involving the focusing device will be allowed.

An additional claim has been added setting forth the novel Roentgen ray device much like the present allowed claim 1, but introducing certain different language and limitations. Its allowance with the other claims is respectfully requested.

Respectfully submitted,

Albert G. Davis

Attorney for Coolidge.

Schenectady, N. Y.
January 29, 1915.

WGG/GAL

998

DIV. 16 Room 109

Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

9-200
F.H.

Paper No. 8

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON [illegible]

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER *in charge of the application of*

W. D. Coolidge, S. No. 766,549, filed May 9, 1913, Vacuum Tubes.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Jan. 30, 1915.

Claim 29, line 6, "may" is misspelled.

Claims 10 and 18 are rejected on the newly discovered reference, Heinze, 729,166, May 26, 1903, 250 - 35. In connection with claim 10 it is noted that the unheated cathode of Heinze is the full equivalent of a heated electrode, the two types being used interchangeably as shown in the British patent to Reiss, 2,111 of 1911, 250 - 27.

Claims 11 and 12 are allowed.

Claims 25 to 29 as redrawn are not deemed good method claims since they are vague and ambiguous inasmuch as they describe conditions rather than definite steps constituting the method sought to be covered. These claims are thought to be allowable in substance, however, and it is suggested that they be recast somewhat as follows, the following being a redraft of claim 25 in a form which the examiner deems proper:

"The method of depriving a metal body of occluded

766,549 -- 2.

gas which consists in generating electrons constituting the origin of an electron discharge independently of the voltage producing the discharge in an evacuated space so attenuated that at the given voltage the gas will not conduct the discharge without the independent generation of electrons, subjecting the metal body to the electron discharge, and coincidentally removing gas evolved from said metal body to maintain the gas pressure so low that at the given voltage a discharge will not occur without the independent generation of electrons."

Claim 32 is allowed.

The remaining claims stand allowed.

Wm A Kinnan

Examiner, Division XVI.

OS

D

UNITED STATES PATENT OFFICE

In re Application of :
WILLIAM D. COOLIDGE, :
Serial No. 766,549, : **VACUUM TUBE**
Filed May 9, 1913, :
Div. 16, Room 109. :

D

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of February 9, 1915, please amend the above-entitled application as follows:-

✓ Claim 10, line 1, cancel "evacuated".

✓ Line 2, after "envelope" insert – evacuated to a pressure so low that evidences of positive ionization are substantially absent during the operation of the apparatus, –

D'

✓ Line 4, after "field" insert – in the neighborhood of the cathode –

D²

✓ Rewrite claim 18 as follows:

D³

18. An electrical discharge device comprising an envelope evacuated to a pressure so low that evidences of positive ionization are substantially absent during the operation of the device, an anode, a cathode adapted to be heated independently of a discharge passing between the same and the anode, and conductive means surrounding, in part at least, the space between cathode and anode for modifying the static field to focus a cathode discharge. B9 – Cl. 19

✓ Cancel claims 25 to 29, inclusive, and rewrite as follows:-

D4 Fr
PW Fr

25. The method of depriving a metal body of occluded gas which consists in generating electrons constituting the origin of an electrical discharge independently of the voltage producing the discharge, in an evacuated space, the residual gas in which is so attenuated that at the given voltage the gas will not conduct the discharge without the independent generation of electrons, subjecting the metal body to the electron discharge, and coincidentally removing gas evolved from said metal body to maintain the gas pressure so low that at the given voltage a discharge will not occur without the independent generation of electrons.

26. The method of depriving a metal body of gas which consists in generating electrons constituting the origin of an electric discharge independently of a voltage producing the discharge, in an evacuated space in which the residual gas pressure is so low that at a given voltage the gas will not conduct the discharge without the independent generation of electrons, subjecting the metal body to the electron discharge, the energy of the discharge being sufficient to heat said metal body to incandescence, and coincidentally removing gas disengaged by said discharge to maintain the gas pressure so low that at the given voltage a discharge will not occur without the independent generation of electrons.

27. The method of preparing a discharge device, comprising an envelope, an anode and a cathode which consists in generating electrons at the cathode independently of the voltage pro-

ducing a discharge from said cathode, the space in the envelope being evacuated so completely that no energy can be passed at a given voltage between said electrodes without the independent generation of electrons at the cathode, removing gas liberated by said discharge and finally sealing the envelope when the residual gas pressure is so low that the device can be operated without appreciable evidence of positive ionization.

28. The method of depriving a metal body of gas which consists in heating a cathode to incandescence to generate electrons, passing between said cathode and said body used as anode an electrical discharge in a vacuum so high that at the discharge voltage the residual gas will not conduct current without the independent generation of electrons at the cathode and coincidentally removing gas evolved from said metal body to maintain the gas pressure so low that at the given voltage a discharge will not occur without the independent generation of electrons.

29. The method of preparing an X-ray device comprising an envelope, an anode and a cathode, both consisting of refractory material, which consists in heating the cathode to incandescence to generate electrons, ~~and~~ passing between said cathode and anode a high voltage electrical discharge of sufficient energy to heat the anode in a vacuum so high that with the given voltage the discharge is not maintainable while the cathode is unheated, removing gas from the evacuated space liberated from the anode by said discharge and

finally sealing the envelope when the residual gas pressure is so low that the device can be operated without appreciable evidence of positive ionization.

Insert B''

Cl. 30-31

REMARKS

Claims 25 and 29 have been rewritten bearing in mind the Examiner's suggestion and it is hoped they now will be found to be in proper form.

The Heinze patent #729,166 altho it describes a device which appears to control the cathode rays by an electrical field and has even led the patentee to believe that the control was by static repulsion, actually operates on an entirely different principle. The patentee himself states (lines 13 to 21, page 2) that the funnel is very highly heated. It is evident because of this heating that there is a liberation of energy and this can only come by bombardment of the funnel with cathode rays with the accompanying production of X-rays such as takes place at the focal surface of the target. Mere electrostatic repulsion would not cause heating. As a matter of fact the funnel D acts only in the nature of a diaphragm having an aperture which receives the impact of the cathode discharge upon its walls and allows only a small pencil of rays to pass through the aperture and to strike the anode. A flat ring would have acted just as effectually, in fact, a diaphragm construction is commonly used in Braun tubes. Such a construction is shown, for example, in Rankin patent #838,273, of record in this application. Of course, in the case of a flat ring some of the X-rays generated would strike the object to be examined and thus interfere with the operation of the tube. In the case of a funnel shaped diaphragm the undesired X-rays generated on this surface are reflected back upon the cathode.

In applicant's new X-ray tube the voltage drop between the cathode and the anode is substantially uniformly distributed between the cathode and anode (except for certain space charge effects due to the geometrical relations between the focusing ring and the cathode). The velocity of the cathode rays immediately adjacent the cathode is low and, therefore, the focusing ring is very effective to change the direction of the rays. In the old style of X-ray tube operating by virtue of the ionization of the residual gas the greatest part of the voltage drop is immediately adjacent the cathode and it is at this region that the cathode rays receive most of their velocity. For this reason the shape of the cathode is so important. A static focusing ring can have practically no effect.

X-ray constructions are common in which the anode is off to one side out of line with the cathode and the rays impinge upon the so-called anti-cathode which is directly opposite. The funnel D operates functionally the same as the anti-cathode except that it has an aperture.

Claims 10 and 18 have been restricted to a device operating by pure electron conduction and it is hoped they will now be found allowable.

Respectfully submitted,

Albert G. Davis

Attorney for Coolidge.

Schenectady, N. Y.
February 20, 1915

10610AL

Div. 16 Room 109

Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

[illegible]-269

P. L.

Paper No. 10

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Mar. 10, 1915.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

W. D. Coolidge, S. No. 766,549, filed May 9, 1913, Vacuum Tubes.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Feb. 23, 1915.

The claims of this case as amended and as redrawn are deemed allowable over the prior art, but claims 25 to 30, which are drawn to a method of depriving a metal body of occluding gas, are not thought to distinguish from certain claims in a copending application to Irving Langmuir, 796,610, which is assigned to the same party as this application. See, for example, claim 10 in the Langmuir application. It is true that the claims are drawn in different language, but the examiner is of the opinion that they are directed to the same invention and that there is no line of division between the claims to this method in the two applications. All the claims to this method should, therefore, be included in one of the two applications.

Sig. 5.

Examiner, Division XVI.

UNITED STATES PATENT OFFICE

In re Application of :
WILLIAM D. COOLIDGE, :
Serial No. 766,549, : **VACUUM TUBE**
Filed May 9, 1913, :
Div. 16, Room 109 :

E

Honorable Commissioner of Patents,

Sir:

In response to the Office Action of March 10, 1915, please amend the above-entitled application as follows:-

Page 9, line 24, cancel "tubes" and substitute - X-ray devices-

Page 11, line 26, cancel "tube" and substitute - device -

Claim 4, line 5, cancel "and direct" and substitute -to control the direction of -

Claim 14, line 8, cancel "glass" and substitute - envelope -

Cancel claim 15, and rewrite as follows:

E

11

15. The combination of an X-ray device comprising an envelope and main electrodes mounted therein, a cathode adapted to be independently heated, at least in part, the space within said envelope being evacuated to so low a pressure that manifestations of positive ions are absent, a source of high potential current, connections between said source and said main electrodes, an independent source of low potential current connected to and heating the cathode, and means for adjusting the heating current to control the resistance of the X-ray device. Cl. 16-17 fol

Claim 16, line 1, cancel "tube" and substitute - device -

Line 2, cancel "the tube proper" and substitute - a tube -

Claim 21, line 4, before "current" insert - ray-producing -

Same line, before "preventing" insert - while -

Line 5, cancel "thus"

Claim 23, line 3, cancel "impressed upon the tube"

Same line, before "voltage" insert - impressed -

Claim 24, line 4, cancel "through the tube"

Claim 29, line 5, before "passing" cancel "and"

Add the following claims:

33. An electron discharge apparatus comprising a sealed envelope, a cathode adapted to be independently heated ~~independently emit electrons~~, an anode of large mass which has been deprived of gas disengageable by electron bombardment, the space within said envelope being evacuated to such low pressure that conduction of current can take place in the evacuated space independently of gas ionization.

34. The combination of an electron discharge apparatus comprising a sealed envelope, a cathode, means for independently heating said cathode, an anode of large mass free from gas disengageable by electron bombardment at high voltage, the space within said envelope being evacuated to a pressure so low that evidences of positive ionization are substantially absent during passage of current, [a source of alter-

nating current and connections between said source and the electrodes of said device.

3

Insert F.

R E M A R K S

The method claims in the copending application to Irving Langmuir, Serial No. 795,610 differ from method claims 25 to 29 in the present application by the inclusion of certain limitation, particularly the limitation that the energy of the electron discharge used for driving gas out of the anode is insufficient to appreciably heat the anode. Certain of the claims also include the specific steps of progressively raising the discharge voltage as the gas is removed. The applicant Coolidge describes a more general method of removing gas by electron bombardment at low pressure. Specifically the electrodes are heated to a high temperature while the tube is operating on the pump. When gas is removed from a massive electrode such as used in an X-ray tube, the high temperature appears to be useful in bringing gas from the interior of the electrode to the surface, but when the anode consists of a fine wire such as in the Langmuir discharge device it has been found that the electron bombardment is sufficient to remove the gas even if not sufficient in energy to visibly heat the metal. The step by step increase in voltage is also useful, particularly when working with the delicate relaying and amplifying devices described in the Langmuir application. In one aspect, the process claims of the Langmuir application cover refinements of the method and the claims could not be made in the Coolidge application.

The present new claims added to the application are similar to claims already allowed except that they are not limited in terms to an X-ray device.

An allowance is respectfully requested.

Respectfully submitted

Albert G. Davis

Attorney for Coolidge

Schenectady, N. Y.
March 26 1915.

WOG/CAL

1010

Div. 16 Room 109

Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

2-260

J. E. R.

Paper No. 12

All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON Apr. 3, 1915.

Mr. A. G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER *in charge of the application of*

W. D. Coolidge, S. No. 766,549, filed May 9, 1913,
Vacuum Tubes.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Mar. 30, 1915.

Applicant's remarks in connection with the line of division between this application and the copending application to Irving Langmuir, serial number 795,610, in which it is stated that the process claims in the copending application have "the limitation that the energy of the electron discharge used for driving the gas out of the anode is insufficient to appreciably heat the anode" have been carefully considered. It is noted, however, that claims 2 and 4 in the copending application do not contain the limitation referred to. It is true they contain the limitation to the effect that the discharge voltage is progressively raised as the gas is removed, but this feature is old in the art, as shown by the references of record in the two cases, and does not make the two claims patentably distinguished from the process claims in this application.

The requirement to maintain a clear line of division between the process claims in the two applications is therefore repeated. It is suggested that this be done either by canceling or amending claims 2 and 4 in the copending application.

It is further noted that claims 33 and 34, submitted in the last amendment, are substantially identical in scope with certain claims in said copending application, 795,610. See, for example, claims 8 and 16 in the copending application. Applicants have apparently elected to place the broad apparatus claims in the copending application. Attention is directed to the fact that there is apparently an inconsistency in placing the broad method claims in this application and the broad apparatus claims in the said copending application. Claims 33 and 34 are allowable in substance but, as above explained, they destroy the line of division between the apparatus claims in the two cases.

New claim 15 is allowed.

Wm A Kinnan

Examiner, Division XVI.

QAS

1012

PAPER NO. 13
AMENDMENT F
10

UNITED STATES PATENT OFFICE

In re Application of :
WILLIAM D. COOLIDGE, :
Serial No. 766,549, : VACUUM TUBE
Filed May 9, 1913. :
Div. 16, Room 100. :

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of April 3, 1916, please amend the above-entitled application as follows:-

Page 3, line 13, cancel "in this direction"

Page 6, line 29, after "anode 3" insert - which in this case is plate-shaped. It is -

Page 8, line 26, after "gas" insert - particularly the anode which is of large mass relative to the cathode -

Page 9, line 4, after the sentence ending with "filament" insert - When the source 22 furnishes alternating current, as for example, a transformer or an induction coil, only half waves of current are transmitted by the device. -

F'

Claim 25, line 4, place a comma after "discharge"

Line 5, place a comma after "discharge"

Claim 27, line 5, place a comma after "cathode"

Claim 30, line 1, before "device" cancel "a and insert - an X-ray -

Line 6, before "impressing" cancel "and"

Line 10, after "voltage" change the period to a comma and insert - and increasing or decreasing the penetrating power of the X-rays by e-respectively increasing or decreasing the impressed voltage. -

Claim 33, lines 2 and 3, cancel "independently emit electrons" and insert - be independently heated -

Line 3, after "anode" insert - of large mass -

Claim 34, line 4, after "anode" insert - of large mass -

Line 5, after "bombardment" insert - at high voltage -

Add the following claims:

J3

~~36. An electrical discharge device comprising a sealed envelope, a cathode adapted to be independently heated, and a plate-shaped anode, said device being substantially deprived of gas disengagable by electron bombardment at high impressed voltage, and conducting energy by an electron discharge operatively independent of positive ionization.~~

Per G

38 ~~36.~~ An X-ray tube comprising a sealed envelope, a cathode adapted to be heated independently of a discharge transmitted by said device, an anode and a dished focusing member surrounding the cathode having its concave side facing the anode, said tube being exhausted of gas to a pressure so low that evidences of positive ionization are substantially absent during operation.

REMARKS.

It is believed that the proper lines of division have now been drawn between this application and that of Langmuir application, Serial No. 795,610.

The broad invention of a device transmitting energy operatively independent of positive ionization belongs to Dr. Langmuir as not all pure electron discharge devices are necessarily dependent for their evacuation on the method of depriving a metal body of gas covered by claims 25 to 29 of the present case. This method is particularly applicable to the preparation of a tube having a plate-shaped or massive anode not adapted to be heated by passage of current. Dr. Coolidge, the present applicant, however, is the inventor of an x-ray tube operating by pure electron conduction.

An allowance is respectfully requested.

Respectfully submitted,

March 14, 1916

Albert G. Davis

ATTORNEY FOR LANGMUIR.

1015

Div. 16 Room 109
Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

Paper No. 14
All communications respecting this application should give the serial number, date of filing, title of invention, and name of the applicant.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE
WASHINGTON Apr. 7, 1916.

Mr. Albert G. Davis,
C/o General Electric Co.,
Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of the application of

W. D. Coolidge, S. No. 766,549, filed May 9, 1913,
Vacuum Tubes.

Thomas Ewing
Commissioner of Patents.

This action is in response to amendment filed Mar. 14, 1916.

Claims 33, 34 and 35 are rejected upon the subject-matter of claim 14 in the allowed application to Langmuir, serial number 84,242, belonging to the same party as the present application. It is noted that applicant points out that certain of his claims specify a plate-shaped anode. This is a well-known feature of the prior art and is disclosed in the Langmuir application as well.

The remaining claims appear to be allowable.

Wm. A. Kinnan
Examiner, Division XVI.

1016

G

IN THE UNITED STATES PATENT OFFICE.

In re application of
William D. Coolidge,
Serial No. 746,549,
Filed May 8, 1913.
Div. No. 16, Room 109.

VACUUM TUBE.

Hon. Commissioner of Patents,

S i r:-

In response to the Office Action of April 7, 1916, please this case as follows:

✓ After the paragraph ending with "ring" line 25, insert the following paragraph:

¶Certain broad aspects of the apparatus and methods herein disclosed are not of my invention but are the invention of Irving Langmuir and are defined by the claims of his allowed application, Serial No. 84,242, renewed March 14, 1916, and his application Serial No. 876,[illegible], filed December 10, 1914. -

✓ Cancel claims 33, 34 and 35.

Respectfully submitted,

Albert G. Davis

Attorney for Coolidge.

Schenectady, N.Y.

Apr. 10 1916.

ADDRESS ONLY
THE COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

9—181

AH

Serial No. 766,549

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE

WASHINGTON Apr, 18, 1916

William D. Coolidge Assor.,

Sir: Your APPLICATICN for a patent for an IMPROVEMENT in
Vacuum Tubes
filed May, 9, 1903, has been examined and ALLOWED.

The final fee, TWENTY DOLLARS, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent on this application will be withheld, unless renewed with an additional fee of $15, under the provisions of Section 4897, Revised Statutes.

The office delivers patents upon the day of their date, and on which their term begins to run. The printing, photolithographing, and engrossing of the several patent parts, preparatory to final signing and sealing, will require about four weeks, and such work will not be undertaken until after payment of the necessary fee.

When you send the final fee you will also send, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If you desire to have the patent issue to ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of final fee.

After issue of the patent uncertified copies of the drawings and specifications may be purchased at the price of FIVE CENTS EACH. The money should accompany the order. Postage stamps will not be received.

Final fees will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

Respectfully,

Thomas Ewing
Commissioner of Patents.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

Albert G. Davis
C/o Gen'l Electric Co.,
Schenectady N. Y.

2—884

DEPARTMENT OF THE INTERIOR

UNITED STATES PATENT OFFICE

WASHINGTON, D. C.

Oct 20 1916

In compliance with the provisions of order No. 1718, dated June 8, 1907, and which reads as follows:

It is hereby ordered that, except by formal amendment duly signed or as hereinafter provided, no corrections, erasures, or interlineations be made in the body or written portions of the specification or of any other paper filed in an application for patent.

Obvious informalities in the wording of the specification may be corrected by the examiner, but said correction must be in the form of an amendment, approved by the Principal Examiner in writing, placed in the file, and made a part of the record. The changes specified in the amendment will be entered by the clerk in the regular way.

It is directed that no other changes be made by any person in any record of this office without the written approval of the Commissioner of Patents.

Attorneys, employees of the Patent Office, and all others will be held to strict accountability for any violation of this order.

The following changes are made in—

Application Serial No. 766.549

of W. D. Coolidge

✓ Page 11, line 21 after "equally" insert "as"

wak

Examiner, Division

2

REG'D OCT 1916 C.C. U.S. PAT. OFFICE

3—397.

MEMORANDUM

OF

FEE PAID AT UNITED STATES PATENT OFFICE.

(Be careful to give correct Serial No.)

Serial No. 766549 , 191

INVENTOR: William D. Coolidge

PATENT TO BE ISSUED TO General Electric Company

NAME OF INVENTION, AS ALLOWED: Vacuum Tubes

DATE OF PAYMENT: October 5. 1916.

FEE: $20.00 (final)

DATE OF FILING: May 9. 1913

DATE OF CIRCULAR OF ALLOWANCE: April 18 1916

The Commissioner of Patents will please apply the accompanying fee as indicated above.

Albert G. Davis
Attorney.

SEND PATENT TO Albert G. Davis
General Electric Company
Schenectady, New York

3—396

United States District Court

17 Southern DISTRICT OF New York

HONORABLE COMMISSIONER OF PATENTS,
Washington, D. C.

SIR:

In compliance with the Act of February 18, 1922 (42 Stat. L. ______), you are advised that there was filed on the 13th day of October 1921, 192~~1~~, in this court an action, suit, or proceeding No. E22-194 entitled:

Name Victor X-Ray Corporation and General Electric Company Plaintiff,
Address 131 East 23rd St. New York, N.Y. Schenectady N.Y.

versus

Name Vitrode X-Ray Tube Company Incorporated Defendant,
Address 33 West 46th St. New York N.Y.

brought upon the following patents:

	PATENT NO.	DATE OF PATENT	PATENTEE
1	1203495	Oct. 31, 1916	General Electric Company
2	1211091	Jan 2 1917	" " "
3	1326029	Dec 23 1919	" " "
4			
5			

In the above-entitled case, on the ______ day of ______ 192 , the following patents have been included by ______ (insert amendment, answer, cross bill, or other pleading):

	PATENT NO.	DATE OF PATENT	PATENTEE
1			
2			
3			
4			
5			

In the above-entitled case the following decision has been rendered or decree issued:

Decree sustaining patents, adjudging that defendant has infringed upon said patents and perpetually enjoining defendants

In witness whereof I have affixed my hand this 20th day of March, 1923, at New York N.Y.

Alex Gilchrist Jr.
Clerk of said Court

W. D. COOLIDGE.
VACUUM TUBE.
APPLICATION FILED MAY 9, 1913.

1,203,495. Patented Oct. 31, 1916.

Fig. 1.

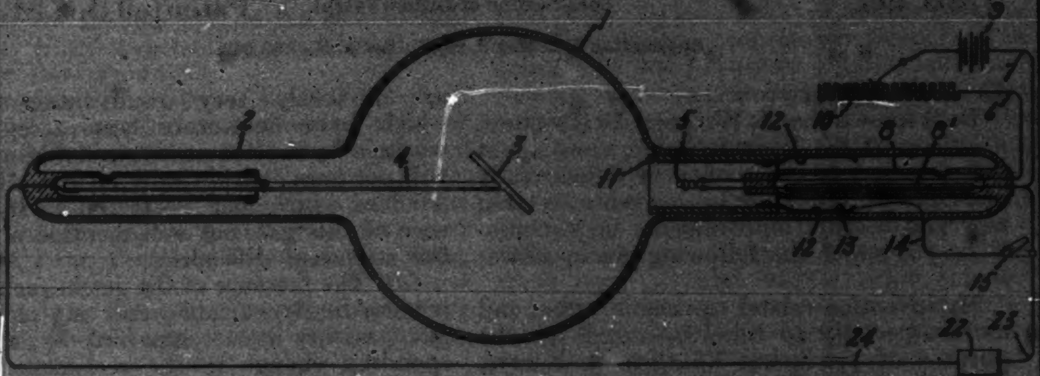

1
2
3
4
5
6
7
8
8'
9
10
11
12
12
13
14
15
22
23
24

Fig. 2.

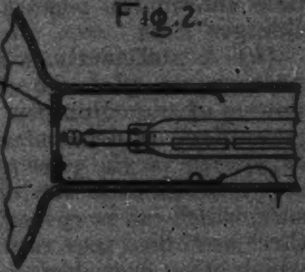


Fig. 5.

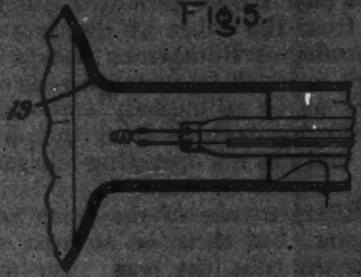


Fig. 3.

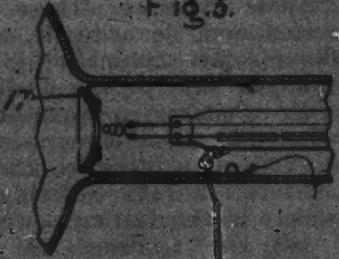


Fig. 6.

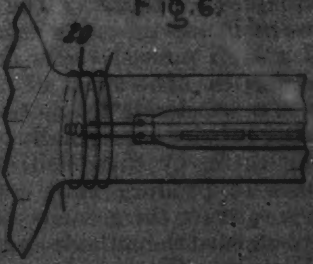


Fig. 4.

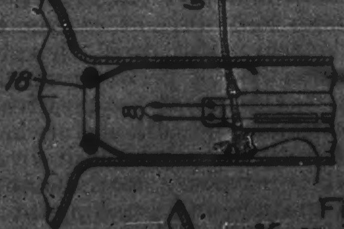


Fig. 7.

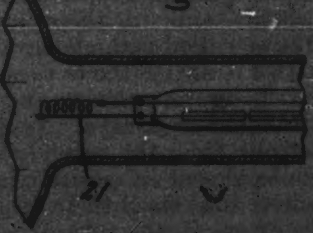
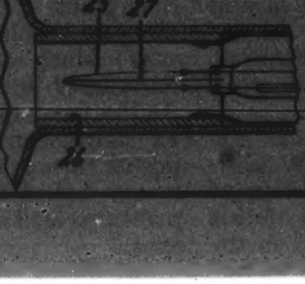


Fig. 8.



Witnesses
Chas. H. B. [illegible]
J. Ellis Glen

Inventor
William D. Coolidge
by Albert G. Davis
His Attorney

= Apr. 14, 1916.

UNITED STATES PATENT OFFICE.

WILLIAM D. COOLIDGE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

VACUUM-TUBE.

1,203,495. Specification of Letters Patent. Patented Oct. 31, 1916.

Application filed May 9, 1913. Serial No. 766,549.

To all whom it may concern:

Be it known that I, WILLIAM D. COOLIDGE, a citizen of the United States, residing at Schenectady, in the county of Schenectady and State of New York, have invented certain new and useful Improvements in Vacuum-Tubes, of which the following is a specification.

My invention relates to vacuum tubes and more especially to tubes operated for the purpose of producing Röntgen or X-rays. The tube which I have produced differs so radically from the tubes of the prior art used for producing Röntgen or X-rays as to amount not so much to an improvement on prior tubes as to an entirely new variety of tube differing both in its principles of operation and in its operating characteristics.

In the Röntgen tube of the prior art, it was necessary that there be at least some free gas in the tube, the reason for which may be explained as follows: The number of ions present in the tube was exceedingly small until a high potential was impressed upon its terminals. The effect of this high potential was to accelerate the motion of the small number of ions originally present, thus causing them, by their collision with gas molecules to produce more ions, and, further, to so attract the positive ions that they would bombard the cathode and so cause it to emit electrons. These electrons, directed by the electric forces in the tube, move toward the anti-cathode and in their movement constitute the so-called cathode rays. Upon colliding with the anti-cathode these undergo a sudden change in velocity and so give rise to the Röntgen or X-rays. As the emission of electrons from the cathode was due solely to bombardment by positive ions, and as these positive ions owed their existence to the presence of gas in the tube, it is seen at once that the X-ray tube of the prior art was absolutely dependent for operativeness upon a proper amount of gas. Without the presence of sufficient gas to permit a discharge to take place between the electrodes the cathode would not be bombarded by positive ions and so no resulting production of X-rays would occur. The presence of this gas, heretofore considered a necessity in the operation of such a tube, gave rise to certain features of operation of the tube which are obviously very disadvantageous but which have heretofore been accepted by workers in the art as unavoidable evils. I will not here attempt to point out all of the troubles which may be traced to the presence of this gas, but will mention a few of the attendant difficulties.

(*a*) The pressure of the gas in such a tube is exceedingly variable, and any change in gas pressure is accompanied by a corresponding change in the resistance of the tube and in the penetrating power of the Röntgen rays.

(*b*) A sufficiently exact adjustment of pressure, to give the desired penetrating power of the Röntgen rays, calls for a great deal of manipulative skill and long experience on the part of the operator.

(*c*) Besides the slow changes in gas pressure, which can be corrected by the operator, there are other very rapid pressure changes which go on even during a very short radiographic exposure. These cannot be corrected and, as a result, the exposure or fluoroscopic examination is made, not with Röntgen rays of the quality desired, but with whatever approximation to that is allowed by the idiosyncrasies of the particular tube in question, in other words, with a mixture of rays differing perhaps very widely in penetrating power.

(*d*) The tendency to undergo rapid changes in gas pressure increases with use, until finally the tubes of the prior art show such instability of vacuum that they are no longer useful, even though they may be otherwise in perfect condition.

(*e*) Many of the positive ions instead of striking the cathode, strike the glass constituting the tube wall around it, and, by their excessive local heating, cause disintegration and cracking of the envelop at this point. This imposes a limitation on the permissible energy input in such a tube.

(*f*) Many tubes of the prior art show variability in the location of the focal spot. As the focal spot is the source of the X-ray, its movement during a radiographic exposure, means a blurring of the picture. It is my belief that sudden changes in gas pressure lead to movements of the focal spot.

(*g*) Some of the electrons coming from the cathode are impeded in their passage to the target by impact with intervening gas molecules and so do not have, upon reaching the target, the same velocity as those electrons which have passed through the entire potential drop from cathode to target without meeting an obstruction. The higher the gas pressure in the tube the greater will be the influence of this effect and, consequently the greater will be the lack of uniformity in the penetrating power of the resulting Röntgen rays.

(*h*) There is a strong bombardment of the glass, constituting the entire anterior hemisphere, of such a tube, by secondary cathode rays emitted from the anticathode. This causes excessive local heating of the glass and a vigorous emission of secondary X-rays from the bombarded glass. These secondary rays, unless prevented by the use of a proper diaphragm, cause a blurring effect in the radiograph and on the fluorescent screen.

(*i*) Any electromotive force in the source of current supply for such a tube, in a direction which would make the target function as cathode, must be carefully suppressed, as it otherwise leads to changes in gas pressure.

In order to overcome these troubles met with in the X-ray tubes of the prior art, I remove the cause of the trouble, namely, the gas in the tube, and produce the electrons from the cathode necessary to the production of the X-rays, not by a bombardment of the cathode by positive ions due to ionization of the gas by the voltage impressed upon the tube, but by heating the cathode to incandescence by energy from a suitable source. In tubes made according to my invention I eliminate the action of positive ions as far as it is possible to do so by evacuating the tube to the highest vacuum which can possibly be attained and by thoroughly freeing the electrodes from gas. In the tube of the prior art the pressure of gas was quite appreciable and varied from say one to ten microns (0.001 to 0.010 millimeters) of mercury. With a tube made according to my invention, the tube proper and the electrodes being thoroughly freed from gas as hereinafter described, the pressure of gas may be say five hundredths of a micron (0.00005 millimeter) or lower and in any event lower than that at which the tube would operate as an ordinary Röntgen ray tube. The upper limit of pressure may therefore be placed roughly at say about 0.6 of a micron or thereabout. With such a vacuum in a tube of the prior art so far as I am aware no current whatever would pass in the tube and no X-rays would be produced.

As a cathode I ordinarily use a tungsten filament and this may be conveniently heated by current from a storage battery or transformer with suitable regulating devices so that the temperature of the cathode or filament may be adjusted at will. I have found that electrons will be emitted from such a cathode, which electrons will traverse the space between the cathode and the target under the influence of the electromotive force impressed upon the tube, and by bombardment of the target, will give rise to X-rays. In this new type of tube positive ions appear to play no rôle whatsoever. The excessively low gas pressure must make their number exceedingly small. The fact that they do not play an appreciable rôle at the cathode is experimentally shown by the fact that the temperature of the heated cathode is not measurably raised by passing heavy discharges through the tube. In the same tube, with gas pressures approximating those used in tubes of the prior art, the tungsten filament, functioning as cathode, is raised by these same discharges from room temperature to extreme incandescence, and may even be melted by the bombardment of the positive ions.

Gas pressure in the tube being thus eliminated to the highest possible degree, those features of instability in the tubes of the prior art which it can now be seen were due to the presence of the gas in the tube are likewise eliminated. Furthermore, by static or electromagnetic means I cause the cathode rays or electrons to be focused on the anode or target and this focusing effect is steady and unwavering.

A tube made in accordance with my invention differs from the tubes of the prior art in the possession of most remarkable characteristics. Thus there are no marked changes in the operation of the tube during a considerable length of time, with the result that X-rays may be constantly generated of a much more uniform degree of penetrating power and much more constant in volume and in the location of their source or focal spot. The penetrability or in other words the "hardness" or "softness" of the X-rays may be adjusted at will by adjusting the temperature of the cathode. There is practically no fluorescence of the glass of the tube and this is important because it indicates that the glass is not bombarded by secondary cathode rays emanating from the target or anode and is therefore not being locally heated thereby. There is only a more or less negligible production of the secondary X-rays from the glass which form such a useless and disturbing factor in the ordinary Röntgen tube. The voltage consumed by the tube may in certain forms of embodiment of my invention be made to remain more or less constant even though the voltage of the source of current supply varies. The focusing effect is steady and the sharpness of definition of the X-ray photographs is increased. These and other features and advantages of my invention will be better understood by reference to the following description taken in connection with the accompanying drawings. The features of novelty I have endeavored to point out in the appended claims.

In the accompanying drawings, Figure 1 is a sectional view of a complete tube equipped with one type of focusing device; Figs. 2 to 7 illustrate alternative forms of focusing devices, and Fig. 8 illustrates a modified tube having a constant voltage characteristic.

Referring to Fig. 1, showing one embodiment of my invention, the tube or envelop is indicated at 1, consisting as usual of glass, or other transparent material. In the tubular end 2 is sealed an anode 3 which in this case is plate-shaped. It is supported by a stem 4, both anode and stem consisting, preferably, of wrought tungsten. Opposite this anode, which serves also as target, is a cathode 5 adapted to be heated, in this case a filamentary spiral of tungsten, tantalum, carbon or other highly refractory material. In this case the filament is wound non-inductively, though this is not essential. It is connected to leading-in wires 6, 7, sealed into a glass support 8, the wires being insulated from each other by little glass tubes 8′ as clearly shown. The wires 6, 7 are connected to a source of current, such as a battery 9, or to a transformer, through a regulatable resistance 10. The battery, or transformer secondary, should be well insulated owing to the high potential used in operating the tube. Around the cathode proper is a hollow cylinder 11 consisting of tungsten, aluminum, iron, or other suitable conductive material held in position by springs 12, one of which engages with a little knob 13 on the glass. This cylinder or tube is preferably electrically connected to the cathode by means of wire 14, either inside the tube or brought outside of the tube as shown, and containing in circuit a switch 15. In normal operation the cylinder 11 performs the important function of modifying the static field to focus the cathode discharge, as will be explained.

Instead of being tubular the focusing device may assume various other shapes. It may be a perforated flat disk, as shown at 16, Fig. 2, or a perforated dished or concave disk 17, Fig. 3, or even a simple ring 18, Fig. 4. In fact, even a metallic deposit, such as a film of chemically deposited silver, on the walls of the globe, as shown in Fig. 5 at 19, will act as a static focusing means.

Magnetic focusing means may be used, instead of the static focusing devices, and as shown in Figs. 6 and 7. The magnetic focusing means may take the form of a solenoid, either inside the tube similarly to the static focusing ring, or outside the walls of the tube in the vicinity of the cathode, as diagrammatically indicated in Fig. 6, at 20, or the cathode itself is wound inductively, as shown by cathode 21 in Fig. 7.

In the preparation of the tube the glass is first freed from moisture and gas by heating and other approved methods and the electrodes preferably are freed from gas as by heating them to a high temperature in a vacuum. Exhaustion of the tube is preferably carried on by means of a pump which will remove vapors as well as gases, such as the Gaede molecular pump. For the removal of the last portions of gas from the electrodes and from the glass, the tube is operated on the pump. The electrodes should be made of refractory metal such as tungsten so that they will withstand the very high temperatures attainable by operating the tube while connected to the pump, whereby gas may be effectively driven out. In case the usual constriction in the exhaust tube is employed, pumping is thereby greatly delayed. In some cases much time can be saved by omitting the constriction until the tube has been exhausted to the point where the operation is satisfactory. Carefully dried air can then be admitted and the constriction put in. Upon exhaustion of the dry air it will be found that the condition of the tube, even without further running on the pump, is essentially what it was before air was admitted.

When the electrodes have been sufficiently freed from gas particularly the anode which is of large mass relative to the cathode and the tube has been exhausted to a vacuum of about .0[illegible] microns (0.00005 millimeters of mercury) or lower it is sealed off from the pump. It may be operated, in accordance with my invention, by closing the battery circuit through the resistance 10 so as to heat the filament 5 to incandescence. When a sufficiently elevated temperature has been reached, electrons are emitted by the filament. When a sufficient potential is applied across the tube by completing connection to a suitable source 22, through conductors 23 and 24, current is transmitted, provided the negative terminal of the source is connected to the filament. When the source 22 furnishes alternating current, as for example, a transformer or an induction coil, only half waves of current are transmitted by the device. The electrons soon charge the hollow cylinder 11 to a negative potential with respect to the cathode unless the cylinder and cathode are connected. Whether connected or not, the cylinder so modifies the nature of the static field within the tube that the electrons are directed upon a spot of small area upon the anode 3.

In my opinion the focusing action is caused by the electrons tending to move perpendicularly to the equipotential surfaces which may be drawn in the space between cathode and anode. This manner of focusing the cathode discharge is especially effective as the speed of the electrons is relatively low near the cathode and therefore their movement is easily directed by the focusing devices. The focal spot on the anode remains fixed during the normal operation of the tube. This is in sharp contrast to the operation of the ordinary Röntgen tube in which the focal spot often moved about so rapidly as to produce blurring of all lines not parallel to the direction of motion, even during very short radiographic exposures.

The operation of X-ray devices made in accordance with my invention is markedly affected by the temperature to which the cathode is raised. If the temperature of the filament is low only a small number of electrons escape, and therefore the saturation current through the tube is relatively small. Increasing the impressed voltage on the tube will cause substantially no further increase in current. It will increase the velocity of the cathode rays and hence the penetrating power of the Röntgen rays. If the filament temperature on the other hand is very high, further increase of temperature produces no appreciable effect on the tube characteristics, more electrons being emitted by the filament than can be carried, by the voltages employed, from one electrode to the other. At higher filament temperatures, the space relations of the elements of the tube such as the distance between cathode and anode, the location of the focusing means relative to the cathode, the diameter of the opening in the focusing device, etc. constitutes a current limiting factor, as will be later explained. Except for these limiting cases, an increase in impressed voltage will in general cause an increase in discharge current and in the potential drop in the tube, thus increasing the penetrability of the X-ray. However, by giving the cathode its main extension in the direction of the axis of the tube, and also suitably proportioning and locating the focusing device, a most important new characteristic may be attained. Such a construction is shown in Fig. 8 in which a filament 25 extends nearly through the whole length of tube 26, being anchored at its tip by a support 27. With a low impressed voltage, only that part of the filament 25 nearest the anode will furnish the electrons necessary to carry the discharge current. With higher impressed voltages, a progressively greater part of the filament will contribute electrons. The increase in the number of electrons thus rendered available by the increase of impressed voltage and the accompanying change in distribution in the static field, tends to reduce the tube resistance and thus counteract the tendency of the higher impressed voltage to increase the potential drop through the tube. A tube thus constructed, therefore, exhibits within certain limits an important new characteristic of operating with a substantially constant potential drop over a range of variable impressed voltage. The advantages of this new characteristic of the tube are manifold. A most important advantage is gained in the homogeneity of the X-rays obtained when the tube is operated from a current source, in which the voltage varies periodically, as, for example, when a transformer, induction coil or a rectifying device such as a mechanical selector, are used which gives current impulses of variable voltage.

My novel apparatus, therefore, has the following valuable and striking characteristics. First, the resistance of the tube, and, hence the penetrating power of the Röntgen rays produced in the tube, may be controlled with certainty, and may be instantly increased or decreased at will, by raising or lowering of the temperature of the cathode; second, a much more homogeneous bundle of X-rays can be produced even though a several-fold increase, or decrease of gas pressure takes place in the tube, providing the pressure remains within the limits above indicated; third, as the discharge can pass through the tube only when the heated electrode is made the cathode, the tube may be operated on alternating current almost equally as well as on direct current; fourth, if desired, a tube may be proportioned to give over a predetermined range of impressed voltage X-rays of substantially uniform penetration.

The operator is thus enabled to determine, with a properly calibrated device, from a curve, or chart, just what current values and voltages he needs for a given purpose, and may be sure that when he has prepared his patient he can get exactly the service he requires from his tube without troublesome and dangerous experimentation.

One of the main causes for the uniformity of the penetrability of the X-rays is to be ascribed to the fact that the operation of the tube is not dependent upon positive ion bombardment of the cathode. Another cause is its complete independence of vacuum changes within the permissible range of pressure. It will also be noted that with the high vacuum existing in the tube, the mean free path between gas molecules is much greater than the distance between anode and cathode and, therefore, very few electrons can collide with gas molecules in passing from cathode to anode, therefore, practically all of the electrons reach the target with uniform velocity. Because of the low gas pressure the number of positive ions is so small that the filament is not heated at all by bombardment. Even when a very heavy discharge current is sent through the tube, a voltmeter and ammeter in the filament circuit indicate no change in the resistance and hence the temperature of the filament. Another observation, which has a similar significance, is that at low filament temperatures, where the electrons emitted by the cathode are all used in carrying current, a several-fold increase in voltage brings substantially no accompanying increase in the discharge current. This could hardly pertain, in case positive ions played an appreciable rôle, for increased voltage would mean higher velocities, and hence, a greater emission of electrons which, in turn, would mean an increase in the discharge current.

The wall of the tube exposed to the anode is not heated by secondary cathode rays from the anode, thereby removing the limitation formerly imposed by local tube heating. Tube fluorescence due to secondary cathode rays is likewise absent. Not only are current carrying limitations thus removed but it should also be noted that a marked gain of efficiency is secured in the tube. For example, in the former type of tube with a platinum target, about three-fourths as many electrons left the target as "secondary cathode rays" as were received by it in the form of primary cathode rays. The elimination of secondary cathode rays also greatly improves the tube as the secondary X-rays produced by the secondary cathode rays striking the tube were a serious disturbing factor as already mentioned.

While I have described and illustrated specific forms of tubes embodying my invention, I wish it to be understood that various changes and modifications may be made in the tube within the scope of my invention. As already indicated the spacial relations of the elements of the tube affect its characteristics. For example, increasing the distance between the front of the focusing device and the incandescent cathode increases the resistance of the tube; decreasing the opening in the static focusing ring or tube increases the resistance of the tube. Decreasing the distance between cathode and anode lowers the resistance of the tube, but this effect is probably not to be ascribed to any considerable resistance change due to linear separation of the electrodes but to the fact that the glass walls of the tube are charged negatively during operation and thus act as though they represented an extension of the focusing device. Bringing the cathode nearer to the anode therefore, would have an effect similar to that caused by bringing it nearer to the front of the focusing tube or ring.

Certain broad aspects of the apparatus and methods herein disclosed are not of my invention but are the invention of Irving Langmuir and are defined by the claims of his allowed application, Serial No. 84,242, renewed March 14, 1916, and his application, Serial No. 876,432, filed December 10, 1914.

What I desire to secure by Letters Patent of the United States, is:—

1. In a device for the production of X-rays, the combination of a tube provided with electrodes, the vacuum in the tube being so attenuated as practically to eliminate the production of positive ions, and means for generating electrons at the cathode or negative electrode substantially independently of the voltage impressed upon said electrodes.

2. An X-ray device comprising a gas-tight envelop, the space within said envelop being exhausted to a pressure at which substantially no gas ionization occurs, a cathode, an anode, and means for generating electrons at the cathode, the current transmitted by said device with a given cathode temperature being independent of the voltage over a range of impressed voltage values.

3. An electrical vacuum discharge tube, comprising an envelop, coöperating electrodes, at least part of one of which is adapted to be maintained at incandescence, the vacuum within said envelop being so high that evidences of positive ionization are substantially absent during operation and means for focusing the discharge.

4. An electrical vacuum discharge tube, comprising an envelop, coöperating electrodes therein, one of which is adapted to be independently heated, and a conducting body surrounding said cathode, said body serving to modify electrostatic forces in the tube, to control the direction of the cathode rays, the residual gas in said envelop being insufficient to produce appreciable ionization by collision during the operation of the tube.

5. An X-ray device comprising electrodes consisting of tungsten freed thoroughly from gas, the negative electrode being adapted to be independently heated, at least in part, and an inclosing envelop so highly evacuated that evidences of positive ionization are substantially absent during the operation of the device.

6. An electrical discharge device comprising an envelop, the space within said envelop being evacuated to a pressure below the value at which appreciable positive ionization can occur, electrodes therefor, the cathode being adapted to be heated independently of energy transmitted by said device and conductive means in part at least surrounding the space between said electrodes to control electrostatic forces in the tube.

7. An electrical discharge device compris-

ing an evacuated envelop the residual gas in which is insufficient to conduct current between ordinary unheated electrodes, a cathode adapted to be independently heated, an anode from which gas is not disengageable during the operation of the device, and means near the cathode for maintaining a static field focusing a cathode discharge upon the anode.

8. A Röntgen ray tube, comprising an envelop evacuated to a pressure of less than about .6 micron, a cathode therein adapted to be heated independently of the operating current, a coöperating anode and means for focusing the cathode discharge upon the anode.

9. A Röntgen ray device comprising the combination of an envelop evacuated to a pressure at which positive ionization is substantially absent during the operation of the device, an electron-emitting cathode, an anode and a source of energy connected to said electrodes having a voltage in excess of the minimum value at which the current is substantially independent of the voltage.

10. A Röntgen apparatus comprising an envelop evacuated to a pressure so low that evidences of positive ionization are substantially absent during the operation of the apparatus, electrodes therein, external means for independently heating the negative electrode, and means for modifying the static field in the neighborhood of the cathode to focus the cathode discharge upon a spot of small area on the anode.

11. A Röntgen tube comprising an evacuated envelop, main working electrodes therefor, one of which is of filamentary character, means for heating said filamentary electrode, and an electrical conductor at least in part surrounding the space between said electrodes for concentrating a discharge from said cathode upon a spot of small area on the anode.

12. A Röntgen ray tube comprising an evacuated envelop, electrodes therein, the cathode being arranged to be heated independently, and a focusing device surrounding and electrically connected with said independently heated cathode.

13. The combination of a source of current alternating in potential, and a Röntgen-ray tube operatively connected therewith comprising coöperating electrodes at least part of one of which is adapted to independently generate electrons, and an envelop therefor evacuated to such high degree that manifestations of positive ions are absent.

14. A Röntgen ray tube comprising an envelop, coöperating electrodes therein, at least part of one of which may be independently heated to emit electrons, the space in said envelop being so highly evacuated that manifestations of positive ions are absent, means for producing a cathode discharge in said tube and means for controlling the static field in said tube to prevent electrons from striking the envelop.

15. The combination of an X-ray device comprising an envelop and main electrodes mounted therein, a cathode adapted to be independently heated, at least in part, the space within said envelop being evacuated to so low a pressure that manifestations of positive ions are absent, a source of high potential current, connections between said source and said main electrodes, an independent source of low potential current connected to and heating the cathode, and means for adjusting the heating current to control the resistance of the X-ray device.

16. In a device for the production of Röntgen rays, the combination of a tube evacuated to such a degree that practically no current can pass due to ionizing action of the impressed voltage upon such gases as may remain in the tube, positive and negative electrodes in the tube provided with suitable leading-in conductors, and means for heating the cathode to a high temperature, said means being independent of the impressed voltage.

17. An electrical vacuum tube, comprising an envelop the space in which is exhausted to below the pressure at which residual gas will conduct current, a cathode adapted to be heated to incandescence, a coöperating anode substantially deprived of gas evoluble by electron bombardment, and means disposed about an axis passing through cathode and anode for directing the cathode discharge.

18. An electrical discharge device comprising an envelop evacuated to a pressure so low that evidences of positive ionization are substantially absent during the operation of the device, an anode, a cathode adapted to be heated independently of a discharge passing between the same and the anode, and conductive means surrounding, in part at least, the space between cathode and anode for modifying the static field to focus cathode discharge.

19. The method of producing Röntgen rays which consists in independently heating the cathode to incandescence, producing an electric discharge between the incandescent cathode and a coöperating anode in a vacuum so highly attenuated that evidences of positive ionization are substantially absent during the passage of current, and focusing the cathode rays by means of an electrical field.

20. The method of regulating the penetrability of Röntgen rays produced by a discharge from an incandescent cathode in a vacuum so attenuated that electrical conductivity of the residual gas is substantially absent, which consists in adjusting the cathode temperature and impressed voltage.

21. The process of producing Röntgen rays by current from a source alternating in potential which consists in emitting electrons at a negative electrode, transmitting thereby a ray-producing current wave of one polarity, while preventing at the same time the formation of positive ions, and suppressing the other half wave of the alternating current.

22. The process of producing X-rays which consists in impressing an alternating electromotive force upon electrodes of an X-ray tube and causing electrons to be emitted from one electrode only while preventing any accompanying manifestations of positive ions, and projecting said electrons upon a target surface, whereby one-half wave of an alternating current is utilized and the opposite half wave suppressed.

23. The method of operating a tube for the production of X-rays which consists in maintaining within the tube a vacuum so highly attenuated that practically no current can flow through the tube under the influence of the impressed voltage through the medium of ionization of gas molecules in the tube, and rendering the tube unilaterally conducting by generating electrons at the cathode independently of the voltage impressed upon the tube.

24. The method of operating a tube for the production of X-rays which consists in maintaining within the tube a vacuum so highly attenuated that practically no current can flow under the influence of the voltage impressed upon the tube, through the medium of ionization of gas molecules in the tube, and rendering the tube unilaterally conducting by generating electrons at the cathode by current independent of the voltage impressed upon the tube.

25. The method of depriving a metal body of occluded gas which consists in generating electrons constituting the origin of an electrical discharge, independently of the voltage producing the discharge, in an evacuated space, the residual gas in which s so attenuated that at the given voltage he gas will not conduct the discharge without the independent generation of electrons, subjecting the metal body to the electron discharge, and coincidentally removing gas evolved from said metal body to maintain he gas pressure so low that at the given voltage a discharge will not occur without he independent generation of electrons.

26. The method of depriving a metal body f gas which consists in generating elecrons constituting the origin of an electric ischarge independently of a voltage proucing the discharge, in an evacuated space n which the residual gas pressure is so low hat at a given voltage the gas will not conuct the discharge without the independent eneration of electrons, subjecting the metal body to the electron discharge, the energy of the discharge being sufficient to heat said metal body to incandescence, and coincidentally removing gas disengaged by said discharge to maintain the gas pressure so low that at the given voltage a discharge will not occur without the independent generation of electrons.

27. The method of preparing a discharge device, comprising an envelop, an anode and a cathode which consists in generating electrons at the cathode independently of the voltage producing a discharge from said cathode, the space in the envelop being evacuated so completely that no energy can be passed at a given voltage between said electrodes without the independent generation of electrons at the cathode, removing gas liberated by said discharge and finally sealing the envelop when the residual gas pressure is so low that the device can be operated without appreciable evidence of positive ionization.

28. The method of depriving a metal body of gas which consists in heating a cathode to incandescence to generate electrons, passing between said cathode and said body used as anode an electrical discharge in a vacuum so high that at the discharge voltage the residual gas will not conduct current without the independent generation of electrons at the cathode and coincidentally removing gas evolved from said metal body to maintain the gas pressure so low that at the given voltage a discharge will not occur without the independent generation of electrons.

29. The method of preparing an X-ray device comprising an envelop, an anode and a cathode, both consisting of refractory material, which consists in heating the cathode to incandescence to generate electrons, passing between said cathode and anode a high voltage electrical discharge of sufficient energy to heat the anode in a vacuum so high that with the given voltage the discharge is not maintainable while the cathode is unheated, removing gas from the evacuated space liberated from the anode by said discharge and finally sealing the envelop when the residual gas pressure is so low that the device can be operated without appreciable evidence of positive ionization.

30. The process of operating an X-ray device comprising a gas-tight evacuated envelop, a cathode and an anode, which consists in generating electrons at the cathode independently of current passed by said device while preventing any accompanying manifestations of positive ions, impressing on the electrodes a voltage at least as high as the value at which substantially all of the electrons are utilized, whereby the current becomes substantially independent of the impressed voltage, and increasing or

decreasing the penetrating power of the X-rays by respectively increasing or decreasing the impressed voltage.

31. An X-ray device comprising a gas-tight envelop, an electron emitting cathode, and an anode deprived of ionizable gas, the space in said envelop being evacuated to a pressure at least as low as five hundredths of a micron of mercury pressure, the current transmitted by said device with a given electron-emissivity of the cathode being substantially constant with an impressed voltage variable over a working range.

32. A Röntgen ray device comprising a sealed envelop, the space within which is evacuated to a pressure so low that evidences of positive ionization are substantially absent during the operation of said device, a cathode of refractory metal adapted to be heated substantially independently of a voltage impressed upon said electrodes and a coöperating anode.

33. An X-ray tube comprising a sealed envelop, a cathode adapted to be heated independently of a discharge transmitted by said device, an anode and a dished focusing member surrounding the cathode having its concave side facing the anode, said tube being exhausted of gas to a pressure so low that evidences of positive ionization are substantially absent during operation.

In witness whereof, I have hereunto set my hand this 8th day of May, 1913.

WILLIAM D. COOLIDGE.

Witnesses:
Benjamin B. Hull,
Helen Orford.

Copies of this patent may be obtained for five cents each, by addressing the "Commissioner of Patents, Washington, D. C."

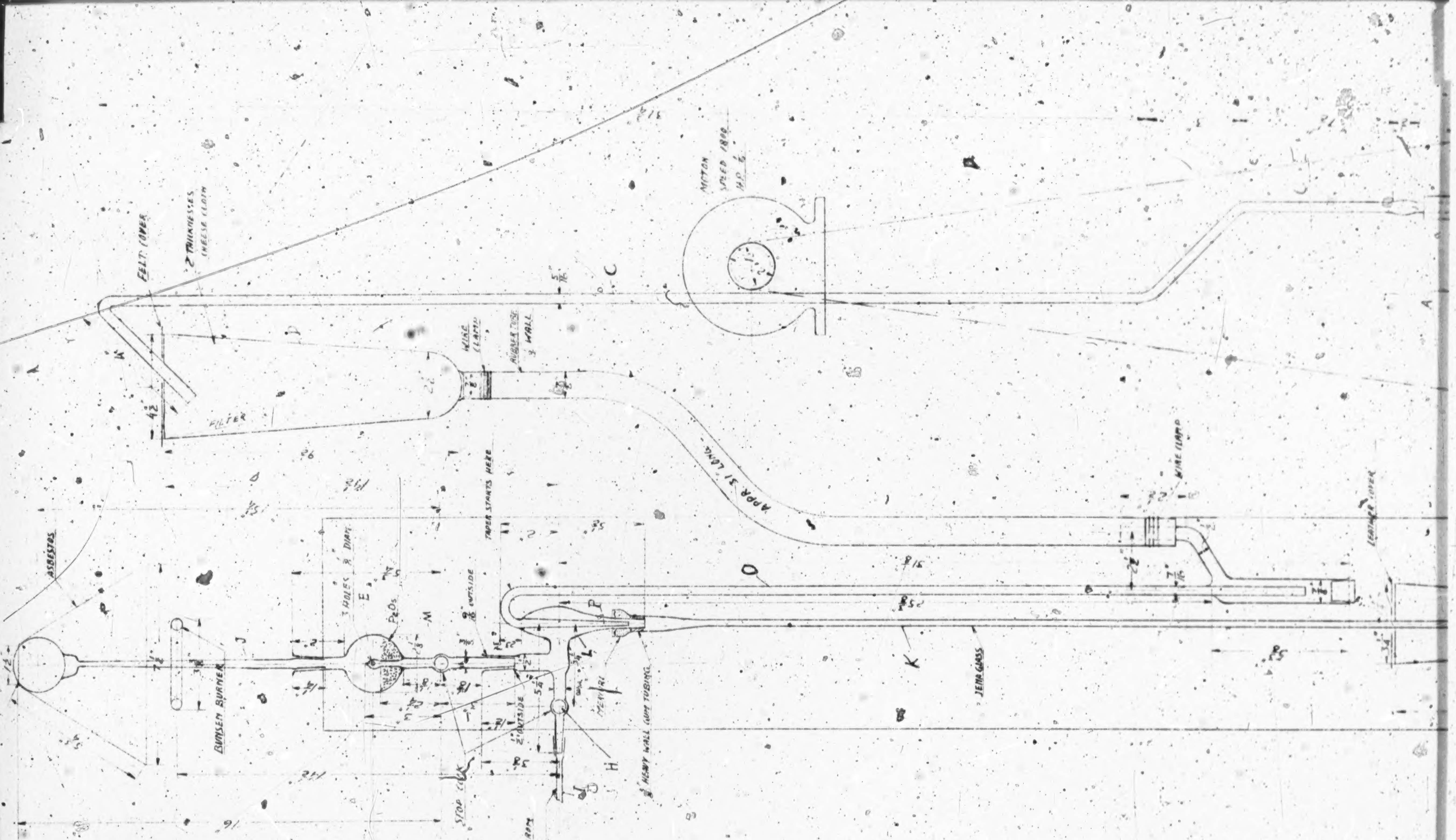
1030

2—421

1913

CONTENTS:

1. Application papers. O K
2. Rejection July 28, 1913
3. Amendt A Oct 15-1913
4. Rejection Jan 7, 1914
5. Amendt B Dec 19-1914
6. Rejection Jan. 12, 1915
7. Amendt C Jan. 30-1915
8. Rejection Feb 8, 1915
9. Amendt D Feb 23-1915
10. Letter Mar 10, 1915
11. Amendt E Mar 30-1915
12. Letter Apr 3, 1915
13. Amendt F Mar 14-1916
14. Rejection Apr 7, 1916
15. Amendt G Apr 11-1916
16. Ex. Amdt. Oct. 20-1916
17. Notice of Suit, Mar. 21-23
18.
19.
20.
21.
22.
23.
24.
25.
26.
27.
28.
29.
30.
31.
32.
33.
34.
35.
36.
37.
38.
39.
40.
41.
42.
43.
44.
45.
46.
47.
48.
49.
50.



FELT COVER
2 THICKNESSES CHEESE CLOTH
FILTER
WIRE CLAMP
RUBBER TUBE 1/4 WALL
MOTOR
SPEED 1800
HP 1/4
APPR. 31 LONG
WIRE CLAMP
LEATHER COVER
TAPER STARTS HERE
3 HOLES 3/8 DIAM.
P_2O_5
3/8 OUTSIDE
1/2 OUTSIDE
ASBESTOS
BUNSEN BURNER
STOP COCK
MERCURY
HEAVY WALL GUM TUBING
JENA GLASS
A
B
C
D
E
H
J
K
L
M
O
91

AMERICAN MACHINE & MFG. CO

SAN FRANCISCO CAL.

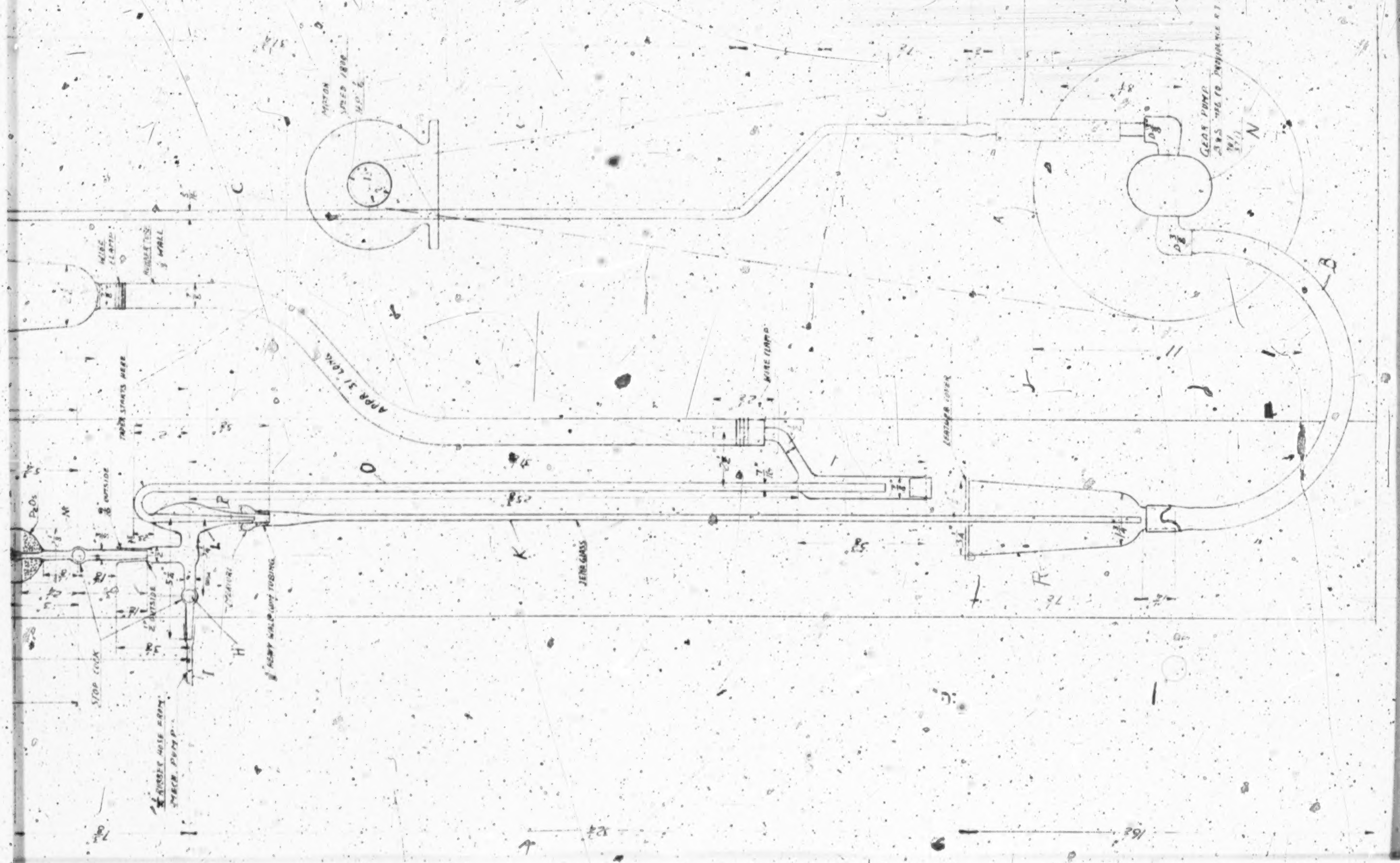
DATE 11-3-29

VACUUM PUMP

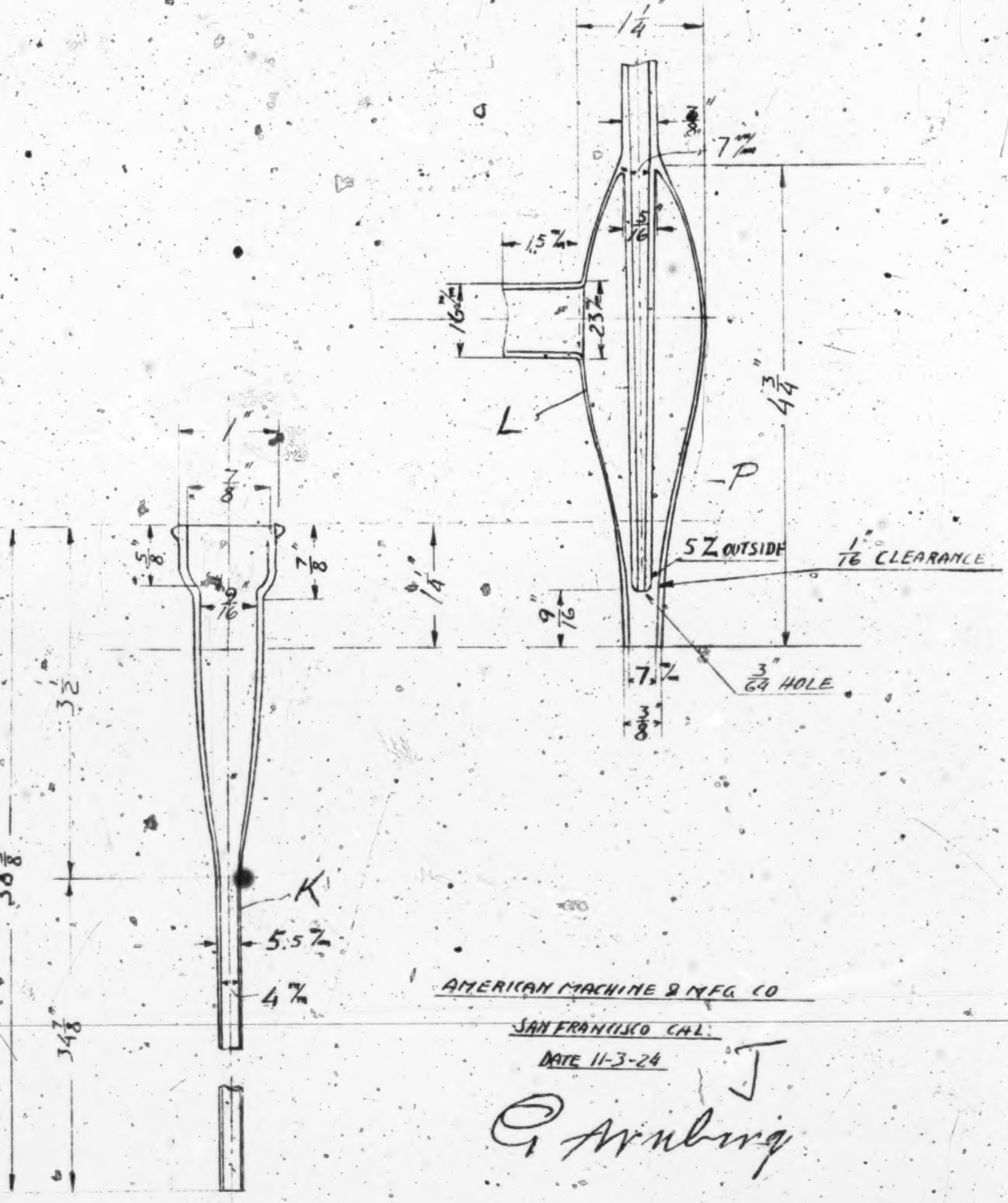
SCALE 1÷2

G. Arnberg

DEFENDANT'S EXHIBIT No. 68.
Drawing of Pump Used by Lamont.


MOTOR
SPEED 1800
H.P. 1/6
GEAR PUMP
N
A
B
C
WIRE CLAMP
RUBBER TUBE 1/8 WALL
APPR 21 LONG
WIRE CLAMP
LEATHER COVER
O
P
K
R
JENA GLASS
TAPER STARTS HERE
OUTSIDE
P_2O_5
M
L
VENTURI
HEAVY WALL LAMP TUBING
H
I
STOP COCK
RUBBER HOSE FROM MECH. PUMP

DEFENDANT'S EXHIBIT No. 59.
Drawing of Pump Used by Lamont.

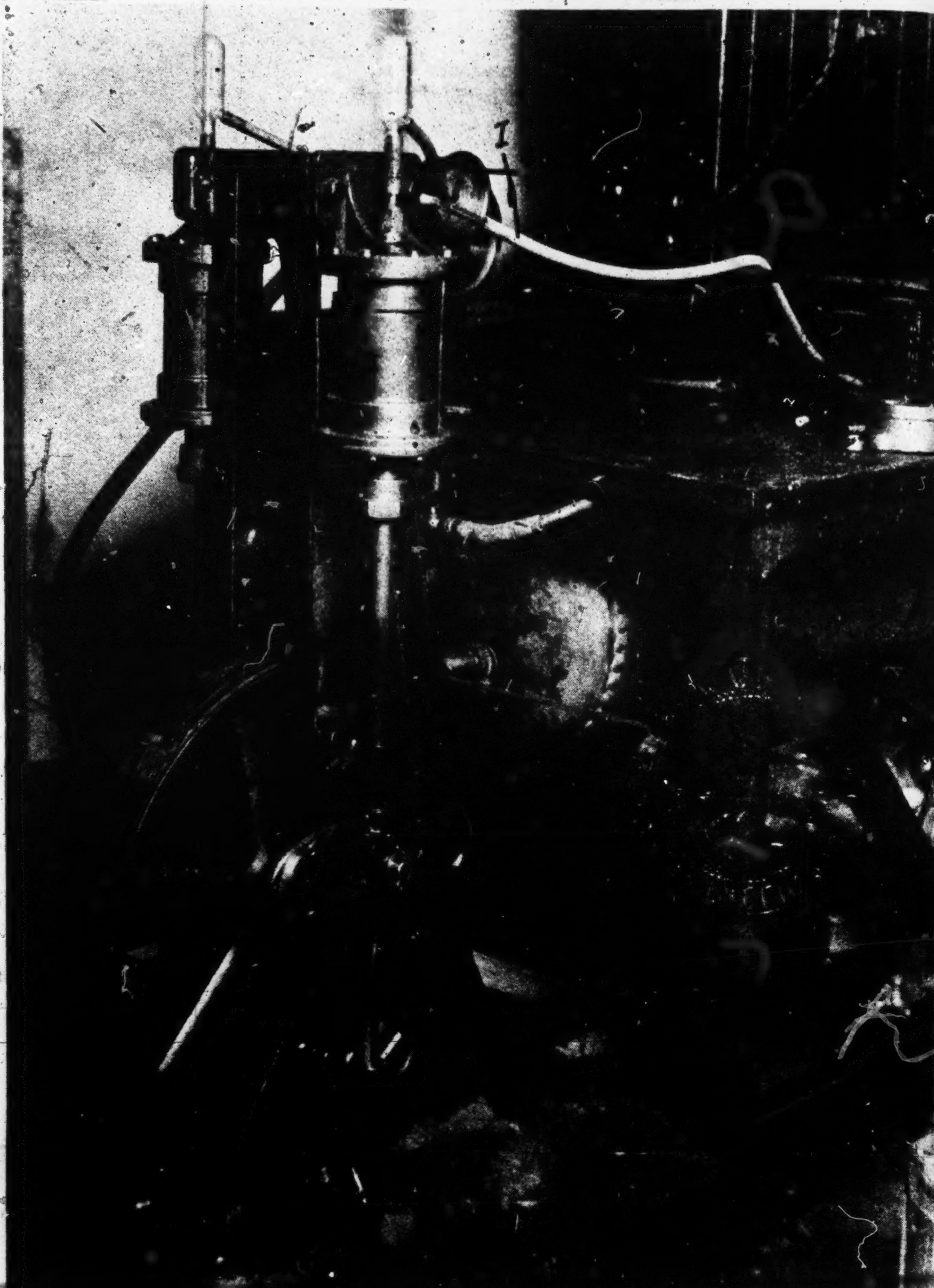

1 1/4"
3/8"
7 m/m
5/16
15 m/m
16 m/m
23 m/m
L
4 3/4"
P
5 Z OUTSIDE
1/16" CLEARANCE
9/16
7 m/m
3/64 HOLE
3/8
1"
7/8"
5/8"
7/8"
9/16"
1 1/4"
3 1/2
38 3/8"
K
5.5 m/m
4 m/m
34 7/8

AMERICAN MACHINE & MFG CO
SAN FRANCISCO CAL.
DATE 11-3-24
J

G Arnberg

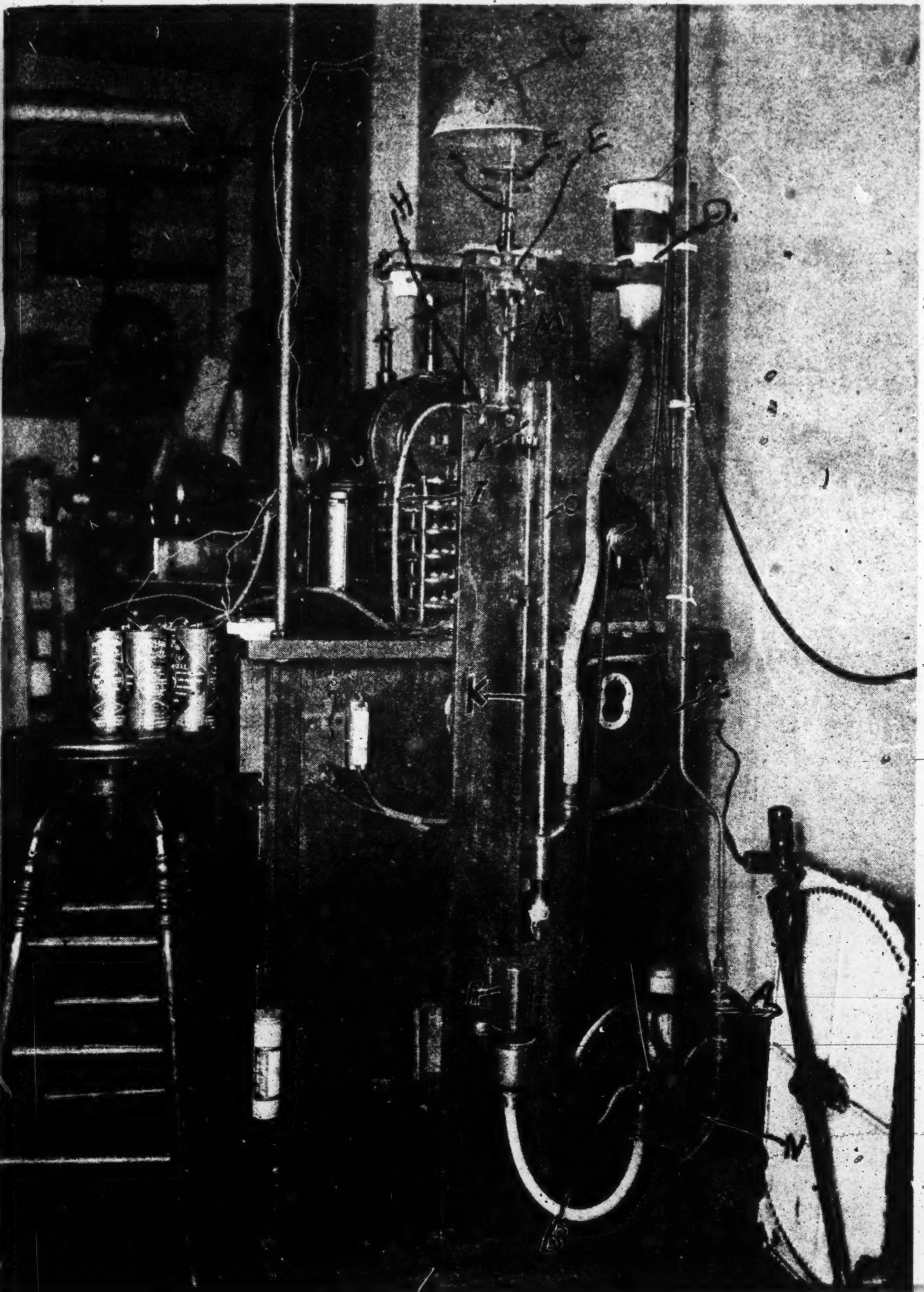
DEFENDANT'S EXHIBIT No. 70.

Photograph of Lamont Preliminary Pump.



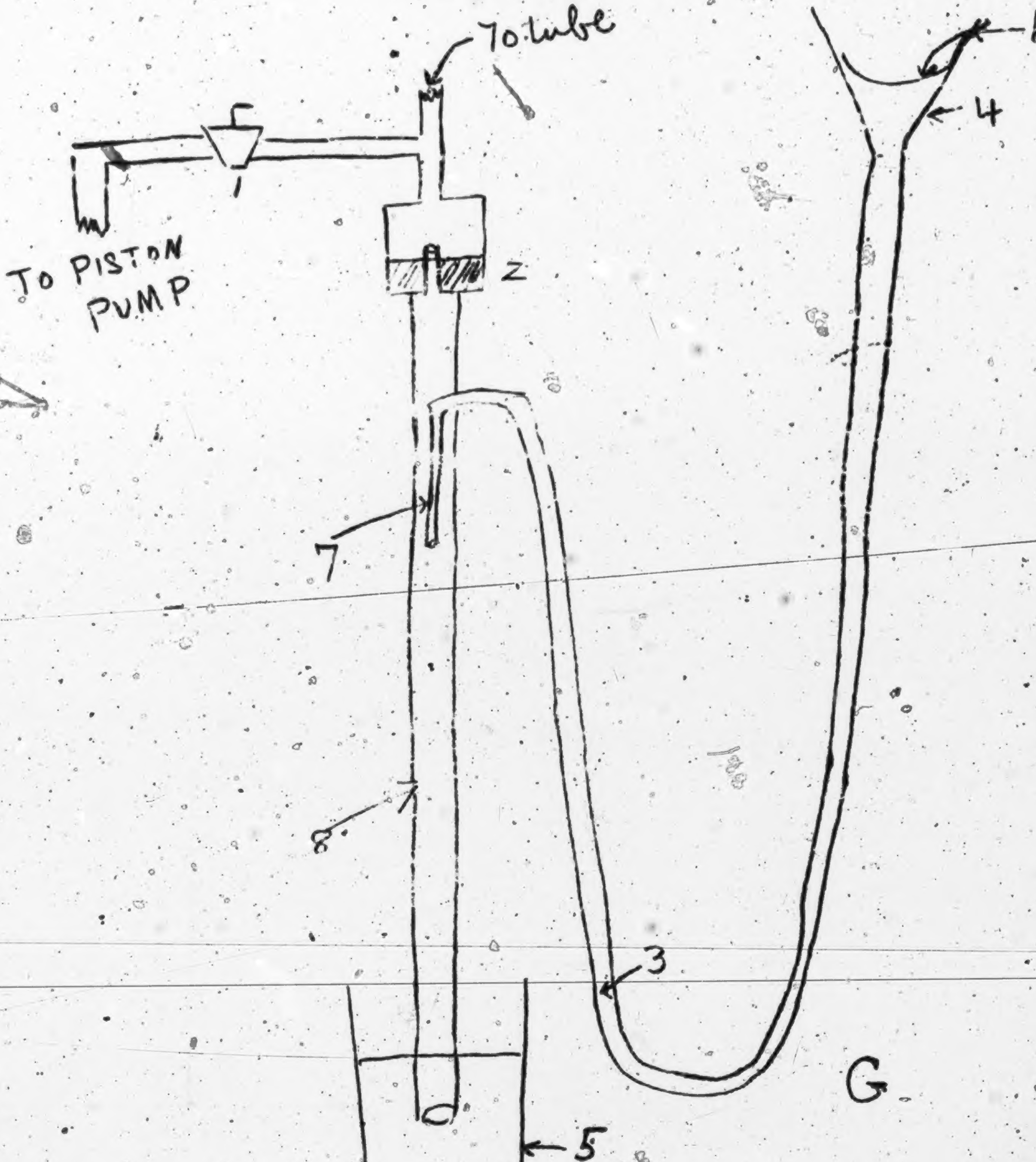
DEFENDANT'S EXHIBIT No. 71.

Photograph of Lamont Mercury Pump.

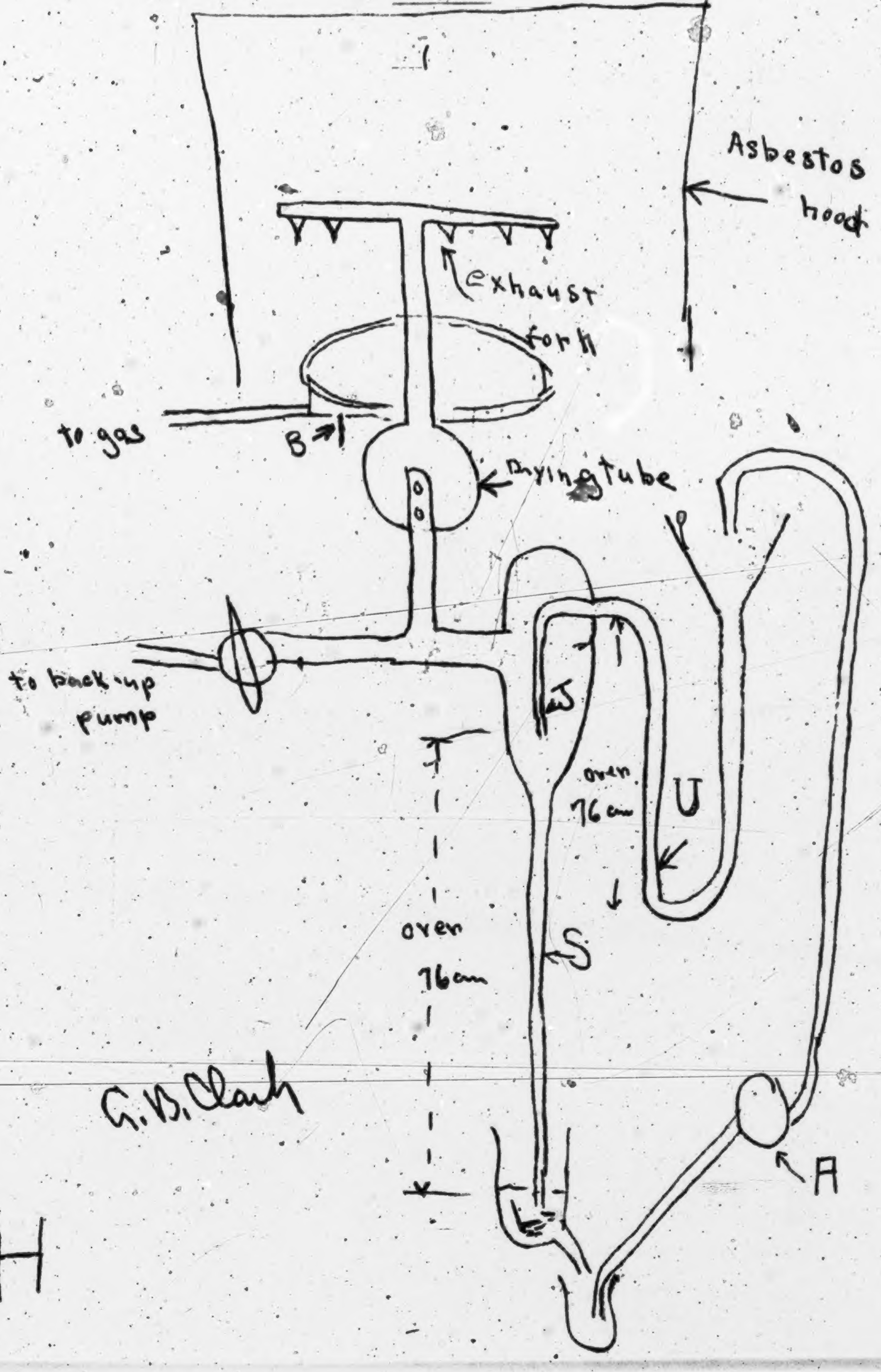


G
E
E
H
D
M
L
I
O
K
C
F
A
N
B

DEFENDANT'S EXHIBIT No. 72.
Hewlett Pump Sketch.


To tube
6
4
1
To PISTON PUMP
Z
7
8
3
G
5

DEFENDANT'S EXHIBIT No. 73.
Clark Pump Sketch.


Asbestos hood
exhaust fork
to gas
B
Dryingtube
to back-up pump
J
over 76 cm
U
over 76 cm
S
A

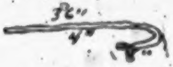
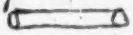
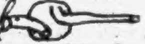
G. B. Clark

H

August & September

August		
8-29	The C Lichty Co	
29	Walters Surgical Co	
30	Braun Knecht Heimann Co	
31	S. H. Taylor & Son	
9-3	S. M. Barusch	September
9-3	Cal Wine Ass'n	
4	Cal Wine Ass'n	
5	Braun Knecht Heimann Co	
5	Aylsworth Agencies Co	
10	W. P. Fuller & Co	
10	J. C. Sala	
11	The Wonder Cloak & Suit House	Cor J & Tulare Sts Fresno
11	Braun Knecht Heimann Co	
11	Bischoffs Truss & Surgical House	102 Stewart St
12	F. A. Jones	
12	Dr. Lawhead & Fairchild	
13	Walters Surgical Co	
14	Percy J Meyers	
16	City & County Hospital	
16	French Hospital	
17	Garlock Packing Co	
19	Bausch Lomb Optical Co	
19	Federal Telegraph Co	
20	Dr. C. L. Lichty	
21	Braun Knecht Heimann Co	
23	Walters Surgical	
23	Coffin & Redington Co	
24	University of Cal.	Purchasing Dept.
24	Marine Electric Co	
25	German Hospital	
26	Southern Pacific Hospital	
26	Wm O Eddy	
26	Bausch & Lomb Optical Co	
17	Percy J Meyer	
27	Oscar Krenz Copper & Brass Works	
28	German Hospital	

1912

	1	Therm rep	$1.75			
	1	" angle	3.25	5 00	9 - - -	P.
	1	manometer rep	1.00			
	1	interupter	25	1 25	9.14.12	P
6578		Bulbs on flasks		75	9.12.12	P
		special Graduated Measure		4 00	10.14.12	P
1912	1	2 contact Therm		5 00	9.9.12	P
	2	angle Therm rep	$3.50 ea	7 00	10.3.12	P.
31203	1	" " well	3 50	5 00	10-3.12	P.
6318	3	Gas pipettes rep " 50 ea	1 50	1 50		
6339	1	adapter		25	10.11.12	P
	1	Jar cut 5-½" long		1 00	10.14.12	P.
F1437	2	Therm rep	5 00 ea	10 00	10.5.12	P.
	1	round bulb therm		1 50	2.3.13	P.
	30	tubes bent as per sketch 		7 50	10.10.12	P
6724		cutting glass tube 3" long		25		
6844	1	glass [illegible] rep		25	10.11.12	P
678	1	gas pipette rep		75		
	½	doz Murphy drops		1 50	12.28.12	P.
	8	tubes cut 	.18 ea	1 45	9.12.12	P
	1	X Ray tube rep on cathode end	7 00	8 00		
	2	interupters sealed	50	7 50	10.14.12	P
	1	Electrode rep		50	11.13.12	P.
240	1	X Ray tube		30 00	10.23.12	P.
	8	points	.75 ea	6 00	10.14.12	P.
58331	1	doz Glasses Fused		.75	9.21.12	P
	18	Traps as per sketch 	.85 ea	15 30	10.10.12	P.
2787	18	audion lamps exh.	.30 ea	5 40	10.17.12	P
	2	Electrodes rep	$1.50 ea	3 00	9.20.12	P
1233	3	tube lengthened		25		
1232	1	[illegible] app		25		
	1			1 00	10.11.12	P
	1	X Ray tube rep cathode end	7 50			
	3	interupters rep anticathode end	7 50 3 75	15 75	10.14.12	P
	27	bottles bored	7½ ¢ ea	1 82	12.17.12	P.
#9103	2	Glass tubes as per sketch	$3.50 ea	7 00	11.5.12	P.
12403	2	36cp 22 volt lamps Double filaments	$2 00 ea bulb	4 00	10.16.12	P.
B1626	12	doz Irrigation tips		7 20	10.22.12	P.
	1	X Ray tube rep small anode end	7 00			
	1	" " " " new reducer	7 50	14 50	10.5.12	P
	1	" " " " cathode end	4 00			
	1	" " " exh	2 50	6 50	10-12	P.
	16	Glass Cylinders as ordered		2 50	10.10.12	P.
	1	~~Blood Pressure Gauge rep~~		~~75~~		
	1	Therm rep		7 50	11.13.12	P
B1641	1	X Ray tube rep		7 50	10.22.12	P
441	1	angle therm rep	1 75			
	2	" "	3 50	4 75	11.20.12	P.

December

7.	Garlock Packing Co	
2	Marshall-Newell Supply Co	
2	Berkeley Electric Cooker Co	
2	W. P. Fuller & Co	
4	Dr A H Davenport	
9	National Wireless Tel. & Tel. Co	
9	Wm O Eddy	
9	The A. Lietz Co	
11	George H Fay Co	
12	Walters Surgical Co	
9	Giant Powder Works	
16	Braun, Knecht, Heimann Co	
16	Children's Hospital	
17	Walters Surgical Co	
18	Dr Woorsanger	
21	Braun, Knecht Heimann Co	
21	Braun — — —	
26.	Hirsch & Kaiser	
27.	Wm O Eddy	
30	Braun, Knecht Heimann Co	
30	University of Cal.	
31	{Curtis & Tompkins}	
31	{~~Bischoffs Truss & Surgical House~~	
31	Bischoffs Truss & Surgical House	
31	The Thilgen Co.	260 Cal St
31	Dr F. P Freytag	

1912

	3 doz Gauge Glasses fused		2 25	12.11.12	P.
	1 angle therm rep		3 50	1.14.13	P.
	2 U tubes Barometer tubing $1.50 ea		3 00	12.2.12	P.
F1636	2 Therm rep 1 new well	$15 00 1 00	16 00	12.23.12	P.
	1 X Ray tube new bulb		18 00	1.31.13	P
	3 audions tubes rep 2.00 ea		6 00	12.9.12	P.
	1 X Ray tube ends 4 electrode rep 1 " tube rep	2 50 50 35	3 35	12.30.12	P.
16081	1 Barometer rep		5 00	1.13.13	P.
5115	1 Thermometer rep		7 50	1.14.13	P.
	1 doz m tips 3 interrupters (new)	75 1 05	1 80	1.13.13	P
	1 Thermostate		9 50	12.9.12	P
8950 8918	24 Burette tips Hydrometers		35 25	1.11.13	P
	6 doz downtubes 6 doz connectors	7 50 3 00	10 50	3.3.13	P
	3 interrupters 1 X Ray tube rep, new reg.	1 05 6 00	7 05	1.13.13	P
	1 Glass app rep		8 50	1.22.13	P.
8930 8987 8998	1 Barometer rep 3 filtering tubes 12 Hydrometer tips		4 00 1 50 1 30	1.11.13	P
9119 9155	1 tube rep 1 manifold rep		21 50	1.11.13	P
	1 Barometer tube		4 00	1.9.13	P
	2 interrupter tubes 2 electrodes rep 1 X Ray tube rep (ante cathode end	1 00 70 8 00	9 70	12.30.12	P.
9013 9165 9194	2 Glass app rep 1 filtration rep 4 U tubes		50 20 1 20	1.11.13	P
order# 1106 Dept # 7304/169	2 regulators rep $1.50 ea		3 00	1.23.13	P
	4 Burettes rep 1 reducing milk testers	10 00 75	10 75	12.31.12	P.
	1 doz glass tubes for burner 1 doz glass tubing 4 adapters on funnel tubes	2 50 1 00 1 00 2 00	6 50	12.31.12	P.
	1 X Ray tube rep		14 00		P
	Glass app rep		7 50	1.3.13	P
	1 X Ray tube rep ante cathode end		9 00	4.25.13	P

18 February

2-[illegible] 21	Marine Electric Co
6	Garlock Packing Co
6	Collins McCarthy Candy Co
8	Paul Seiler Electrical Works
8	Braun Knecht Heimann Co
8	Storekeeper of the Navy Yard Mare Island
10	Hawaiian Pineapple Products Co
10	M J Brandenstein
12	Dr Jno Gallwey
12	Percy Meyer
12	Wm Hatteroth Surgical Co
12	Wm O Eddy
13	Elmer Burlingame [illegible] 256- 38th St Oaklan [illegible]
13	J. C. Sala
13	Federal Telegraph Co
12	W W Montague Co
15	Merritt Hospital
19	Treasury Department, U S Mint
20	Pacific Rubber & Supply Co
20	German Hospital
21	Dr H M Sherman
21	J. C. Sala
26	Levy Electric Co
26	Walters Surgical Co
26	Braun Knecht Heimann Co
24	Elmer Burlingame
27	Levy Electric Co
27	Walters Surgical Co
28	Walters Surgical Co

1913

13378	50 Indicator Lamps		20.00	3.10.13	P.
	Glass fused		40	2.12.13	P.
	100 Glass jars	10¢ ea	10.00	2.14.13	P.
1051	" Electrode		75	2.12.13	P.
7765 7775 7776	" Glass tube [illegible] " [illegible] " for [illegible]		35 35 35	3.11.13.	P
496 N.S.G. M.D. Bal	4 Keys Vacuum Relay	$25.00 ea	100.00	3.14.13	P.
	1 doz tubes		2.50	3.15.13	P.
	1 " "		2.50	3.19.13	P
	1 X Ray tube rep (anti cathode rep)		8.00	2.12.13	P
	1 " " " " new reg		6.00	3.13.13	P
	1 " " " " small		4.00	4.14.13.	P
	1 " " " new reg		6.00	3.14.13	P.
	expenses on tubing 1 Geisler tube 1½ tube	5.00 5.00	10.00	2.13.13	P
	2 Therm rep $1.50 ea		3.00	7.26.13	P.
3109	11 Audion Bulbs exh .45 ea		4.95	3.27.13	P
4181	1 tube cut & ground		25	3.21.13	P
	1 X Ray tube cleaned & rep 1 "	$15.00 7.50	22.50	3.14.13	P
	1 doz right handed propellers 1 " left handed "	.40 ea	9.60	3.27.13	P
	14 lengths 9' 2" cutting, forming, & straightening Glass tube		9.00	3.13.13	P
2026	2 X Ray tube rep grow [illegible] tips	$15.00 7.20	22.20	3.21.13	P
	Glass blowing as ordered		1.50	3.29.13	P
	1 Therm rep		1.50	7.26.13	P
865	1 Interrupter		75	3.15.13.	P
	3 interrupters .75 1 [illegible] electrode .30 3 doz [illegible] tips 1.75 1 X Ray tube rep cathode and 12.00 1 " " " " $21.05 [illegible]		21.05	3.13.13	P
9851 9084 10141	1 tube [illegible] 6 C [illegible] 2 6 [illegible] 2 [illegible] cut 10162 interrupter changed		25 25 50	3.11.13.	P
	1 Geisler tube		5.00	2-26.13	P
879	1 Glass interrupter our style		3.50	3.15.13.	P
	1 X Ray tube rep #23964		12.00	3.13.[redacted]	X
	14 Interrupters		4.90	3.13.[redacted]	P

June

6-1	Percy J Meyer Co	
1	Louis Wenle Co	
2	Walters Surgical Co.	
3	Percy J Meyer	
5	Dr A. G. Ross	
5	Percy J Meyer Co	
9	Mittle Mfg Co	
9	Crane Co	
9	Wm O Eddy	
11	Electro-Alkaline Co	D. Mosher 809 Hight St Oakland
15	Medical Supply Depot	
15	Perc J. Meyer Co	
15	Walters Surgical Co	
[illegible]	Shreve & Co	
[illegible]	Percy J Meyer Co	
16	C. J. Tagliabue Mfg Co	268 Market St.
17	St. Francis Hospital	
18	Federal Carrier Co	
18	Percy J Meyer Co	
19	Herrold College	
19	Federal Telegraph Co	
19	Wm O Eddy	
20	Pacific Hardware & Steel Co	
23	Mt Zion Hospital	
23	Dr O F. Freytag	
24	Standard Oil Co	
24	Walters Surgical Co	
24	Percy J Meyer	
26	The J. A. Lilly Co	
26	Dr H M Sherman	
27	Selby Smelter Commission	Gould
27	Walters Surgical Co	
30	Italian Swiss Colony	
7-1	Dr Morrow	

1914

	8	606 tubes.		5.20	7.14.14	P
	1	Thermo rep		2.00	6.1.14	P
	3	interupters rep.		75	7.14.14	P
	1	X Ray tube exhausted		4 00	7.14.14	P
	1	" " " rep		6 00	6.3.14	P
	1	" " " "		12 00	7.14.14	P
	1	Thermo + Frame rep		7 00	7.28.14	P
8521	1	" rep		3 00	7. 14	P
	1	X Ray tube rep		5 00	8.1.14	P
	3 6	Test tubes 1 1/4" x 36" Gauge Glass tubes bent on both ends	4 00 3 50	7.50	8.24.14	P
#953 11867-J.	2	X Ray tubes rep		18 00	6.26.14	P
	1	" " " "	12 00 20 00	32 00	8.28.14	P
	3 2	interupters rep new "	75 70	1.45	7.14.14.	P
378	1	small glass tube		50	7.13.14	P
	1	X Ray tube rep new reg		6 00	7.28.14	P
	1	Thermo rep		5 00	7.25.14	P
4858	1 1	X Ray tube rep [illegible] new reg " " " " with mercury reg	7.50 9 00	16 30	8. 14	P
	1	doz Thermostats.		18 00	7.15.14	P
	1	interupter Plat + tube		3 00	7.28.14.	P
	6	Audions rep new filaments		10 00	7.7.14	P
4320	8	Audions exh		5 00	8. 28	
	3.	Electrodes rep 75¢ ea		2 25	8.1.14	P
	1	do 30 1/2 1 3/4		0 00	7.11.14	P
	1	X Ray tube exh.		5 00	10.16.14	P
	1	" " " "		4 00	7.7.14	
R13891 -50-	30	Glass Sulphur Lamp Absorbers		19 50	7. 14	P
	16	Interrupters new		5 60	7.14.14	P
	1	X Ray tube rep new wire		6 00	7.28.14.	P
1307	1	V tube 3/8 x 48 - 3/4 ap		1 00	7.13.14	P
	1	X Ray tube rep		12 00	6.29.14	P
	3 2	Glass Absorbers extra caps	15 00 6 00	21 00	8.18.14	P
	1	X Ray tube rep		4 00	7.14.14	P
	2	Burettes rep		2 50	7.22.14	P
	1	tube exh		3 55	7.1.14	P
				104 25		

July

7-4	Standard Oil Co	
7	Percy J Meyer Co	
7	Dr A Raymond	
7	Marconi Wireless Telegraph Co. of America,	Marshall, Cal.
8	A Lietz Co	
9	Louis Heule	
9	C J Wells	
13	Dr F R Fairchild	1030 Forum Sacramento
14	Dr H H Markel	
14	Dr G L Camter	
14	Dr F. Freytag	
14	Dr Francis Williams, M.D.	
14	Practitioners' Laboratories	
14	Dr H H Markel	
21	St Luke's Hospital	
23	Wm O Eddy	
23	Dr E Schmoll	
23	Walters Surgical Co	
24	Dr A H Davenport	
30	Haller-Cunningham Electric Co	
30	Dr H. Kreutzmann	
30	Gould-Fish	
30	German Hospital	
31	Butte Engineering & Electric Co	
31	Percy J Meyer Co	
31	St Lukes Hospital	
27	Dr A K Davenport	

Wm O Eddy Paid 25.00 - 11-13.15 { whole bill $87.50
Balance on whole bill $62.50

1915

R.4532-6	48 Glass Absorption Bulbs .85 ea		4080	8.19.15	P
	1 X Ray tube rep cathode		500	9.21.15	P
	1 " " " exhausted		500	7.13.15	P
A 6	6 Audion bulbs rep+exh		1000	7-15	P
8311	1 Barometer		400	8.12.15	P
	1 high reading therm rep		1000	7.9.15	P
	4 holes ground in plate		150	12.22.15	P
	1 X Ray tube rep. reg.		750	8.3.15	P
	1 " " " "		750	2-16	P
	1 X Ray " "		600	7.14.15	P
	1 " " " cathode		750	7.27.15	P
	1 " " " " red		750	7.14.15	P
	1 " " " new bulb		2000	8.~~18~~ 17.15	P
	1 " " " rep		750	2-16	P
	~~1 " " [illegible]~~	~~700~~			
	1 " " new bulb	2000	2000	8.22.15	P
	1 " " cathode red		700	11.13.15	P
	1 " " " exhausted		500	8-15	P
	4 interrupters resealed	35 ea	140	8.12.15	P
	1 X Ray tube rep		750	8.21.13	P
	1 Geissler tube		400	7.30.15	P
	1 water cooler tube 8" bulb		2500	7.31.15	P
	1 pump 600 21 test tubes .35 = 7.35 14 condenser tubes 21.00 material required + installing pump 17.60		18595	8.11.15	P
	1 X-Ray tube rep cathode+anti 10.00 1 " " " exh 500		1500	8.31.15	P
24019	6 glass tubes as per sketch	15 ea	900	10.27.15	P
	1 X Ray tube rep. new red 600 1 " " " exh 300		900	9.21.15	P
	1 " " " rep		1000	9-21.15	P
	1 " " " exh		500	8.21.15	P

DEFENDANT'S EXHIBIT No. 75.

Lamont Account Book (Orig.) (3 Sheets).

September

9 2	Wm Hatteroth Surgical House
2	Lane Hospital
3	Dr D. Montgomery
3	Dr Keck
4	University Hospital
4	Prof Janke
7.	~~[illegible]~~
3.	Walters Surgical Co
11	Marine Electric Co.
15.	Walters Surgical Co
15.	Portland Gas Co
17	Dr. Tuchler
18	Dr Freytag
18	
21	Lane Hospital
22	St. Francis
22	Western Meat Co
23	Wm Tompson
23	W P Fuller
27	Paul Sezler Electrical Works
28	J. C. Sala
29	Walters Surgical Co
29	~~[illegible]~~ Nina Lumber Co
28	Henry Kalin

1909

	6 interupters	10 25	9.28.09	P
	1 x Ray tube rep 8 00 1 " " " 7.60 mining	13 50	11.5 09	P
	2 x Ray tubes (new reg.	15 00	9.4.09	P.
	1 x " " rep.	8 00	9.3.09	P
	1 x "	5 00	9.28.09	P.
	2 Audion Receivers	15 00	9.4.09	P.
~~#1752~~	~~1 Permeolate~~	~~3 00~~		
	5 interupters rep	1 25	9.28.09	P.
	1 doz 4 V Tungsten Lamps	6 00	10.11.09	P.
	1 x Ray tube rep 3 50 2 interupters 70	4 20	9.28.09	P.
#12449	1 Burette repaired	2 50	10. 09	P
	1 treatment tube rep	2 50	9.17.09	P.
	1 x Ray tube	16	9.18.09	P
	1 x " " " exh	3 50	9.18.09	P.
	1 " " " rep	7 50	11.29.09	P.
	1 " " " "	8 00	11.13.09	P
	2 automatic filling burettes rep	6 00	10.25.09	P.
	1 X Ray tube rep	6 00	9.23.09	P
	2 Burettes rep.	3 00	10.13.09	P.
	1 Special Electrode	2 25	10.13.09	P.
	2 Thermo to scale. $1.25 ea	2 50	10.28.09	P
	3 doz connectors 50¢ doz	1 50	11.13.09	P
	3 Gauge tubes	2 50	10.15.09	P
	1 Therm rep	9 00	10.8.09	P

November

11-1 Fisher Furniture Co
2 Dr G. F. Reinhardt
3 A Jahnke
3 Walters Surgical Co
4 Dr G. Selfridge
8 Dr. H. G. McGill
11 Dr. Eichler
11 " "
12 St Marys Hospital
16 Squires + Byrne Co.
16 Squires + " "
16 American Electric Novelty Co
17 Dr Martin Richmond
17 Dr Keck
19 " "
19 Louis Weale
19 Dr Montgomery
20 Dr Stubbel
23 Walters Surgical Co
24 ~~Metropolitan Light + Power Co~~ Walters
24 Metropolitan Light + Power Co
27 St Joseph Hospital
27 Dr Freytag

1909

	Thermostat			5 00	12.2.09	P.
	1 X Ray tube repaired			5 00	11.5.09	P
	2 Special Apparatus			22 50	11.4.09	P
	3 interrupters sealed ½ doz connecters	75 25		1 00	12.9.09	P
	1 doz Lamps 10V. 1A. 65¢ ea			7 80	11.5.09	P.
	1 vacuum tube			7 50	12.8.09	P.
	1 X Ray tube rep. 1 " " " "	6 00 5 00		11 00	12.1.09	P
	setting up X Ray coil			3 50	12.1.09	P
	1 " Ray tube rep.			6 00	11.29.09	P
ndev 357	Shaped Glasses 7/8 tube @ 50¢ ea			2 00	11.16.09	P.
	4 Therm rep @ 35¢ ea			1 40	11.16.09	P.
	1 interrupter			2 50	11.29.09	P
	1 X Ray tube exhausted 2 " " " rep.	3 50 10 00		13 50	11.17.09	P.
	2 X Ray tubes rep.			10 00	11.19.09	P
	2 " " " "			10 00	11.19.69	P
	1 Therm tube rep.			1 50	11.19.09	P
	2 X Ray tube exh.	3 50		7 00	11.19.09	P.
	X " " rep			6 00	11.20.09	P
	1 X Ray tube rep 1 interrupter	4 00 35	5 80	4 35	12.9.09	P
	½ treatment tubes exh. " " rep	25 70 50		1 45	12.9.09	P
4453	2 Flasks @ $2 00 ea			4 00	12.28.09	P.
	1 X Ray tube set			5 00	11.24.09	P.
	1 " " " "			7 50	11.28.09	P

October

10 2 Walters Surgical Co
2 Braun, Knecht Heimann
2 Braun Knecht
6 French Hospital
7 Dr H. C. Hiner
7 Walters Surgical Co
10 Braun Knecht Heimann Co
10 Braun ——————
10 Braun ——————
10 Walters Surgical Co
11 Southern Pacific Hospital
12. J. C. Sala
14 Braun, Knecht, Heimann Co
16 Phoenix Tool & Valve Co
14 Southern Pacific Hospita
19 Libby McNeill & Libby
19 Dr F. R. Fairchild
14 Mt Zion Hospital
20 W. P. Fuller
20 Walters Surgical Co
20 Dr W. C. Alvarez
23 Richard Grey
24 Braun, Knecht Heimann
24 Dr Grant Selfridge
24 Dr W. C. Alvarez
25 Walters Surgical Co
25 Walters Surgical Co
25 Braun Knecht, Heimann Co
26 Percy Meyer
27 U.S. General Hospital
27 French Hospital
30 Walters Surgical Co

		53 50	
Nov. 13. 11	J. C. Sala paid on acc.	$ 30 00.	
		23 50	
Last Item Oc-10-11	Balance Paid	10 00	Dec 28. 11
	Bal. Due	$ 13 50	

	6 interupters rep	1 50			
	1 doz in. plso	60	2 10	12-11 11	P
185 ~~304~~	5 manometer tubes 15¢		1.05	11-13-11	P
~~304~~	3 Hydrometer tubes 30¢				
1173	6 caps to fit 5000 Burette	30			
1170	25 tubes 8" long	35	65	11-13-11	P
	1 X Ray tube (new reg)		7 50	11-13-11	P
	144 In hall	7 20			
	144 vials	2 16	9 36.		
	33 Interupters		11 55	12-11-11	P
1312	5 tubes 4" long	25	25		
1323	6 Burette caps		30	11-13 11	P
1299	3 A tubes		25		
1269	2 U tubes 35 1 special tube	15	30	11-13 11	P
1261	1 Burette stop cock rep		50		
1282	1 Barometer rep		50	11-13-11	P
	1 X tube rep		6 00	12 1?.11	P
	1 X Ray tube rep		5 00	12-2 11	P
	1 Thermo rep		3 50	2 15 12	Q
	4 Glass Elbows	1 00			
1384	3 Glass tubes	60	1.60	11-13 11	P
G 8768	2 oil cups		50	11.4.11	P
	1 X Ray tube rep		6 08	12.2.11	P
	3 Angle Thermo rep		1.50	10.23 11	P
	1 X Ray tube — new reg.	$7 50			
	1 Electrode	1 00	8 50	10 22 11	P
	1 X Ray tube	$25.00			
	1 " " " rep	6.00	31 00	11 13 11	P
F.596	1 Thermo rep + well		10 00	11.22.11	P
	1 Doz sets murphy drops		3 00	12-11-11	P
	1 X Ray tube rep		9 00	12 4.11	P
	2 doz blanks 5" long 1" dia		4 80	10.25 11	P
1411	6 U tubes very Heavy glass		2 50		
1449	cutting glass tubing				
4876	1 Barometer rep		2 00	11-13-11	P
	1 doz special lamps 65¢ ea		7 80	10 2? 11	P
	1 X Ray tube new		20 00	11 16 11	P
	2 interupters rep	50			
	1 Doz 1/4 bulbs	1 00	1.50	12-11-11	P
	1 Doz high frequency tubes	6 00			
	3 Murphy drops	1 00	7 00	12-11-11	P
1437	6 U tubes as sketch		1 .50	11-13-11	P
	1 Gross glass connectors	6 00			
	1 " " connecting ties	[illegible]			
	1 doz murphy drops	3 [illegible]	16 20	12-28 11	P
# 46	2 X Ray tubes exhausted		8 00	11.25 11	P
	1 X " " repaired		7 50	11-13 11	P
	1 doz glass connectors		75	12-11-11	P

DEFENDANT'S EXHIBIT No. 76.

AUDION AMPLIFIER.
"Three-in-one" box.

Shop Card, Amplifiers (3-Stage).

1912.			Quantity	[redacted]	Quant. Used	Job No.	Balance
11	29	1-330, Fleischman		40.70	Chgd	Sa. b.	without audion bulbs
1913 4	31 25	Put in 3 audion bulbs		11.65			
4	29	One to one Radio Set 1-712-Anderson		10.10	62.45		
"	"	Shipped to San Francisco-Beach					

DEFENDANT'S EXHIBIT No. 77.

Audion Lamps
(Detector Bulbs).

Shop Card, Amplifier Tubes.

1913			Quantity	Cost	Quant. Used	Job No.	Balance
1	22	H W McCandless Co 67-69 Park ave	Expr 2	30¢ ea 4^{00} ea			2
"	"				2	Sal	—
				2^{50}			
3	25				3	Sexling	
4	3	Amplifier Bulbs					
4	24	6;6-1/2 3-1/2 V. Band. Capped with rubber insulation Double Grid and Plate	24	3^{10} ea deld Disc 5%	5		24 19
	26	F 287			1	So S F	18
	29	F 349			3	Beach	15
		F 404			3	Los A	12
5	10				2	So S F	10
6	4	Fuller			1	"	9
"	16				3	Los A	6
"	27				3	Beach	3
7	10	" " (Tested by Showroom)	12	3^{10} ea deld			15
"	13				6	Los A	9

DEFENDANT'S EXHIBIT No. 78.

U. S. DISTRICT COURT
DISTRICT OF DELAWARE
NOS 690 & 5[illegible] IN EQUITY

GENERAL ELECTRIC COMPANY
V
DE FOREST RADIO COMPANY

H. W. McCandless & Co. Inc.
MANUFACTURERS OF THE
EMPIRE
INCANDESCENT LAMPS & ELECTRICAL NOVELTIES
DECORATIVE [illegible]
A SPECIALTY
67-69 Park Place
Telephone 7089 Barclay
Cable Address
McANDLESS - NEW YORK
Lieber Code used.

New York, May 4, 1912.

Federal Telegraph Company,
Merchants Exchange Bldg.,
San Francisco, Cal.

Gentlemen:-

We have yours of the 27th ultimo and thank you for your order 2096 for 24 Aduion Bulbs embracing improvements of which we wrote.

This order will receive our best attention and we expect to make shipment by Express about Friday the 10th instant.

As we do not find your Company rated in the Commercial Agencies, we are taking the liberty of forwarding this material C.O.D. which we trust will be entirely satisfactory to you.

Yours very truly,
H.W. McCandless & Company,
by-

HWMcC/M.

DEFENDANT'S EXHIBIT No. 78-A.

H. W. McCandless & Co.
Manufacturers of
EMPIRE
CANDELABRA AND MINIATURE ELECTRIC LAMPS
TELEPHONES 5950 5951 BARCLAY
67-69 Park Place
CABLE ADDRESS
MCANDLESS—NEW YORK
LIEBER CODE USED

New York June 19, 1912.

Federal Telegraph Company,
Merchants Exchange Building,
San Francisco, Cal.

Gentlemen:-

Your order and favor of the 14th instant calling for three (3) Audion Bulbs with double plate and grid per sketch at hand.

We will make these up and expect to ship in about one week. Your list price will be $4.00 each net, and we suppose will be satisfactory to send C.O.D. as we did on previous order.

Awaiting your further commands, we remain,

Yours very truly,
H.W.McCandless & Company,
by- S H Boale

SHB/M.

Send Copy to De Forest

OK McH

DEFENDANT'S EXHIBIT No. 78-B.

H. W. McCandless & Co.
Manufacturers of
EMPIRE
CANDELABRA AND MINIATURE ELECTRIC LAMPS
TELEPHONES 5950 5951 BARCLAY
67-69 Park Place
New York
CABLE ADDRESS
MCANDLESS—NEW YORK
LIEBER CODE USED

Dec.23, 1912.

Federal Telegraph Company,
c/o U.S.Wireless Station,
Arlington, Va.

Gentlemen:-

December 17th we shipped C O D to your address as above, four (4) Audions, per Dr.DeForest's order.

We received card from the Adams Express Co. today dated Dec.20th from Washington, D.C. stating that your address is beyond the free delivery limits of this Company.

You probably have received notification from them that the Audions are there and if not will you kindly call at once upon them and take up same. Charges are $16.00 plus the Express delivery charges.

Yours very truly,
H.W.McCandless & Company,
by- S H Boates.

TSC/M.

Received + opr at Arlington ~~fo~~ with set rented to Navy for 250.00 per month

DEFENDANT'S EXHIBIT No. 78-C.

H. W. McCandless & Co.

Manufacturers of

EMPIRE

CANDELABRA AND MINIATURE ELECTRIC LAMPS

TELEPHONES 5950 5951 BARCLAY

67-69 Park Place

CABLE ADDRESS
MCANDLESS—NEW YORK
LIEBER CODE USED

New York

Jan. 8, 1913.

Federal Telegraph Co.,
Palo Alto, Cal.

Gentlemen:-

December 17th Dr. DeForest was in our office and asked that we forward to Federal Telegraph Co., c/o U.S. Wireless Sta., Arlington, Va. Four (4) of the double plate and grid detector bulbs which we did with C O D charges of $16.00 on the 17th of Dec.

Dr. DeForest was in again today and we called his attention to the fact that this C O D had never been taken up and he stated the gentleman who was to make a test there, finished the test before the lamps were delivered and he requested us to notify the Adams Express Co. to re-forward the lamps to you at Palo Alto, which we did according to copy of enclosed letter.

We are also sending to you today C O D, two (2) more of these bulbs which Dr. DeForest had ordered and on which the charges will be $8.00 and trust you will receive the two packages in good condition.

Yours very truly,
H. W. McCandless & Company,
by S H Boole

SHB/M.

DEFENDANT'S EXHIBIT No. 79.

April 27, 1912.

MESSRS. H. W. McCANDLESS & CO.,
67-69 Park Place,
New York City.

Gentlemen:-

Inclosed find Order #2096 for 24 Audion Bulbs embracing the improvements of which you wrote.

Kindly express these as soon as possible to the Factory of the Federal Telegraph Company, Palo Alto, California.

You can make out bill either to the writer or to the Federal Telegraph Company.

Trusting to receive an early shipment, I am

Very truly yours,

L de F /MCH

DEFENDANT'S EXHIBIT No. 79-A.

July 26, 1912.

H.W. McCANDLESS & CO.,
67-69 Park Place,
New York City.

Gentlemen:-

Out of the last lot of 24 audion bulbs which you manufactured for us there are only 4 that came up to proper sensitiveness test. Apparently the vacuum in the other bulbs is too low, because in these latter bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive. We are paying you a good price for these bulbs and expect therefore that you will send us others in exchange for these 20 or make proper allowance. In either case we must have 20 good bulbs at the earliest possible moment.

We are returning under separate cover one of these inferior bulbs so that you can judge for yourselves as to its vacuum

Awaiting your early reply,

Very truly yours,

P.S. Address reply to our Factory, 913 Emerson St., Palo Alto, Cal.

LdeF/MCH

DEFENDANT'S EXHIBIT No 79 B.

August 14, 1912

H. W. McCandless & Co.,
67 Park Place,
New York, N. Y.

Gentlemen:-

In reply to your favor of the 8th would say that the question of suitability of the audions is solely one of the standard of excellence which may be fixed upon. Evidently our standard is considerably higher than yours for there were only four of the 24 bulbs which meet that standard of sensitiveness. We took two of the poorest of the discarded 20 to a San Francisco glass-blower, unknown to fame, and had him exhaust same to as high a vacuum as his pumps would take. These re-exhausted bulbs now show a sensitiveness equal to those of the first four which prooves exclusively that our contention is correct. For the work which we demand from these bulbs they are not sufficiently sensitive and we would be glad therefore if you will reexhaust them. You certainly should be able to put them in as good condition as the aforesaid San Francisco glass-blower.

Awaiting your reply and trusting that we may receive the four special bulbs at an early date and in good condition and of highest vacuum, we are,

Yours very truly,

FEDERAL TELEGRAPH COMPANY

LdeF/M

By ____________________

DEFENDANT'S EXHIBIT No. 79-C.

October 16, 1912

Mr. G. E. Lamont,
San Francisco, Cal.

Dear Sir;-

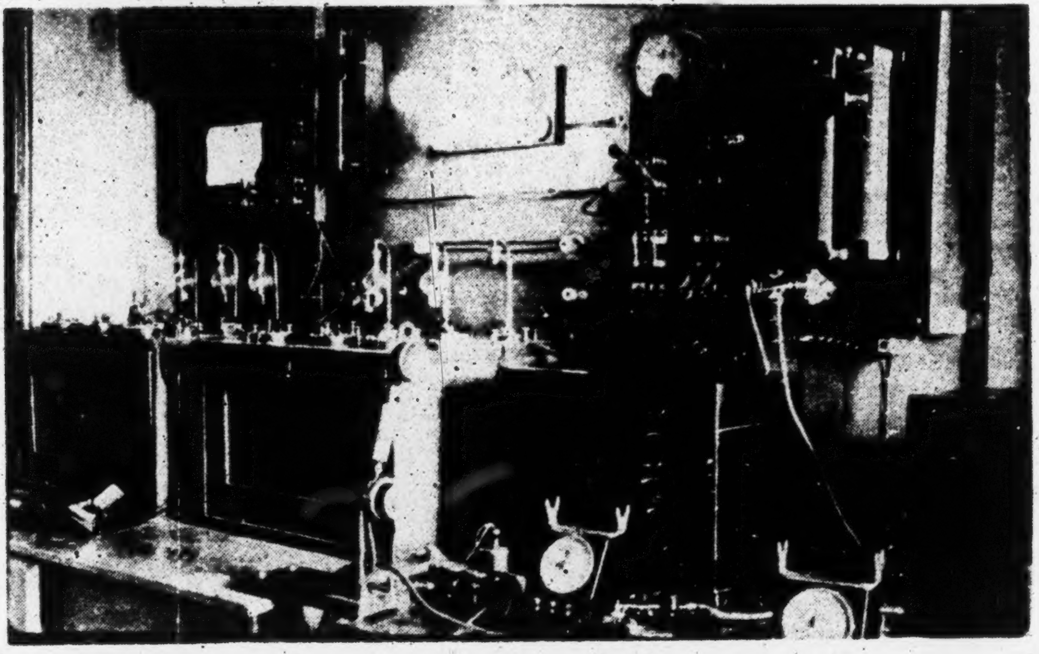
We enclose check in your favor for $5.40 covering your invoice of September 19th,

Yours very truly,

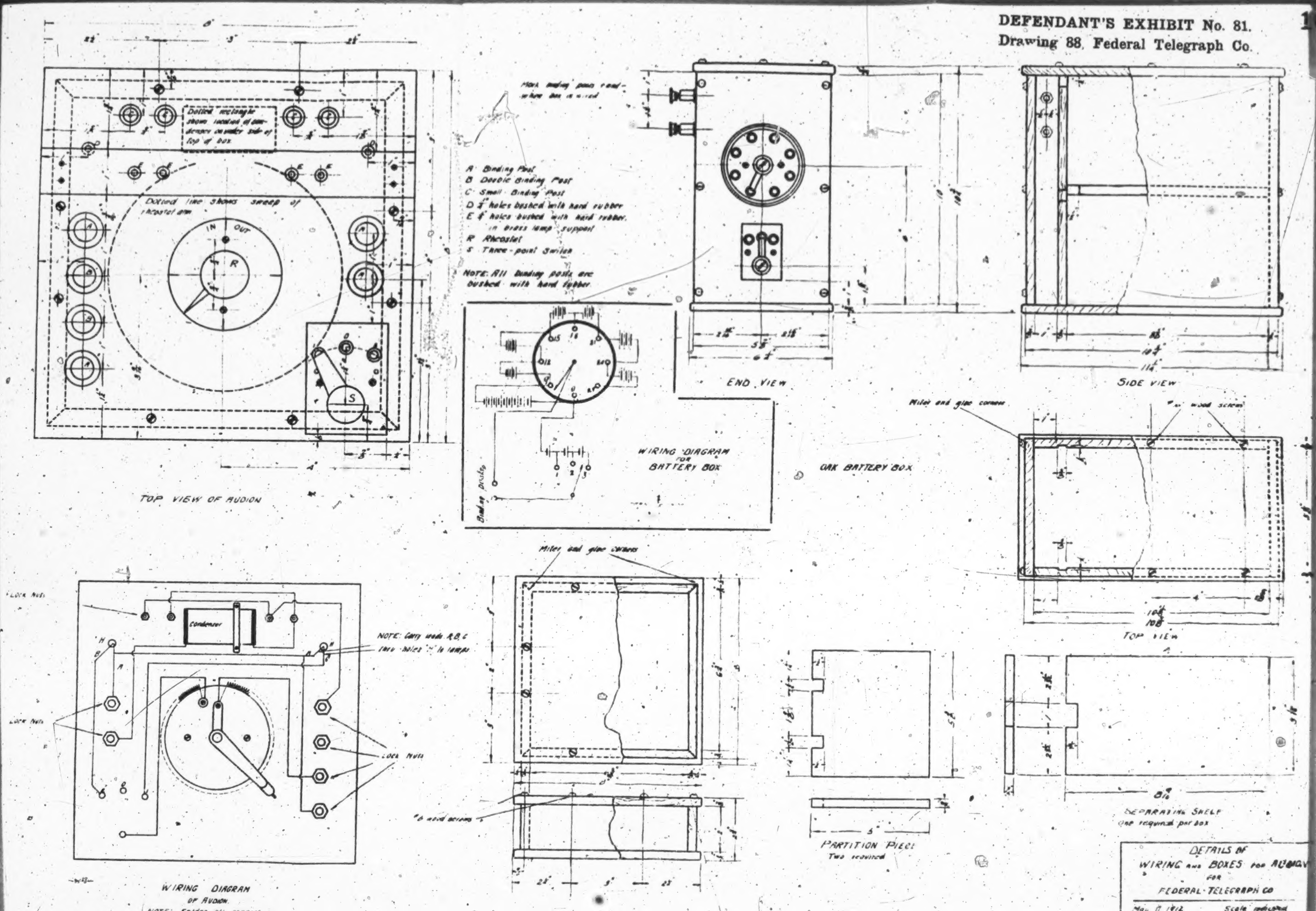
HPV/M

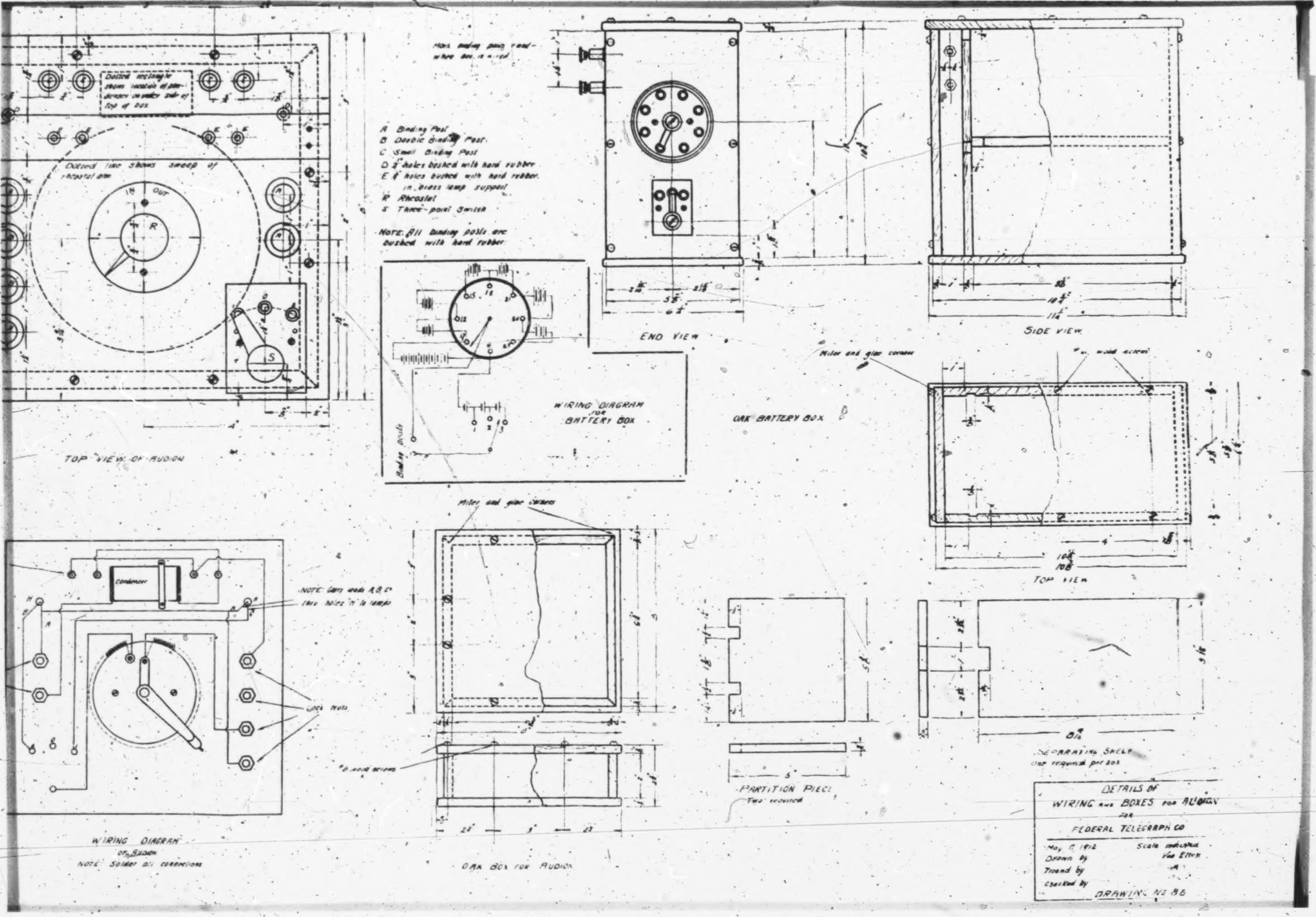
Secretary

DEFENDANT'S EXHIBIT No. 80.
Watkins Photograph.



DEFENDANT'S EXHIBIT No. 81.
Drawing 88, Federal Telegraph Co.


Dotted rectangle shows location of condenser on under side of top of box
Dotted line shows sweep of rheostat arm
IN
OUT
R
S
TOP VIEW OF AUDION
Mark binding posts read- where box is wired
A Binding Post
B Double Binding Post
C Small Binding Post
D holes bushed with hard rubber
E holes bushed with hard rubber in brass lamp support
R Rheostat
S Three-point Switch
NOTE: All binding posts are bushed with hard rubber
WIRING DIAGRAM FOR BATTERY BOX
Binding posts
END VIEW
SIDE VIEW
Miter and glue corners
wood screws
OAK BATTERY BOX
TOP VIEW
Lock Nuts
Condenser
NOTE: Carry leads A, B, C thru holes "H" to lamps
#6 wood screws
PARTITION PIECE
Two required
SEPARATING SHELF
One required per box
WIRING DIAGRAM OF AUDION
DETAILS OF WIRING AND BOXES FOR AUDION
FOR
FEDERAL TELEGRAPH CO
Scale indicated


TOP VIEW OF AUDION
Dotted rectangle shows location of partition on under side of top of box
Dotted line shows sweep of rheostat arm
IN
OUT
R
S
WIRING DIAGRAM FOR BATTERY BOX
Binding posts
END VIEW
SIDE VIEW
OAK BATTERY BOX
Miter and glue corners
TOP VIEW
WIRING DIAGRAM OF AUDION
Condenser
Lock nuts
OAK BOX FOR AUDION
PARTITION PIECE
Two required
SEPARATING SHELF
One required per box

Make binding post read- where box is used

A Binding Post
B Double Binding Post.
C Small Binding Post
D ½" holes bushed with hard rubber
E ¼" holes bushed with hard rubber. in brass lamp support
R Rheostat
S Three-point Switch

NOTE: All binding posts are bushed with hard rubber

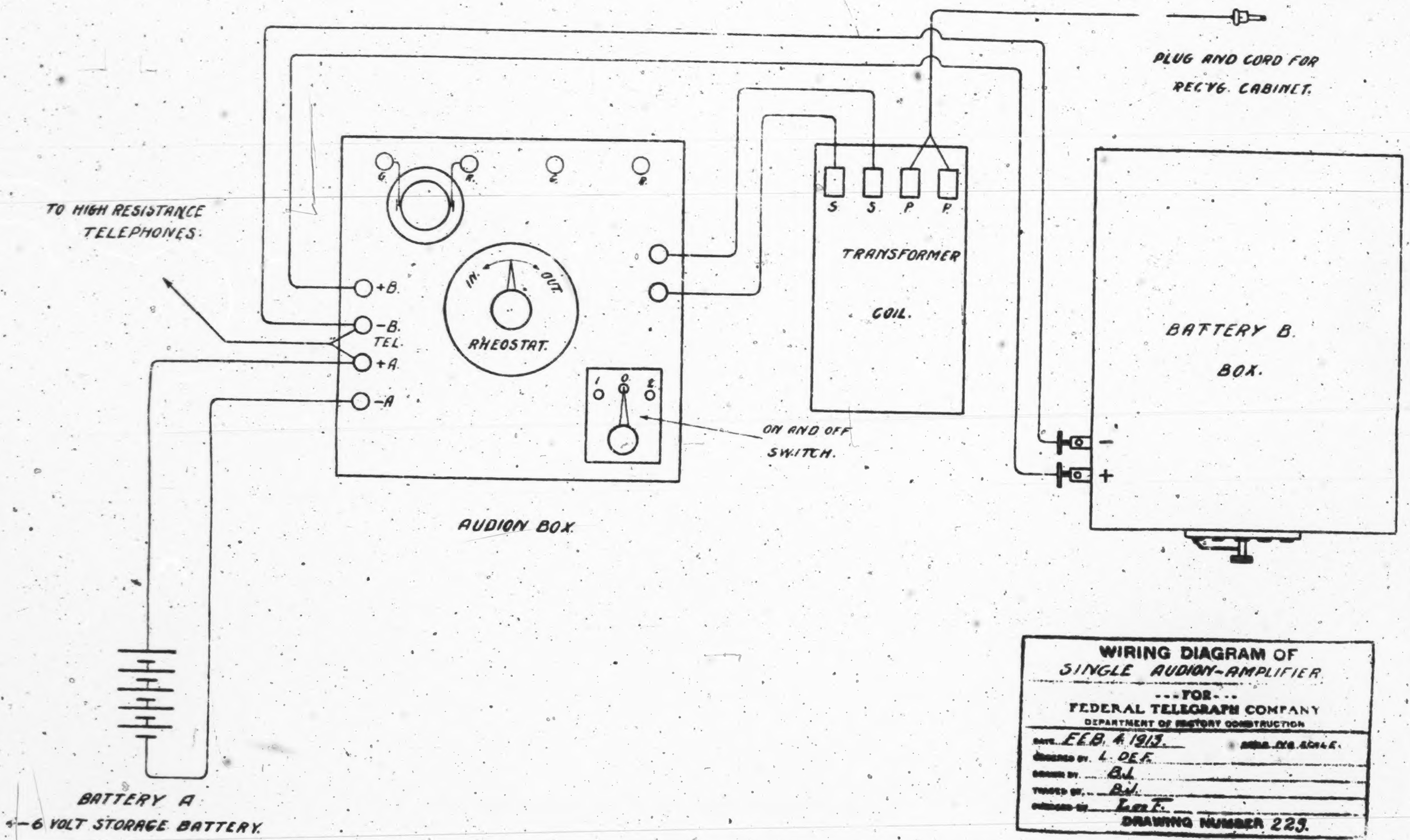
NOTE: Carry leads A, B, C thru holes "n" to lamps

NOTE: Solder all connections

DETAILS OF
WIRING AND BOXES FOR AUDION
FOR
FEDERAL TELEGRAPH CO

May 8, 1912
Scale indicated
Drawn by Van Etten
Traced by
Checked by
DRAWING NO 88

DEFENDANT'S EXHIBIT No. 82.
Drawing 229, Federal Telegraph Co.


PLUG AND CORD FOR
RECVG. CABINET.
TO HIGH RESISTANCE
TELEPHONES.
G.
R.
C.
B.
IN.
OUT.
RHEOSTAT.
+B.
-B.
TEL.
+A.
-A
I
O.
E.
ON AND OFF
SWITCH.
S.
S.
P.
P.
TRANSFORMER
COIL.
BATTERY B.
BOX.
-
+
AUDION BOX.
BATTERY A
—6 VOLT STORAGE BATTERY.

WIRING DIAGRAM OF
SINGLE AUDION-AMPLIFIER
---FOR---
FEDERAL TELEGRAPH COMPANY
DEPARTMENT OF FACTORY CONSTRUCTION

DATE FEB. 4. 1913. [illegible] NO SCALE.
DESIGNED BY L. DE F.
DRAWN BY B.J.
TRACED BY B.J.
CHECKED BY L. de F.
DRAWING NUMBER 229.

DEFENDANT'S EXHIBIT No. 83.

DeForest Audion Structure (California Depositions).

(*Exhibit Withdrawn.*)

DEFENDANT'S EXHIBIT No. 84.

Jahnke Tube (California Depositions).

(*Exhibit Withdrawn.*)

DEFENDANT'S EXHIBIT No. 85.

(Copy)

Room No. 261
Address only
"The Commissioner of Patents,
Washington, D. C.,"
and not any official by name.

DEPARTMENT OF THE INTERIOR
UNITED STATES PATENT OFFICE.
Washington, D. C.

IAW September 8, 1916.

In Re Interference No. 40380.

Arnold v. *Langmuir.* } Before the Examiner of Interferences.

Irving Langmuir, c/o Albert G. Davis, Schenectady, N. Y.

Please find below a communication from the EXAMINER in charge of Interferences in regard to the above-cited case.

Very respectfully,

(Sgd.) THOMAS EWING,
Commissioner of Patents.

In the preliminary statement of Langmuir the date, namely, the month of November, 1912, for the several allegations set forth therein, is too indefinite for the purposes of this interference. A more definite date should be given, if possible, in an amended statement to be filed on or before September 18, 1916.

For failure to so amend Langmuir will be restricted to November 30, 1912, for all of the allegations contained in the statement now on file.

(Sgd.) Louis E. Giles,
Acting Exr. of Interf.

DEFENDANT'S EXHIBIT No. 86.

(Copy)

POSTAL TELEGRAPH—COMMER[CIAL
CABLE]
Clarence H. Mackay, President
TELEGRAM

Received at
Interior Department
11th and F Streets, N.W.
63 W sf 34

G. E. Wks., Schenectady, N. Y., Sept. 15—16.

Edw. Williams,
Gen'l. Elec. Co., McLachlen Bldg.

Interference 40380 Arnold Langmuir offices
request for additional data preliminary
statement requires extensive investigation
interrupted by visitors here endea[vor]
secure week farther extension tel[egraph]
me early as possible tomorrow [ ]
morning.

Albert G. Da[vis]

DEFENDANT'S EXHIBIT No. 87.

(Copy)
IN THE
UNITED STATES PATENT OFFICE.

Arnold
v.
Langmuir.
Interference No. 40,380.

Supplemental Petition by Langmuir that Claims be Added to the Issue.

Hon. Commissioner of Patents,
Sir:

In a decision rendered herein and dated February 23, 1917, the Honorable Acting Commissioner of Patents held as follows:

> "Langmuir has filed an amendment to his application containing certain claims, and requests that they be added to the issue of the interference. Under the circumstances this amendment may be considered by the Law Examiner in connection with the motion to dissolve."

Counsel for Langmuir now respectfully petitions your Honor for an order directing that certain additional claims, proposed in the accompanying amendment, be considered by the Law Examiner at the same time and together with those which under the aforesaid decision, dated February 23, 1917, are to be considered by the Law Examiner.

The grounds for this petition may be stated briefly as follows:

A motion to dissolve has heretofore been filed by the opposing party Arnold, and has not yet come up for hearing. That motion, together with a supplemental motion filed by Arnold, cites a very large number of alleged anticipatory references, many of them in the German language. The subject-matter involved in interference is peculiarly difficult and complex and involves the work of scientists on the subject of the conduction of electricity through space.

Because of the enormous difficulties connected with a proper consideration of the subject-matter involved, the party Arnold moved for leave to take testimony of experts explanatory of the invention involved and of the bearing of the alleged references as anticipations of that invention. That motion was granted. Pursuant to an order of the Honorable Assistant Commissioner of Patents, a commission was issued for the taking of testimony in England on behalf of Arnold. That commission has been executed and the testimony taken and filed in this case. Other testimony has also been taken by the party Arnold and the *prima facie* case for Arnold under the motion completed.

The times set for Langmuir to complete his testimony have been extended from time to time during the period while the war was in progress because of the inability of the various parties interested to do anything other than work on scientific matters of great importance in connection with the prosecution of the war. Conditions having now become such that Langmuir and his associates have to a large extent been freed from work on Government matters, it is proposed to proceed with the taking of testimony on behalf of Langmuir. No testimony has as yet been taken in behalf of Langmuir.

It is to the interest of both parties, the office, and the public, that all questions relative to the subject-matter common to the devices of the interfering parties be determined if possible in one proceeding. The party Arnold has filed a motion to dissolve as already stated, and has filed a supplemental motion to dissolve, both of which, together with the additional claims heretofore proposed by Langmuir as claims that ought to form a portion of the issue, are to be considered by the Law Examiner upon the completion of the testimony in connection with the said motions to dissolve. The patentability of claims now forming the issue of the interference has been vigorously attacked by the party Arnold. It is desirable, therefore, in order that the proceedings may be expedited, that the Law Examiner should have before him, not only the claims of the issue as it now stands, but also any claims which might form a basis for a redeclaration of the interference to bring in issue the patentable invention common to the disclosures of the parties.

The case of Kurowski vs. Ramsey, 181 O. G., p. 820, is a precedent for the granting of a request to consider new claims in a case where a motion to dissolve has been brought by the opposing party and upon which no hearing has been had. Under such circumstances no additional delay or hardship would be imposed upon either party.

In the present case the request to add further claims is brought in such a time as to permit the party Arnold to conduct his cross-examination of Langmuir's witnesses in view thereof and also in time to permit Arnold to take such rebuttal testimony in view of said claims as may to him seem advisable.

The phrasing or drafting of claims in order clearly and lucidly to distinguish the invention common to the applications of the parties herein over the disclosures of the prior art is, because of the extreme complexity and technicality of the subject-matter involved, a most difficult matter. The claims presented in the accompanying amendment are believed by counsel for Langmuir to be patentable over every reference which has been cited by the Primary Examiner in the ex parte prosecution of both of the applications of the parties hereto and over every reference cited in Arnold's original motion to dissolve and in his supplemental motion to dissolve, as well as over all other prior art known to him.

The proposed claims are believed to be equally applicable to the structures of both parties (Ames v. Ryan, 238 O. G., p. 1639) but, on account of the extreme complexity of the subject matter involved, which is the basis for the practically unprecedented action of the Office in allowing herein the taking of testimony on Arnold's motions to dissolve, it would be premature for counsel, at this time without the light to be had from the testimony to be taken, to attempt to discuss the claims in detail.

However, we are not asking the Patent Office to pass upon these claims at this time. We are only asking for an order from your Honor that this offered amendment and the addition of these claims as further counts of the issue in the interference may be considered by the Law Examiner when he comes to pass upon the motion to dissolve. At that time the Law Examiner will have before him also the evidence, elicited by examination and cross-examination of the witnesses, to show the relation of these claims to the subject matter disclosed by the specifications of the parties and to the prior art which has been offered in evidenec by Arnold under the pending motion to dissolve.

It will then clearly appear that these claims should be added to the issue in order to insure a proper determination of the question of priority of invention.

Respectfully submitted,

IRVING LANGMUIR,

By (Sgd.) ALBERT G. DAVIS,

His Attorney.

DEFENDANT'S EXHIBIT No. 88.

(Copy)

R-d 142

Subject: Arnold v. Langmuir, Interference No. 40380.

* * * * * * * * * * * *
* Mail Room *
* Oct. 16, 1920 *
* U. S. Patent Office *
* * * * * * * * * * * *

* * * * * * * * * * * *
* Docket Clear *
* Oct. 15, 1920 *
* U. S. Patent Office *
* * * * * * * * * * * *

American Telephone and Telegraph Company
Telephone and Telegraph Building,
195 Broadway

New York, October 14, 1920. (M)

Commissioner of Patents,
Washington, D. C.

Dear Sir:

In connection with the motions to dissolve and to add counts to the issue, on which a hearing is set for 1:30 P. M., Thursday, October 21, 1920, ten copies of a brief for Arnold are now transmitted to the Patent Office under another cover, to be filed. To accompany this brief, counsel for Arnold have prepared a "reference book," containing printed extracts of the relevant portions of the "references" on the said motions. Ten copies of this reference book accompany the copies of the brief, and are to be filed therewith.

A copy of this letter and copies of the brief and reference book are at this time being sent to counsel for Langmuir.

Respectfully submitted,

(Signed) G. E. FOLK.

prosecution of both of the applications of the parties hereto and over every reference cited in Arnold's original motion to dissolve and in his supplemental motion to dissolve, as well as over all other prior art known to him.

The proposed claims are believed to be equally applicable to the structures of both parties (Ames v. Ryan, 238 O. G., p. 1639) but, on account of the extreme complexity of the subject matter involved, which is the basis for the practically unprecedented action of the Office in allowing herein the taking of testimony on Arnold's motions to dissolve, it would be premature for counsel, at this time without the light to be had from the testimony to be taken, to attempt to discuss the claims in detail.

However, we are not asking the Patent Office to pass upon these claims at this time. We are only asking for an order from your Honor that this offered amendment and the addition of these claims as further counts of the issue in the interference may be considered by the Law Examiner when he comes to pass upon the motion to dissolve. At that time the Law Examiner will have before him also the evidence, elicited by examination and cross-examination of the witnesses, to show the relation of these claims to the subject matter disclosed by the specifications of the parties and to the prior art which has been offered in evidenec by Arnold under the pending motion to dissolve.

It will then clearly appear that these claims should be added to the issue in order to insure a proper determination of the question of priority of invention.

Respectfully submitted,

IRVING LANGMUIR,

By (Sgd.) ALBERT G. DAVIS,

His Attorney.

DEFENDANT'S EXHIBIT No. 68.

(Copy)

R-d 142

Subject: Arnold v. Langmuir, Interference No. 40380.

Mail Room
Oct. 16, 1920
U. S. Patent Office

Docket Clear
Oct. 15, 1920
U. S. Patent Office

AMERICAN TELEPHONE AND TELEGRAPH COMPANY
Telephone and Telegraph Building,
195 Broadway

New York, October 14, 1920. (M)

Commissioner of Patents,
Washington, D. C.

Dear Sir:

In connection with the motions to dissolve and to add counts to the issue, on which a hearing is set for 1:30 P. M., Thursday, October 21, 1920, ten copies of a brief for Arnold are now transmitted to the Patent Office under another cover, to be filed. To accompany this brief, counsel for Arnold have prepared a "reference book," containing printed extracts of the relevant portions of the "references" on the said motions. Ten copies of this reference book accompany the copies of the brief, and are to be filed therewith.

A copy of this letter and copies of the brief and reference book are at this time being sent to counsel for Langmuir.

Respectfully submitted,

(Signed) G. E. FOLK.

DEFENDANT'S EXHIBIT No. 89.

(Copy)

AMERICAN TELEPHONE AND TELEGRAPH COMPANY
Telephone and Telegraph Building
195 Broadway

Docket Clerk
Oct. 15, 1920
Patent Office
George E. Folk,
General Patent Attorney.

NEW YORK, October 14, 1920.

(JC)

Honorable Commissioner of Patents
Washington, D. C.

Dear Sir:—

Interference No. 40380—Arnold v. Langmuir

This interference is now before the Law Examiner on a motion to dissolve and motions to amend the issue. By an order dated February 23, 1917 permission was granted to take testimony on the motion to dissolve, and a large volume of testimony relating to the patentability of the issue has been taken, printed and filed. The proofs were closed in January of the present year. Since then, the Patent Office has deferred the hearing from time to time on stipulations accompanied, during the latter part of the interval, by showings that the parties were negotiating for a settlement of their patent differences. A comprehensive license agreement has now been reached as a result of the negotiations.

Under the circumstances of the situation, I desire fully to acquaint the Patent Office with the changed situation, and to meet its views as to further procedure. I represent Arnold, the moving party on the motion to dissolve. The interests of the assignees of the respective applications in interference have now become in a measure identical by virtue of the license agreement.

The interference issue completely dominates the "vacuum tubes" now in common use for radio telegraphy and telephony and for wire telephony and telegraphy. The assignees of the respective applications in interference (or corporations affiliated with them) own or control patents of broad scope applying to vacuum tubes for these uses. Before these assignees reached their agreement, this situation created a deadlock; this was overcome for war needs, but became acute after the war. Upon the urgent suggestion of officials of the United States Government, the parties undertook negotiations to end this deadlock. The difficulties were enormous due to the wide variety and extent of the interests of the parties. After many months of patient effort, a far reaching contract of settlement was effected, involving the exchange of licenses for certain fields of use, which fields are different for different parties.

Accordingly, if the pending motions should be decided wholly against Arnold, and, if thereafter upon trial of the issue of priority the decision should be wholly against him, nevertheless Arnold's assignee has a license under the patent that would be granted to Langmuir, for certain fields of use, but not for all purposes.

Thus it will be seen that *practically* Arnold's assignee has no such interest in demonstrating the unpatentability of the subject matter of the pending motions as before this contract was effected. On the other hand, Arnold's assignee has an interest in that direction that is at least technical, for there are fields for which vacuum tubes might be used and for which the contract gives no license to Arnold's assignee. If it be assumed that the issues of the interference are patentable, then for the fields for which Arnold's assignee has a license, its interest, as a purely commercial matter, would be to have such a patent granted to Langmuir rather than to neither Langmuir nor Arnold; but for the fields for which it does not have a license the situation would be different.

After the testimony was closed in January, we prepared a careful brief on the motions. As shown by an affidavit accompanying the stipulation of March 31, 1920, the brief was in proof at that date. Since then, it has been changed a little but not extensively, and only in the direction of strengthening it.

The foregoing is an outline of the situation; stated briefly, the interest of the party Arnold and his assignee has been greatly modified, but by no means completely reversed. It is the expectation of the parties that when the patentability of the issues has been determined, if that leaves any issue of priority to be decided, it may be settled by concession of priority or by an agreed statement of facts upon which a judgment can be based, but of course the parties cannot by stipulation dispose of the question of patentability.

I am filing the brief and a copy of the contract at this time. Among the considerations that influence me to take this action is the knowledge that the Patent Office, in its care for the public interest, will desire all the data that may be available on the question of patentability. Having filed our record and having already prepared the brief, candor compels me to place it within the reach of the Patent Office.

I am not prepared to say on which side of the pending motions lies the balance of interest of Arnold and his assignee, and for this reason I am not prepared to withdraw my motions. But in view of the divided interest, I beg to be excused from making oral argument and it is my present expectation not to appear for that purpose.

If the Patent Office has any suggestions to make as to the course it wishes me to pursue in view of the changed situation here stated, I should expect to be guided thereby.

Respectfully submitted,

(Sgd) G. E. FOLK
General Patent Attorney.

DEFENDANT'S EXHIBIT No. 90.

(Copy)

IN THE UNITED STATES PATENT OFFICE.

Arnold
vs.
Langmuir.

Interference No. 40,380.

BEFORE THE LAW EXAMINER ON MOTION TO DISSOLVE AND TO AID COUNTS.

On a more careful and extended study of the counts of this interference and of the counts which Langmuir has proposed to add thereto, Langmuir has become convinced that certain of the counts do not bring out with all desirable directness or certainty, or both, certain features of the invention. In many cases a very slight change in the wording of the count would be sufficient to bring out those features in a perfectly clear way; in many cases the distinction, though not made directly, is contained in the counts by implication.

On the other hand, if the counts above referred to be corrected, directly or by implication, some of them become quite similar to other counts or claims also before the Law Examiner for his consideration in connection with this interference.

For the above reasons, to avoid duplicating claims, to relieve the Tribunal of unnecessary labor, to bring about an early decision of the pending motion so that the interference may proceed, and to reduce the number of claims in the application, Langmuir withdraws from the consideration of this Tribunal counts 1, 2, 3, 4, 6 and 7, and claims 24, 25, 27 and 28, leaving before the Tribunal for its consideration count 5, claim 26, and claims 1 to 9 of the claims presented in the motion of May 19th, 1919, and printed on pages 37, 38 and 39 of Arnold's brief herein.

If in order that counts 1, 2, 3, 4, 6 and 7 and claims 24, 25, 27 and 28 may be withdrawn from consideration it is technically necessary that the Law Examiner should rule that as drawn they are met by the prior art, Langmuir waives appeal from any such holding, his action in that respect being influenced by the motives above set forth, without any admission as to the patentability of the claims when construed with due regard to the invention as set forth in the specification.

A copy of this paper is being sent to Counsel for Arnold.

Respectfully submitted,

(Sgd.) ALBERT G. DAVIS,
Attorney for Langmuir.

Dated, New York City, New York,
February 2, 1921.

DEFENDANT'S EXHIBIT No. 91.

(Copy)

IN THE UNITED STATES PATENT OFFICE.

ARNOLD
vs.
LANGMUIR

INTERFERENCE No. 40,380.

STIPULATION.

WHEREAS, on February 25, 1921, the Law Examiner rendered a decision adjudging to be patentable certain claims that had been proposed as interference counts by the party Langmuir and suggesting to the party Arnold to make those claims, and

WHEREAS, the party Arnold has made said claims by a letter of Amendment filed March 17, 1921, of which letter the party Langmuir now acknowledges notice, and

WHEREAS, the party Arnold is also making two additional claims in said letter of Amendment which the party Langmuir desires to make and has made in a letter of amendment filed March 17, 1921, of which letter the party Arnold now acknowledges notice:

THEREFORE, IT IS STIPULATED AND AGREED, that, with the consent and approval of the Patent Office, the said two added claims shall be added to the interference issue along with the claims favorably adjudicated in the Law Examiner's decision of February 25, 1921, and

That Arnold's preliminary statement heretofore filed shall stand as his preliminary statement with respect to any and all counts that may be added from the claims contained in Arnold's said letter of Amendment, and

That an additional preliminary statement by Langmuir will be filed in the near future, and that notice thereof will be given to Arnold, and

That the Patent Office, immediately upon redeclaration of the interference adding counts from the said letters of Amendment, may set times for taking testimony.

The parties join in stating that they expect to prepare a stipulation as to the facts relating to priority and they hope to be ready to file it soon after the interference is redeclared, so that the Patent Office can then proceed at once to a decision of the question of priority based on such stipulation.

(Signed) ALBERT G. DAVIS
In Behalf of the Party Arnold.

Schenectady, N. Y.
March 15th, 1921.

(Signed) GEORGE E. FOLK
In Behalf of the Party Arnold.

New York, N. Y.
March 16, 1921.

DEFENDANT'S EXHIBIT No. 92

(Copy)

Docket Clerk
U. S. Patent
Office
Mar. 18, 1921
Copy Mailed

IN THE UNITED STATES PATENT OFFICE.

ARNOLD vs. LANGMUIR.

Patent Interference No. 40,380.

STIPULATION TO AMEND.

Electric Discharge Apparatus and the Process of Preparing the same.

Application of Harold de Forest Arnold filed November 2, 1915. No. 59,210.

Application of Irving Langmuir filed March 14, 1916, No. 84,242.

Renewal of Application filed October 16, 1913.

MESSRS. DE WITT C. TANNER and JOHN G. ROBERTS and MR. GEORGE E. FOLK for Arnold.

MR. ALBERT G. DAVIS for Langmuir.

The party Arnold has filed an amendment presenting the claims approved for additional counts of the issue in the decision of the law examiner dated February 25, 1921. He also includes two new claims, one of which adds to certain subject-matter deemed allowable and common to the two interferants, a third electrode which appears not to be specifically included in any original or proposed count heretofore considered. The other claim defines common patentable subject-matter in the form of a method.

The party Langmuir stipulates for the entry of the two new claims as additional counts, if the Patent Office should approve and adopts them by amendment. Upon consideration of the new claims it is found they are patentable and expressive of common subject-matter. No objection is seen to the inclusion of these claims as additional counts. The amendments may be entered and the interference will be redeclared in conformity with the decision of the law examiner dated February 25, 1921, supplemented by the present decision.

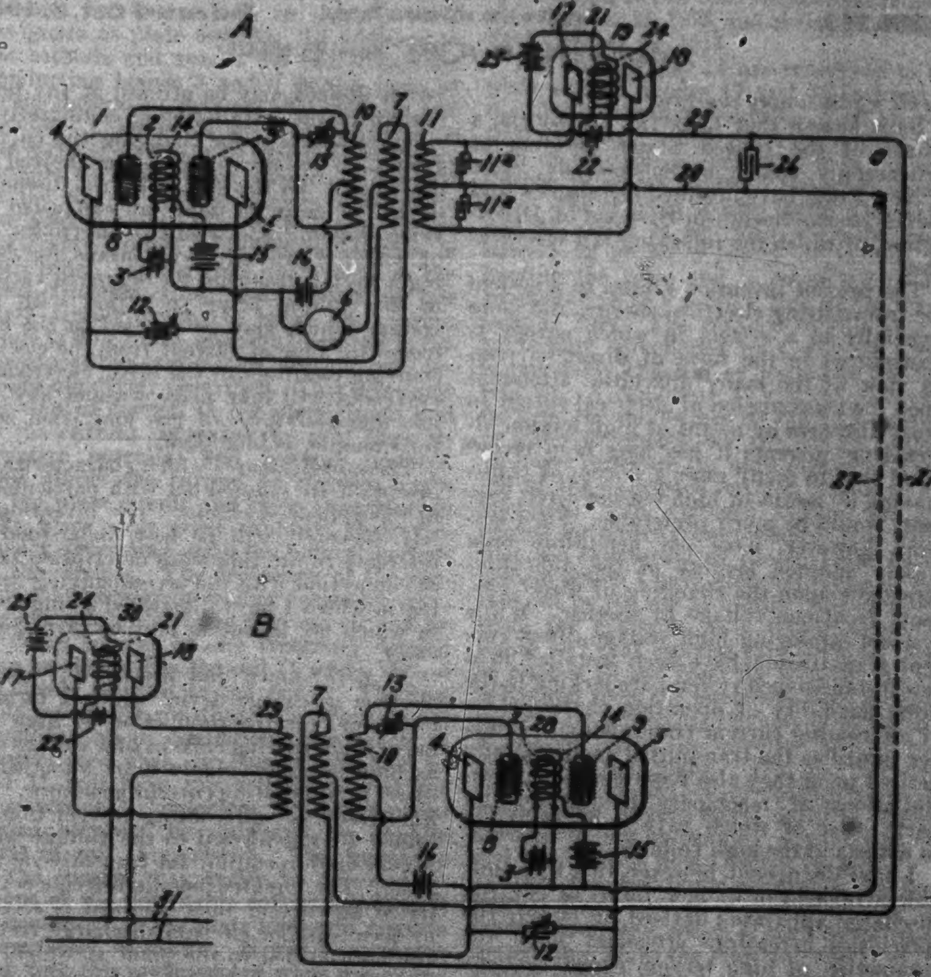
(Signed) I. P. DISNEY,
Law Examiner.

March 18, 1921.

DEFENDANT'S EXHIBIT No. 93.

I. LANGMUIR.
SYSTEM OF DISTRIBUTION.
APPLICATION FILED MAR. 31, 1914.

1,280,769. Patented Oct. 8, 1918.


A
B
1
2
3
4
5
6
7
8
9
10
11
11ª
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
30
31

Witnesses:
J. Ellis Glen.

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

SYSTEM OF DISTRIBUTION.

1,280,7[illegible]. Specification of Letters Patent. Patented Oct. 8, 1918.

Application filed March 21, 1914. Serial No. 826,479.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Systems of Distribution, of which the following is a specification.

The present invention relates to a system for transmitting electrical energy, and more especially to a system in which energy is transmitted in the form of direct current. In view of the many difficulties attendant upon the transmission of electrical energy to great distances by means of high tension alternating currents it has long been recognized that in many cases a system of transmission by means of high tension direct currents would be much preferable. Such systems, however, have not heretofore been widely adopted because of the difficulties attendant upon the changing of direct currents from one voltage to another. While systems employing high voltage direct current transmission have been installed in a few instances such systems are lacking in the great flexibility of operation characteristic of alternating current transmission. In order to utilize the transmitted energy at any desired point they also require expensive installations of machinery having moving parts, some of which have to be insulated to withstand the high voltages.

I have discovered, however, that by a suitable arrangement of new forms of electron discharge apparatus devised by myself the difficulties heretofore attendant upon the production of high tension direct currents may be overcome and that direct currents having a voltage at least as great as those now used in alternating current transmission may be obtained and economically transmitted to great distances. Furthermore the system which I am about to describe contains no moving parts and hence the insulation problems connected therewith are no more difficult than those met with in alternating current systems. It also has the same flexibility of operation as an alternating current system in that any amount of power desired may be utilized at any point desired by the installation of comparatively simple apparatus for changing the current from high voltage to the voltage desired for utilization. By the term "electron discharge device" I mean to imply an exhausted envelop containing at least two electrodes, one of which is provided with means for causing it to emit electrons, the degree of vacuum in the envelop being such that with any voltage which may be applied to the electrodes the flow of current from the electron emitting electrode to the other electrode or electrodes will take place without any visible manifestations of gas ionization such, for example, as blue glow.

The novel features which characterize my invention are pointed out with particularity in the appended claims. The invention itself, however, will be best understood by reference to the following description taken in connection with the accompanying drawing in which I have illustrated a single way in which my invention may be carried into effect.

As here shown and described I use an electron discharge device which I term an oscillator, for the production of high frequency, alternating current of a voltage such as may be easily obtained by an ordinary direct or alternating current generator. The high frequency alternating current thus obtained is transformed to the voltage which it is desired to employ for transmission purposes. The high tension, high frequency, alternating current thus obtained is rectified by means of an electron discharge rectifier and transmitted to the point at which it is desired to be utilized. At the receiving end of the system the high tension direct current is converted into high frequency, high tension alternating current by means of a second oscillator. The high frequency, high tension alternating current thus obtained is transformed to the voltage desired and is there rectified and led to the bus bars of the receiving station for utilization in any way desired.

As shown in the drawing the oscillator at the transmitting end A of the system comprises an exhausted envelop 1 which is usually of glass, a cathode 2 of filamentary form with means for heating the same consisting of a local battery 3 and two plate shaped anodes 4 and 5. An oscillatory circuit is provided between the cathode and each anode. Each oscillatory circuit comprises a source of energy 6 which may be a battery or a direct or alternating current generator and one-half of the coil 7. These circuits for convenience in description I designate as plate circuits. In addition to the cathode and anodes the tube comprises conducting bodies 8 and 9 in the form of grids interposed between the cathode and anodes. These grids are also connected to the cathode by means of external oscillatory circuits each of which comprises one-half of the coil 10. These circuits I designate the grid circuits. The coils 7 and 10 are preferably placed in inductive relation to each other. If the coils are wound in the same direction, when the current in one plate circuit begins to build up, current tends to flow in the opposite direction in the corresponding grid circuit, and the grid becomes negatively electrified. This cuts down the flow of current in the plate circuit and as the current decreases the grid loses its negative potential and becomes positive. This allows the current to increase again in the plate circuit and these changes may take place with great rapidity, their frequency depending upon the natural periods of the circuits. The frequency of the current changes may be readily varied by varying the constants of the grid circuit and by so doing current of any frequency desired may be obtained in the coil 11 which should be closely coupled to the coil 7. The two coils preferably constitute the primary and secondary of an oscillation transformer so proportioned that the current obtained in coil 11 will have the voltage desired for transmission. Condensers 11^a may be connected between the ends and the middle point of coil 11 as shown. The frequency of the current may easily be adjusted by means of the adjustable condensers 12 and 13 connected to the plate and grid circuits respectively, as shown. It will be apparent that with this arrangement when one of the grids is negative the other is positive and vice versa, and consequently when the current is decreasing in one plate circuit it is increasing in the other. As a result the current induced in the coil 11 is much greater than it would be if only a single plate circuit was in operation. To improve the efficiency of the device a conducting body may be provided in proximity to the cathode. This may take the form of a grid 14 surrounding the cathode but insulated therefrom. Upon this conducting body I impress a positive potential from the battery 15. In some cases also it may be desirable to impress an extra potential on the grids in order that they may normally have a certain definite potential with respect to the cathode. This may be done by means of an extra battery 16, as indicated. The form of electron discharge device here shown and the operation thereof are described and the novel features claimed in my co-pending applications Serial Nos. 795,608 and 795,610, filed October 16, 1913, and Serial No. 797,961, filed October 27, 1913.

The ends of coil 11 are connected to the plate shaped anodes 17 and 18 inclosed in the highly exhausted envelop 19 of an electron discharge rectifier and the middle portion of this coil is connected with the conductor 20 which leads to the transmission line. The envelop 19 also incloses the cathode 21 which is provided with the usual battery 22 or other source of current for heating the same and is connected by the conductor 23 to the other side of the transmission line. The cathode in this case is preferably surrounded by a grid 24 which is positively charged by means of the battery 25. A condenser 26 may be connected between the conductors 20 and 23 as shown, in order to smooth out the current pulses. In order to secure the high degree of vacuum of the exhausted envelop necessary for operation with voltages such as are employed for power transmission I have found that the exhaustion of the envelops in the devices which I have described must be carried out by the use of highly efficient means such, for example, as a Gaede molecular pump and that especial care must be taken to remove all gas from the walls of the envelop and from the electrodes both by heating and by subjecting the anodes to electron discharge while the envelop is still connected to the pump. The rectifier here shown and its method of operation are described and certain novel features thereof claimed in my co-pending application, Serial No. 797,966, filed October 27, 1913.

From the rectifying apparatus the high tension direct current is conducted over the transmission line, which is here indicated by dotted lines 27, to the receiving end B of the system located near a point where it is desired to utilize the energy transmitted. The direct current transmitted is brought to the plate circuits of the second oscillator 28 which may be of similar construction to the first one described. By this means it is converted to a high tension, high frequency alternating current and the voltage of this current is reduced by an oscillation transformer so that it appears in the coil 29 as a high frequency, low voltage alternating current. This high frequency alternating current is rectified by means of the electron discharge rectifier 30 which may be similar to the rectifier used at the transmitting end of the system. Inasmuch as the voltage of rectification may be comparatively low other forms of rectifiers may be employed at the receiving end if desired. From this rectifier current may be led to the bus-bars 31 of the receiving station from which it may be distributed locally as desired. It will of course be understood that as many generating or distributing points as desired may be connected to a single system of distribution.

While I have illustrated only a single organization whereby the desired result may be accomplished, many modifications thereof may be made without departing from the scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination of a source of direct current, an electron discharge device for converting the direct current into alternating current, means for transforming the alternating current into another alternating current of different voltage, and means for reconverting the last named alternating current into direct current.

2. The combination of a source of direct current, an electron discharge device for converting the direct current into high frequency alternating current, means for transforming the alternating current into another alternating current of different voltage, and means for reconverting the last named alternating current into direct current.

3. The combination of a source of current, an electron discharge device for converting the current from said source into high frequency alternating current, means for transforming the alternating current into another alternating current of different voltage, and means for reconverting the last named alternating current into direct current.

4. The combination of a source of direct current, an electron discharge device for converting the direct current into a high frequency alternating current, means for transforming the alternating current into another alternating current of different voltage and an electron discharge rectifier for reconverting the last named alternating current into direct current.

5. In combination in a system for transmitting electrical energy, a source of electrical energy, means for converting the energy from said source into a high frequency alternating current, means for rectifying said high frequency alternating current, an electron discharge device for reconverting said rectified current to a high frequency alternating current, and means for rectifying the last named alternating current.

6. The combination in a system for transmitting electrical energy of a source of electrical energy at the transmitting end of the system, an electron discharge device for converting said energy into high frequency alternating current, means for rectifying said alternating current, means at the receiving end of the system for reconverting said rectified current into high frequency alternating current, and means for rectifying said high frequency alternating current.

7. In combination in a system for transmitting electrical energy, electron discharge apparatus at the transmitting end of the system for producing high voltage direct current and means at the receiving end of the system for changing the voltage of the transmitted current.

8. The combination in a system for transmitting electrical energy of electron discharge apparatus at the transmitting end of the system for producing high voltage direct current and means comprising electron discharge apparatus at the receiving end of the system for changing the voltage of the transmitted current.

9. The combination in a system for transmitting electrical energy of electron discharge apparatus at the transmitting end of the system for producing high voltage direct current from a low voltage source of current and electron discharge apparatus at the receiving end of the system for changing the voltage of the transmitted current.

10. The combination of a source of direct current, means comprising an electron discharge device for producing a high frequency high voltage alternating current therefrom, and means for reconverting the alternating current into direct current.

11. The combination of a source of current, means comprising an electron discharge device for producing a high frequency high voltage alternating current therefrom, and means comprising an electron discharge device for reconverting the alternating current into a direct current.

12. The combination of a low voltage source of current, means comprising an electron discharge device for producing a high frequency, high voltage alternating current therefrom, and means for rectifying said alternating current.

13. The combination in a system of distribution of a source of electrical energy, an electron discharge device for converting the energy from said source into a high frequency alternating current, an electron discharge device for rectifying said high frequency alternating current, means for reconverting said rectified current to a high frequency alternating current, and means for rectifying the last named alternating current.

14. The combination in a system of distribution, of a source of low voltage direct current, an electron discharge device for converting the current from said source into high frequency alternating current, means

for transforming the alternating current into another alternating current of higher voltage, means comprising an electron discharge device for rectifying the last named alternating current, means comprising an electron discharge device for reconverting said rectified current to a low voltage high frequency alternating current and means for rectifying the last named alternating current.

In witness whereof, I have hereunto set my hand this 30th day of March, 1914.

IRVING LANGMUIR.

Witnesses:

Benjamin B. Hull,

William C. White.

DEFENDANT'S EXHIBIT No. 94.

A. W. HULL.

WIRELESS RECEIVING SYSTEM.

APPLICATION FILED MAR. 10, 1916.

1,291,527. **Patented Jan. 14, 1919.**

Fig. 1.

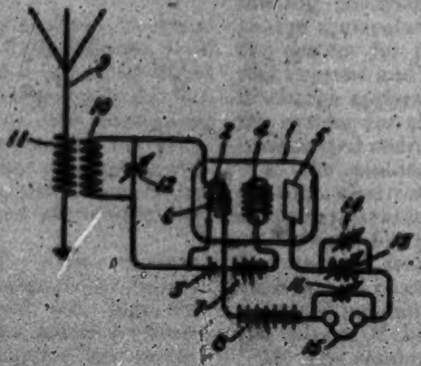
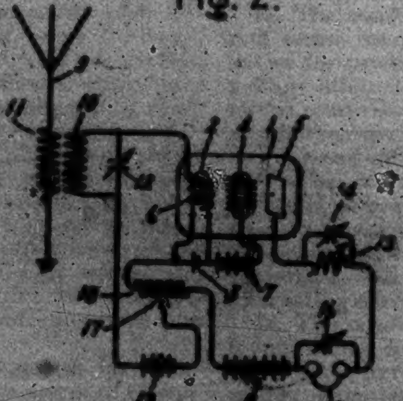

9
10
11
12
6
14
13
8
15

Fig. 2.


9
10
11
12
6
14
13
17
8
15

Inventor:
Albert W. Hull,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

WIRELESS RECEIVING SYSTEM.

1,291,527. Specification of Letters Patent. Patented Jan. 14, 1919.

Application filed March 12, 1917. Serial No. [illegible].

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Wireless Receiving Systems, of which the following is a specification.

My present invention relates to means for amplifying variable currents, and more particularly to means for amplifying and detecting currents produced by wireless signals in a receiving antenna.

In a paper published in the *Physical Review* of January, 1916, I have described an electron discharge device in which a negative resistance characteristic is obtained by producing, from an incandescent cathode, an emission of primary electrons, and from a coöperating electrode, an emission of secondary electrons of such a magnitude that the current between the two electrodes in an external circuit varies inversely as the potential between the electrodes. With this device the value of the negative resistance may be varied by varying the temperature of the cathode and thereby varying the number of primary electrons produced, since a variation in the number of primary electrons which reach the third electrode will cause a corresponding variation in the number of secondary electrons emitted. This device is described and claimed in my prior application Serial No. 47,988, filed August 30, 1915. In a prior application, S. N. 101,729, filed June 5, 1916, I have described and claimed a modification of this device in which the value of the negative resistance may be varied by varying the potential of a discharge controlling member in proximity to the cathode. I have also shown in the above mentioned application how this device may be utilized for receiving wireless signals.

The object of my present invention is to provide an improved circuit arrangement in which the device described in the application referred to may be utilized for receiving wireless signals whereby the sensitiveness and selectivity of the receiving circuit may be greatly increased.

A second object of my invention is to provide a receiving circuit which will be especially adapted for the reception of continuous wave signals by the so-called "heterodyne" method.

In carrying out the first object of my invention I provide inductance and capacity in circuit with the negative resistance, of such values that the circuit is resonant to the radio frequency of the waves to be received. The circuit is so arranged that oscillations will not be produced unless the value of the negative resistance is greater or less than a certain critical value. When the circuit is arranged in this way and received oscillations are impressed upon a controlling grid, the value of the negative resistance will be altered in such a way that oscillations will be produced in the circuit. As a result the selectivity and sensitiveness of the device or the degree of amplification of the received signals will be greatly increased. I also provide in conjunction with the telephone receiver a capacity of such value with respect to the inductance of the telephone receiver that the circuit will be resonant to a desired audio frequency which may be equal to the group frequency of the received signals. In order to provide a still further increase in the degree of amplification I provide means for transferring from the circuit containing the negative resistance to the circuit of the discharge controlling member an amount of energy sufficient to make up the losses in that circuit and in the antenna circuit to which it is coupled.

In attaining the second object of my invention I arrange the circuit containing the negative resistance in such a way that oscillations will be produced therein of a frequency slightly different from the frequency of the received oscillations. As a result the two sets of oscillations will combine to produce beats in the telephone receiver in accordance with the usual "heterodyne" method.

The novel features which I believe to be characteristic of my invention are pointed out with particularity in the appended claims. The invention, itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figures 1 and 2 show diagrammatically two different modifications.

As indicated diagrammatically in the drawing, an evacuated receptacle 1 is provided with a cathode 2, which is preferably a [illegible] of tungsten and which may be hea[illegible] incandescence by means of the battery [illegible] an anode 4 and a third electrode 5. A discharge controlling member 6 is also located in proximity to the cathode. The receptacle 1 is preferably exhausted to such a degree that with any operating voltage which may be employed the flow of current between the electrodes is not accompanied by any visible manifestation of gas ionization, such for example, as blue glow. In the operation of this device a definite positive potential is applied to the anode 4 by means of the battery 7, the cathode being considered as at zero or earth potential. If the cathode is heated to incandescence there will be a flow of electrons from cathode to anode. If the third electrode 5 is at the same potential as the cathode no electrons will be received thereby. If, however, a small positive potential less than that of the anode is applied to the third electrode a portion of the electrons will pass through the anode and reach the third electrode. The velocity with which these electrons will strike the third electrode will depend upon the potential between it and the cathode. If this potential is increased the velocity will increase until the electrons, striking the third electrode, are able, by their impact, to liberate secondary electrons. These secondary electrons leaving the third electrode will be attracted to the more positive anode. As the potential is increased, a point will be reached at which the number of secondary electrons leaving the third electrode increases faster than the number of primary electrons received, and the current which will flow in the external circuit between the cathode and third electrode will begin to decrease. As the potential of the third electrode is increased beyond this point, the current will continue to decrease and may even reverse in direction up to a point where the potential of the third electrode approaches that of the anode. Thus it will be apparent that the device has a working range through which it has a negative resistance characteristic; that is, over which the current in the external circuit between the cathode and the third electrode varies inversely as the potential between the electrodes. If now a constant potential is applied to the third electrode, by means of the battery 8, of such value that the device will operate as a negative resistance, there will be a constant flow of current in the external circuit. If, however, a variable potential is applied between the cathode and the discharge controlling member 6, the number of electrons which leave the cathode and reach the third electrode will be varied, and the current in the external circuit will be varied accordingly, that is, if the member 6 is made more positive, the flow of electrons to the third electrode will increase and if the member 6 is made more negative, the flow of electrons will decrease and a small change in the potential of the member 6 will be capable of producing a large change in the current between the cathode and the third electrode.

In utilizing this device for the reception of wireless signals, waves which are received upon the antenna 9 are impressed upon the discharge controlling member 6 by means of an oscillating circuit comprising an inductance 10 which is coupled to the antenna inductance 11 and a variable condenser 12. I also provide in the external circuit between cathode and third electrode a variable inductance 13 and a variable capacity 14 in parallel. This circuit may include the usual telephone receiver 15 shunted by a variable condenser 16. In receiving signals, by this system, the inductance 13 and capacity 14 may be so adjusted that the circuit is capable of oscillating at a frequency equal to that of the received signals. The value of [illegible] negative resistance is adjusted to such [illegible] point that the circuit is near a point of instability or a point where oscillations will begin. When the potential of the member 6 is varied by received oscillations, the value of the negative resistance will be changed sufficiently so that the circuit will [illegible] oscillating. Under these conditions the amplification of the received signals will be asymmetric and the resulting current will operate the telephone receiver to give the desired indication. Without the condenser 16 the circuit would tend to produce oscillations of an undesirable audio frequency. This condenser 16, however, may be so adjusted as to prevent the setting up of audio frequency oscillations or may be so adjusted as to produce audio frequency oscillations of a frequency equal to the group frequency of the incoming waves. The final adjustments of the system may conveniently be made by varying the value of the negative resistance by varying the temperature of the cathode 2.

In case the system described is used for receiving continuous waves, it may be so adjusted that continuous oscillations will be produced of a frequency slightly different from that of the received waves. The two sets of oscillations will then combine to produce beats in the telephone receiver 15. In order to secure the highest degree of amplification in the system above described, the positive resistance of the circuit should be approximately equal in value to the negative resistance.

In the arrangement shown in Fig. 1 the negative resistance compensates for the losses in the positive resistance of the circuit between cathode and third electrode. In the modification shown in Fig. 2 I have indicated means for compensating also for the losses in the resonant receiving circuit and the antenna. In this case the discharge controlling member 6, instead of being connected directly to the cathode 2, is connected to a suitably selected point 17 in the resistance 18 which is in series with the negative resistance. The voltage supplied to the device by the battery 8 is of such a value that the current in the circuit is negative, that is, positive electricity or its equivalent flows from cathode 2 to third electrode 5 across the evacuated space and thence through the battery 8 and resistance 18 back to the cathode. If the potential of member 6 is made more positive, the current through the resistance 18 will increase and thus the potential of the point 17 and of the member 6 will be still further increased. By means of this resistance coupling energy is fed-back from the negative resistance circuit to the resonant receiving circuit and by properly adjusting the point 17, the amount of energy thus transferred may be made sufficient to compensate for the losses in the receiving circuit and in the antenna without producing oscillations. A battery 19 may be included in this circuit in order to adjust the normal potential of the member 6 to a value at which it will operate most efficiently. Under these circumstances, the antenna coupling may be as close and its resistance as large as desired.

While I have illustrated and described only two modifications of my invention, it is by no means limited to the precise circuit arrangements shown as many modifications in the connections may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a wireless receiving system of an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, and means for applying received waves to the discharge controlling member.

2. The combination in a wireless receiving system of an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, means for applying received waves to the discharge controlling member and capacity and inductance connected in said external circuit and so adjusted that the circuit is resonant to a desired radio frequency.

3. The combination in a wireless receiving system of an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, means for applying received waves to the discharge controlling member, a telephone receiver in said external circuit and a capacity shunting said receiver and having a value so related to the inductance of the receiver that the circuit is resonant to a desired audio frequency.

4. The combination in a wireless receiving system of an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, means for applying received waves to the discharge controlling member, a telephone receiver in said external circuit and a capacity shunting said receiver and having a value so related to the inductance of the receiver that the circuit is resonant to a desired audio frequency, and capacity and inductance connected in said external circuit and so adjusted that the circuit is resonant to a desired radio frequency.

5. The combination in a wireless receiving system of an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, means for applying received waves to the discharge controlling member and capacity and inductance connected in said external circuit and so adjusted that radio frequency oscillations of a frequency slightly different from that of the received oscillations will be generated in said circuit during the operation of the system.

6. The combination in a wireless receiving system of an antenna, an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a dis-

charge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, a resonant circuit associated with said antenna and with said discharge controlling member for impressing received waves upon said member, and means for transferring from the first mentioned circuit to the resonant circuit a sufficient amount of energy to compensate for the losses in that circuit and in the antenna.

7. The combination in a wireless receiving system of an antenna, an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, a resonant circuit associated with said antenna and with said discharge controlling member for impressing received waves upon said member, and a resistance coupling between the two circuits for transferring energy from the negative resistance circuit to the resonant circuit to compensate for the losses in that circuit and in the antenna.

8. The combination in a wireless receiving system of an antenna, an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated receptacle, sources of potential applied to said electrodes of such values that the device has a negative resistance between cathode and third electrode which varies inversely as the potential applied to the discharge controlling member, a resonant circuit associated with said antenna and with said discharge controlling member for impressing received waves upon said member, a positive resistance in series with the negative resistance and a connection from said resonant circuit to a point in said resistance, said point being so chosen that energy will be transferred from the negative resistance circuit to the resonant circuit to compensate for the losses in that circuit and in the antenna.

In witness whereof, I have hereunto set my hand this 9th day of March, 1917.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 85.

J. H. PAYNE, Jr.

RADIOTELEPHONE SYSTEM.

APPLICATION FILED AUG. 26, 1918.

1,313,112. **Patented Aug. 12, 1919.**

Fig. 1.

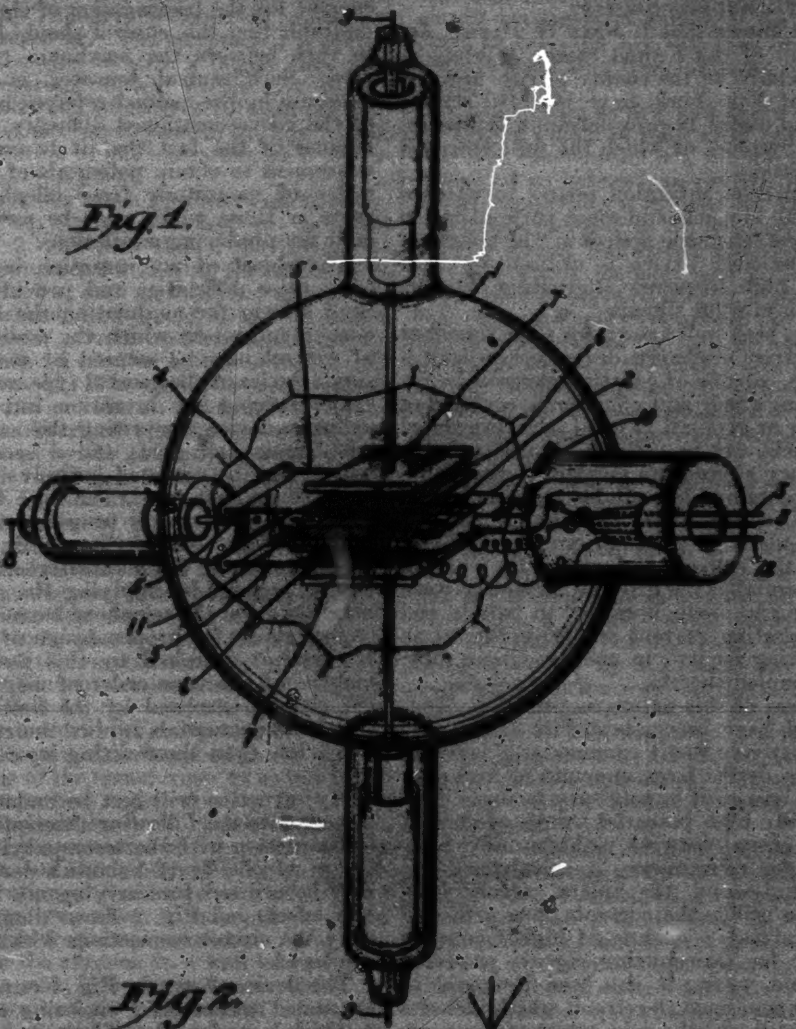
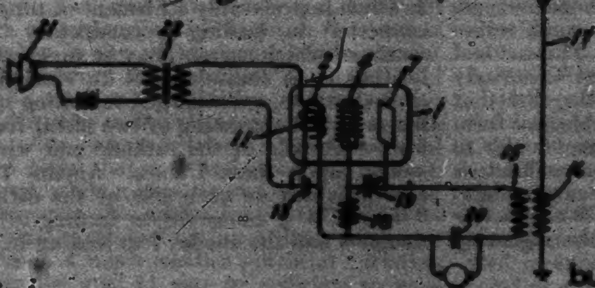

3
4
7
8
2
10
5
6
11
12
9

Fig. 2.


21
22
8
6
7
1
11
14
15
16
13
19
20
18
17

Inventor:
John H. Payne Jr.
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

JOHN H. PAYNE, JR., OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIOTELEPHONE SYSTEM.

1,313,112. Specification of Letters Patent. Patented Aug. 12, 1919.

Application filed August 26, 1916. Serial No. 117,132.

To all whom it may concern:

Be it known that I, JOHN H. PAYNE, Jr., a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Radiotelephone Systems, of which the following is a specification.

My present invention relates to wireless signaling systems, and more particularly to a wireless telephone system in which an electron discharge device is utilized for producing high frequency alternating currents for transmitting signals.

It has been well known for some time that an electron discharge device comprising a cathode, capable of emitting electrons, a coöperating anode and a discharge controlling member or grid, all inclosed in an evacuated receptacle, can be utilized to produce high frequency alternating currents. Such a result is obtained by suitable coupling of an external circuit which includes the cathode and anode with a second circuit which includes the cathode and grid. By varying the potential of the grid the current between cathode and anode is caused to pulsate and this pulsating current will give rise to an alternating current in another circuit suitably coupled thereto.

Devices of this nature as previously constructed have been adapted to carry only comparatively small currents and hence in order to derive large amounts of high frequency energy it is necessary to use a comparatively high potential source of current in the circuit between cathode and anode, which for convenience in description, has been designated the "plate circuit". In order to utilize the currents thus produced for obtaining a modulated high frequency current for transmitting signals produced by sound waves, it has been proposed to superimpose upon the circuit which includes the cathode and the grid, telephone currents which are produced by the sound waves which it is desired to transmit. This method of control has not been found to be entirely practical however because of the fact that when the potentials which are obtained from the telephone currents are large enough to secure an efficient control of the modulation of the signaling current the device tends to become unstable and stop oscillating. For the most efficient control of the signaling current for the transmission of signals it is desirable that this current should be caused to vary between the maximum value and zero. Such control, however, is not easy to secure by the method referred to because of the above mentioned difficulty, and also because of the fact that it is not usually convenient to obtain potentials of the same order of magnitude from telephone currents as those which may be used on the grid for producing oscillations.

The object of my invention is to overcome these difficulties and provide an efficient system for modulating the high frequency current in which the desired range of control may be secured by means of a single device of the general type referred to.

In carrying my invention into effect I utilize a device comprising the usual cathode, anode and grid, and a second grid which may be operated entirely independently of the first grid. The high frequency current is produced by coupling the circuit which includes one of these grids with the plate circuit and the modulation of the current is secured by applying the potential obtained from the telephone currents to the second grid. By proper design of the tube the control exercised by this second grid may be of the same order of magnitude as the control exercised by the first grid although the potentials applied thereto may be much less than those acting upon the first grid.

My invention will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 shows a device which may be utilized for carrying my invention into effect, and Fig. 2 shows diagrammatically the circuit connections which may be employed.

The device shown in Fig. 1 comprises an evacuated receptacle 1 inclosing a cathode 2, which is preferably a filament of tungsten connected to leading-in conductors 3 by means of which current may be supplied for heating it to incandescence to cause it to emit electrons, a discharge controlling member or grid 4 consisting of two metal frames 5 on each side of the cathode and wires 6 wound upon these frames. Anodes 7 are also provided on each side of the cathode. The grid 4 is connected to leading-in conductor 8 and the anodes 7 to leading-in conductors 9. While in the construction shown these anodes are entirely separate they may be connected together externally and operated as a single electrode. The frame work 10 which supports the cathode also supports a second grid 11 consisting of a fine wire wound back and forth upon the frame work in such a manner that it surrounds the cathode. This grid is connected to leading-in conductor 12. The receptacle 1 is preferably exhausted to such a degree that with any operating voltage which may be employed the flow of current between the electrodes is not accompanied by any visible manifestation of gas ionization, such for example, as blue glow.

Connections which I prefer to use in carrying my invention into effect are indicated in Fig. 2. As here shown the battery 13 supplies current for heating the cathode 2 to incandescence and an external circuit between cathode and anode includes a source 14 of direct current and an inductance 15, which may be coupled by the inductance 16 to antenna 17. The circuit between cathode and grid 4 includes an inductance 18. The two last described circuits are coupled to some extent by the electrostatic capacity between the electrodes. An additional coupling, however, is preferably furnished by the variable condenser 19 which is connected between anode 7 and grid 4. The frequency of the current produced may be varied by varying this condenser. The direct current source 14 is preferably shunted by a condenser 20 in order to by-pass the high frequency component of the current flowing in the plate circuit. Current for modulating the signals is furnished by the local circuit of a telephone transmitter 21 and potentials derived from this current are applied to the grid 11 by means of the transformer 22 as indicated. As long as there is no variation in the current flowing in the local circuit of the telephone 21 the potential of the grid 11 will be constant, and this grid will play no part in the operation of the device as a self excited oscillation generator. Under these conditions high frequency currents will be produced in the antenna in a well known manner. As soon, however as the current in the local circuit of the telephone 21 varies, the potential of grid 11 will vary and there will be a corresponding variation in the current flowing in the plate circuit of the device. Apparatus of this type may be so designed that a smaller potential variation upon this grid will be sufficient to vary the current in the plate circuit between a maximum and zero than that required upon the grid 4. Hence, while a variation of several hundred volts upon the grid 4 may be desirable to secure a maximum output of high frequency current, a much smaller potential variation upon the grid 11 may be sufficient to vary the current flowing in the plate circuit between a maximum and zero.

While I have illustrated one form of device which is suitable for carrying my invention into effect, it will be apparent that many modifications in the specific form and design of the apparatus used may be made, and also that various modifications in the circuit arrangement employed may be utilized in carrying my invention into effect without departing from the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a wireless signaling system of an antenna, an electron discharge device comprising a cathode, an anode and two grids inclosed in an evacuated receptacle, a circuit inductively coupled to said antenna which includes said cathode and anode and a source of energy, a second circuit electrostatically coupled to the first circuit which includes the cathode and one of the grids whereby the device acts as a self excited oscillation generator, a third circuit including the cathode and second grid, and a telephone circuit inductively related to the third circuit.

2. The combination in a wireless signaling system of an antenna, an electron discharge device comprising a cathode, an anode and two grids, inclosed in an evacuated receptacle, a circuit coupled to the antenna which includes said cathode and anode and a source of energy, a second circuit including the cathode and one of the grids coupled to the first circuit by a variable electrostatic coupling in such a way that high frequency currents will be induced in the antenna by the action of the device as a self excited oscillation generator, a third circuit including the cathode and second grid, and means for impressing a signaling current upon the third circuit.

3. The combination in a wireless signaling system of an antenna, an electron discharge device comprising a cathode, an anode and two grids inclosed in an evacuated receptacle, one of said grids being located at a greater distance from the cathode than the other, a circuit inductively coupled to said antenna which includes said cathode and anode and a source of energy, a second circuit coupled to the first circuit and which includes the cathode and the grid which is farthest from the cathode, a third circuit including the cathode and the grid nearest the cathode, and a telephone circuit inductively related to the third circuit.

4. The combination in a wireless signaling system of an antenna, an electron discharge device comprising a cathode, an anode and two grids inclosed in an evacuated receptacle, one of said grids being located at a greater distance from the cathode

than the other, a circuit operatively related to said antenna which includes said cathode and anode and a source of energy, a second circuit which includes the cathode and the grid which is farthest from the cathode, means for varying the potential of the grid of said second circuit at radio frequency, a third circuit including the cathode and the grid nearest the cathode, and a telephone circuit inductively related to the third circuit.

5. The combination in a wireless signaling system of an antenna, an electron discharge device comprising a cathode, an anode and two grids inclosed in an evacuated receptacle, one of said grids being located at a greater distance from the cathode than the other, a circuit inductively coupled to said antenna which includes said cathode and anode and a source of energy, a second circuit coupled to the first circuit and which includes the cathode and the grid which is farthest from the cathode, a third circuit including the cathode and the grid nearest the cathode, and means for impressing a low frequency signaling current upon the third circuit.

6. The combination in a wireless signaling system of an antenna, an electron discharge device comprising a cathode, an anode and two grids inclosed in an evacuated receptacle, one of said grids being located at a greater distance from the cathode than the other, a circuit operatively related to said antenna which includes said cathode and anode and a source of energy, a second circuit which includes the cathode and the grid which is farthest from the cathode, means for varying the potential of the grid of said second circuit at radio frequencies, a third circuit including the cathode and the grid nearest the cathode, and means for impressing a low frequency signaling current upon the third circuit.

7. The combination in a system for producing modulated radio frequency currents of an electron discharge device comprising a cathode, an anode and two grids inclosed in an evacuated receptacle, one of said grids being located at a greater distance from the cathode than the other, a circuit which includes said cathode and anode and a source of energy, a second circuit which includes the cathode and the grid which is farthest from the cathode, means for varying the potential of the grid of said second circuit at radio frequencies, a third circuit including the cathode and the grid nearest the cathode, and a telephone circuit inductively related to the third circuit.

8. The combination in a system for producing modulated radio frequency currents of an electron discharge device comprising a cathode, an anode and two grids inclosed in an evacuated receptacle, one of said grids being located at a greater distance from the cathode than the other, a circuit which includes said cathode and anode and a source of energy, a second circuit which includes the cathode and the grid which is farthest from the cathode, means for varying the potential of the grid of said second circuit at radio frequencies, a third circuit including the cathode and the grid nearest the cathode, and means for impressing a low frequency modulating current upon the third circuit.

In witness whereof, I have hereunto set my hand this 25th day of August, 1916.

JOHN H. PAYNE, Jr.

DEFENDANT'S EXHIBIT No. 96.

A. W. HULL.

METHOD OF AND MEANS FOR AMPLIFYING ELECTRICAL VARIATIONS.

APPLICATION FILED NOV. 8, 1915.

1,313,187. Patented Aug. 12, 1919.

Fig.1.

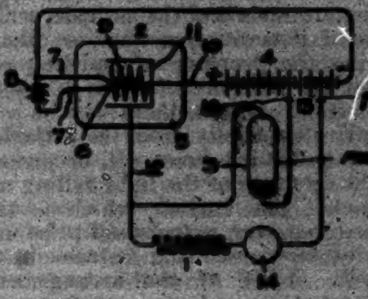

9
2
11
10
7
8
4
7
6
5
16
13
17
12
3
PHOTO ELECTRIC CELL
1
14

Fig.2.

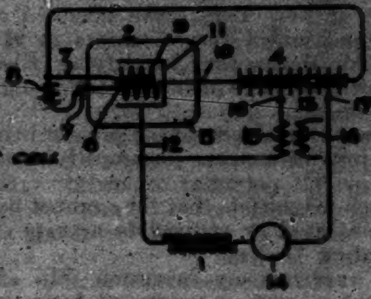
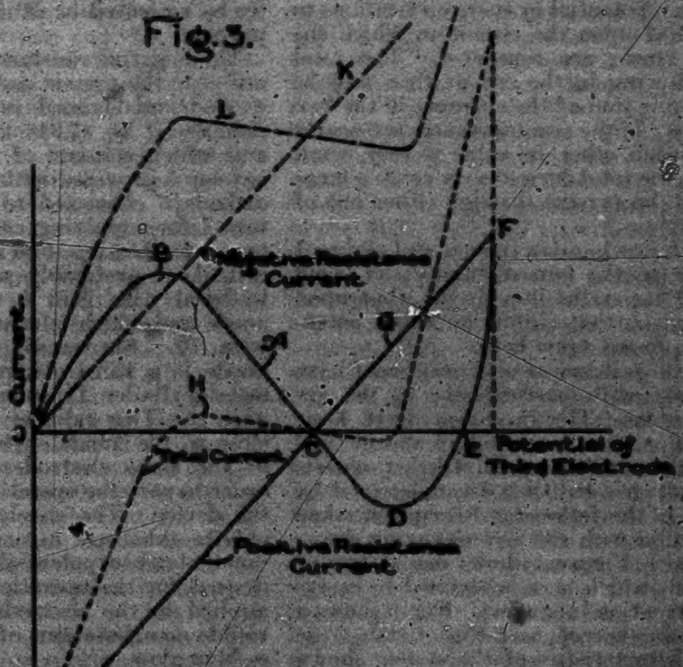

2
9
11
10
7
8
4
7
6
16
13
17
12
5
15
18
1
14

Fig.3.



Inventor:
Albert W. Hull,
by
His Attorney.

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AND MEANS FOR AMPLIFYING ELECTRICAL VARIATIONS.

1,313,187. Specification of Letters Patent. Patented Aug. 12, 1919.

Application filed November 8, 1915. Serial No. 60,431.

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Methods of and Means for Amplifying Electrical Variations, of which the following is a specification.

One of the objects of my present invention is to provide a means for amplifying electrical current, potential or energy variations of such magnitude that they cannot be readily measured or utilized to actuate desired recording devices.

In carrying my invention into effect I connect a negative resistance device in parallel with a positive resistance and impress the current, potential or energy variations to be amplified upon the circuit in which the two resistances are connected. The total current flowing in the circuit then will be the algebraic sum of the currents in the two resistances. If the two resistances are nearly equal to each other in value a very small change in the total current may cause a large change in the current through either one of the resistances.

In the following description and claims I will refer to the two resistances as being connected in parallel in a circuit when upon the closing of that circuit an equal potential is impressed upon both.

The novel features of my invention I have pointed out with particularity in the appended claims. The invention itself, however, both as to its construction and method of operation together with further objects and advantages, will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 shows one system of connections which may be devised in carrying my invention into effect, Fig. 2 shows a modification thereof, and Fig. 3 shows the current characteristics of the system shown in Fig. 2.

In the arrangement shown in Fig. 1 a positive resistance 1 or other device having positive resistance characteristics is connected in parallel with a negative resistance device 2. A photo-electric cell 3 is connected in series with the two resistances and the portion 17 of the battery 4 between the points 17 and 18 is included in the circuit to furnish current. It is a well known characteristic of photo-electric cells that when an electromotive force is applied to their terminals and the cathode, which consists of potassium, sodium or other metal having the property of emitting electrons under the influence of light, is subjected to the action of light, there will be a flow of negative electricity from the cathode to the anode and this current will be proportional to the intensity of the light falling upon the cathode. The current which is thus obtained, however, is too small to be measured by ordinary measuring instruments and the specific object of the arrangement here shown is to provide a means for amplifying this current to such a degree that it can readily be measured or utilized for any desired purpose.

The negative resistance which I prefer to utilize in the present case is one which is described and claimed in my prior application, Serial No. 47,938, filed August 30, 1915, and which consists of a highly evacuated envelop 5 provided with a tungsten filament cathode 6 connected to leading-in conductors 7 for supplying current from the battery 8 for heating it to incandescence. This cathode is preferably surrounded by a cylindrical wire grid 9 which serves as an anode and which is connected to leading-in wire 10. Surrounding the cathode and anode is a third electrode consisting of a metal cylinder 11 connected to leading-in wire 12. This cylinder is preferably fairly close to the anode. The relative positions of the three electrodes may be varied in order to vary the operating characteristics of the device. The envelop 5 should preferably be exhausted to such a degree of vacuum that when potentials of the magnitude desired for the operation of the device are applied to the electrodes there will be no visible manifestations of gas ionization such as blue glow.

If a positive potential is impressed upon the anode 9 there will be a flow of electrons from cathode to anode. If the third electrode 11 is at the same potential as the cathode no electrons will be received thereby. If, however, a small positive potential is applied to the third electrode a portion of the electrons which pass through the grid anode will strike it and it will receive a current of negative electricity. The velocity with which the electrons will strike the third electrode will depend upon the potential between it and the cathode. If this potential is increased the velocity will increase until the electrons striking the third electrode are able by their impact to liberate secondary electrons. These secondary electrons leaving the third electrode will be attracted to the more positive anode. As the potential is increased a point will finally be reached at which the number of secondary electrons leaving the third electrode is just equal to the number of primary electrons that strike it. That is, each electron that strikes liberates on an average one secondary electron. No current will then be received by the third electrode. If the potential of the third electrode is further increased the number of secondary electrons given off becomes greater than the number of primary electrons received and as a result the third electrode loses electrons, thereby supplying current to the anode instead of receiving current.

These characteristics can best be understood by reference to the curve shown at A in Fig. 3, in which the ordinates represent the electron current flowing to or away from the third electrode and the abscissæ represent the potential of the third electrode. The part O B represents the increasing electron current reaching the third electrode as the potential is increased. When the potential of the third electrode increases beyond that corresponding to the point B, the rate of increase in the emission of secondary electrons exceeds the rate of increase in the primary electrons received, and the current begins to decrease. When the potential of the third electrode reaches the point C it loses as many electrons as it receives and the current becomes zero. From C to D the number of secondary electrons given off continues to increase and the electron current from the third electrode to the anode increases. The point D is finally reached, however, at which the potential of the third electrode so closely approaches that of the anode that the number of secondary electrons lost by the third electrode begins to decrease because of the fact that the difference of potential between anode and third electrode is not great enough to attract as many electrons to the anode as before. This continues until the point E is reached where the number of secondary electrons which leave the third electrode and do not return, is equal to the number of primary electrons which strike it and the current again becomes zero. From this point the electron current received by the third electrode increases with increase in its potential as indicated by the part E F of the curve. The part B D of the current curve throughout the greater portion of its length is approximately straight and the straight portion may be represented by the equation

$$I = I_o - \frac{E}{R}$$

where E is the potential of the third electrode I, and R are constants, depending upon the characteristics of the particular device, and I is the electron current flowing to or away from the third electrode as

$$I_o - \frac{E}{R}$$

is positive or negative. R corresponds to the resistance of an ordinary circuit except in this case it is a negative resistance. Thus it will be seen that there is a certain range through which the device may be operated in which the current received by the third electrode will vary inversely as the potential applied thereto. In the description which follows and in the claims the term "negative resistance" is used to designate a device having this characteristic.

In the system shown in Fig. 1 battery 4 furnishes a constant potential for the anode 9. The resistances and the potential applied thereto are preferably so adjusted that when the photo-electric cell 8 is not illuminated and hence there is no current flow therethrough there will be no current through either resistance. This may be accomplished by connecting the end of the resistance 1 to a point 17 in the battery 4, so chosen that the potential thereby applied to the third electrode 11 will correspond to the point C on the current curve. Since under these conditions no current will flow through the negative resistance there will not be any current through the positive resistance. The current through the positive resistance then under operating conditions may be represented by the straight line G which falls above or below the axis of ordinates, as indicated, with reversals in the potential applied thereto. The total current in the circuit or the current in the photo-electric cell will be the algebraic sum of the current through the two resistances. The algebraic sum of these two currents with varying potentials on the third electrode is indicated by the dotted line H. By making the two resistances approximately equal to each other in value so that the slope of curves A and G is approximately the same it will be seen that a very small change in the total current will cause a much greater change in the current through either of the two resistances and it will be apparent that the degree of amplification which can thus be secured will depend upon how closely the two resistances approach each other in value.

When the photo-electric cell is not influenced by any light source the portion 13 of battery 4 is open-circuited in so far as its effect on the current through either resistance is concerned. When the photo-electric cell is illuminated by any light source current starts to flow therethrough and there is, in effect, a potential applied to both the negative and positive resistances in parallel which is equal to the potential of the portion 13 of the battery 4 less the drop in potential through the photo-electric cell. Since the current through the photo-electric cell varies in proportion to the intensity of the illumination thereon this drop in potential will vary in proportion to the intensity of the illumination. The effect of the application of this potential, however, is not the same in both resistances. An inspection of the curves of Fig. 3 will show that a change in potential from that corresponding to point C will produce a current in one direction in the negative resistance and in the opposite direction in the positive resistance. Hence, it will be apparent that the result of applying the potential mentioned to the two resistances will be to produce a current which circulates between the two resistances and which does not flow through the photo-electric cell. The currents in the two resistances, however, will not be equal as the current in the resistance in which the current flows in the same direction as that in the photo-electric cell will be greater than the current in the other resistance by an amount equal to the current in the photo-electric cell. In other words the current through one of the resistances may be considered as made up of two parts; one part which flows through the photo-electric cell and one part which flows through the other resistance, while the current in the other resistance will be merely the current which circulates between the two resistances and does not pass through the photo-electric cell. It may be shown mathematically that the current through either resistance will bear substantially the same ratio to the current in the photo-electric cell that the value of the resistance bears to the difference between the two resistances.

In other words, the current in the recording instrument 14 or other desired device which may be inserted in series with the resistance 1 will bear the same ratio to the current in the photo-electric cell that the resistance 1 bears to the difference between the two resistances. This will be true irrespective of the nature of the current in the photo-electric cell, that is, whether it is a constant current or a pulsating current. The same amplifying action will also take place if a source of alternating current is substituted for the photo-electric cell 3. If the current is alternating the currents in the two resistances will reverse in direction at the same time that the total current reverses in direction as can be seen from curves A, G and H.

In the above description it has been assumed that the total current in the circuit starts from zero or changes in sign. It is not essential however that this should be the case as the same principle can equally well be applied to the amplification of small changes in unidirectional currents of relatively large magnitude. If the resistance 1 were connected, for example, to the same point in the battery as the cathode 6 the current through the positive resistance would be as indicated by the curve K and the total current in the circuit would follow the curve L. If than the total current in the circuit had such a value that it fell on the portion of the curve where the resistance 2 is negative, changes in current would be amplified in the same manner as in the case first described. By varying the point of connection of the resistance 1 to the battery it will be seen that the system can always be adjusted so that the total current in the circuit will fall upon a portion of the curve where the resistance 2 is negative.

The form of my invention illustrated in Fig. 2 differs from that shown in Fig. 1 in that the photo-electric cell is replaced by the secondary 15 of a transformer, the primary 16 of which may be supplied by a telephone current or any other variable current which it is desired to amplify.

In the above description and in the claims which follow, I have used such expressions as "current flow from cathode to third electrode" to designate the net electron current received by the third electrode, or the current which will flow in the external circuit between cathode and third electrode.

While I have described the preferred embodiment of my invention it will be apparent that many changes therein may be made without departing from the scope of the appended claims. For example, in case it is desired to measure or utilize amplified potential variations the device for accomplishing the desired purpose is connected in shunt to the resistance 1 instead of in series therewith. It will also be apparent that the device 14 indicated may assume a great variety of forms in accordance with the purpose which is to be accomplished.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. Means for amplifying electrical variations comprising a positive resistance and a negative resistance in parallel therewith, the two resistances being approximately equal to each other in value.

2. Means for amplifying electrical variations comprising a device having positive resistance characteristics and a negative re-

sistance in parallel therewith, the two resistances being approximately equal to each other in value.

3. Means for amplifying electrical variations comprising a positive resistance, a negative resistance, and means for supplying the variations to be amplified to the two resistances in parallel.

4. Means for amplifying electrical variations comprising a negative resistance having a working range over which the current flow therethrough varies inversely as the potential applied thereto, a positive resistance, and means for supplying the variations which are to be amplified to the two resistances in parallel.

5. Means for amplifying electrical variations comprising a negative resistance having an electron emitting cathode, and having a working range over which the current flow varies inversely as the potential applied thereto, a positive resistance and means for supplying the electrical variations to be amplified to the two resistances in parallel.

6. Means for amplifying electrical variations comprising a negative resistance having an electron emitting cathode, an anode and a third electrode inclosed in a highly evacuated envelop, and having a working range over which the current flow from the cathode to the third electrode varies inversely as the potential applied thereto, a positive resistance and means for supplying the electrical variations which are to be amplified to the two resistances in parallel.

7. Means for amplifying electrical variations comprising a negative resistance having an electron emitting cathode, an anode, and a third electrode near the anode and so positioned with respect to the cathode and anode that it will receive electrons from the cathode when it is more positive than the cathode, and so that secondary electrons given off from the third electrode can readily reach the anode, a positive resistance, and means for applying the electrical variations which are to be amplified to the two resistances in parallel.

8. Means for amplifying electrical variations comprising a negative resistance, a positive resistance, and means for supplying electrical variations which are to be amplified to the two resistances in parallel, the two resistances being approximately equal to each other in value.

9. The method of amplifying electrical variations which consists in supplying variations which are to be amplified to a positive resistance and a negative resistance in parallel, and thereby producing amplified electrical variations in the positive resistance.

In witness whereof, I have hereunto set my hand this 6th day of November 1915.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 97.

A. W. HULL.
MEANS FOR PRODUCING ALTERNATING CURRENTS.
APPLICATION FILED NOV. 3, 1915.

1,313,188. **Patented Aug. 12, 1919.**

Fig. 1.

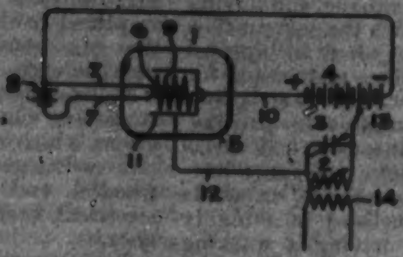
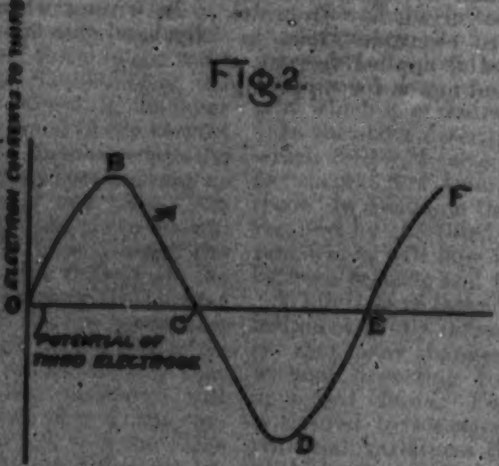

6
9
1
3
8
7
11
5
10
+
4
−
3
13
2
12
14

Fig. 2.



Inventor:
Albert W. Hull.
by
His Attorney.

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR PRODUCING ALTERNATING CURRENTS.

1,312,1[illegible]. Specification of Letters Patent. Patented Aug. 12, 1919.

Application filed November 8, 1915. Serial No. 60,[illegible].

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Means for Producing Alternating Currents, of which the following is a specification.

The object of my present invention is to provide a means for producing alternating currents of any frequency desired from a source of direct current.

In carrying my invention into effect I make use of a negative resistance device in a circuit containing positive resistance, inductance and capacity and a source of direct current. I am aware that systems have heretofore been used in which the negative resistance effect of an arch has been employed. In this case the effect is brought about by gas ionization and as a result there is an appreciable lag in the action. In the present case, however, I make use of a negative resistance device in which the current both increases and decreases inversely with changes in the potential applied thereto, independently of any gas ionization and without any lag in its action.

The novel features of my invention I have pointed out with particularity in the appended claims. The invention itself however both as to its construction and method of operation together with further objects and advantages, will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 shows one system of connections which may be used in carrying my invention into effect; Fig. 2 shows the current characteristics of one of my negative resistance devices.

In the arrangement shown in Fig. 1 a negative resistance device 1 is connected in series with a variable inductive resistance 2 and a condenser 3 and a portion of the battery 4 is included in the circuit to furnish the energy from which the alternating currents are produced.

The negative resistance which I utilize in the present case is one which is described and claimed in my prior application, Serial No. 47,[illegible], filed August 30, 1915, and which consists of a highly evacuated envelop 5 provided with a tungsten filament cathode 6 connected to leading-in conductors 7 for supplying current from the battery 8 for heating it to incandescence. This cathode is preferably surrounded by a cylindrical wire grid 9 which serves as an anode and which is connected to leading-in wire 10. Surrounding the cathode and anode is a third electrode consisting of a metal cylinder 11 connected to leading-in wire 12. This cylinder is preferably fairly close to the anode. The relative positions of the three electrodes may be varied in order to vary the operating characteristics of the device. The envelop 5 should preferably be exhausted to such a degree of vacuum that when potentials of the magnitude desired for the operation of the device are applied to the electrodes there will be no visible manifestations of gas ionization such as blue glow.

If a positive potential is impressed upon the anode 9 there will be a flow of electrons from cathode to anode. If the third electrode 11 is at the same potential as the cathode no electrons will be received thereby. If, however, a small positive potential is applied to the third electrode a portion of the electrons which pass through the grid anode will strike it and it will receive a current of negative electricity. The velocity with which the electrons will strike the third electrode will depend upon the difference of potential between it and the cathode. If this difference of potential is increased the velocity will increase until the electrons striking the third electrode are able by their impact to liberate secondary electrons. These secondary electrons leaving the third electrode will be attracted to the more positive anode. As the potential is increased a point will finally be reached at which the number of secondary electrons leaving the third electrode is just equal to the number of primary electrons that strike it. That is, each electron that strikes liberates on an average one secondary electron. No current will then be received by the third electrode. If the potential of the third electrode is further increased the number of secondary electrons given off becomes greater than the number of primary electrons received and as a result the third electrode loses electrons, thereby supplying current to the anode instead of receiving current.

These characteristics can best be understood by reference to the curve shown at A in Fig. 2 in which the ordinates represent the electron current flowing to or away from the third electrode and the abscissæ represent the potential of the third electrode. The part O B represents the increasing electron current reaching the third electrode as the potential is increased. When the potential of the third electrode increases beyond that corresponding to the point B, the rate of increase in the emission of secondary electrons exceeds the rate of increase in the primary electrons received and the current begins to decrease. When the potential of the third electrode reaches the point C it loses as many electrons as it receives and the current becomes zero. From C to D the number of secondary electrons given off continues to increase and the electron current from the third electrode to the anode increases. The point D is finally reached however at which the potential of the third electrode so closely approaches that of the anode that the number of secondary electrons lost by the third electrode begins to decrease because of the fact that the difference of potential between anode and third electrode is not great enough to attract as many electrons to the anode as before. This continues until the point E is reached where the number of secondary electrons which leave the third electrode and do not return is equal to the number of primary electrons which strike it and the current again becomes zero. From this point the electron current received by the third electrode increases with increase in its potential as indicated by the part E F of the curve. The part B D of the current curve throughout the greater portion of its length is approximately straight and the straight portion may be represented by the equation

$$I=I_0-\frac{E}{R}$$

where E is the potential of the third electrode, I_0 and R are constants, depending upon the characteristics of the particular device, and I is the electron current flowing to or away from the third electrode as

$$I_0-\frac{E}{R}$$

is positive or negative. R corresponds to the resistance of an ordinary circuit except in this case it is a negative resistance. Thus it will be seen that there is a certain range through which the device may be operated in which the current received by the third electrode will vary inversely as the potential applied thereto. In the description which follows and in the claims the term "negative resistance" is used to designate a device having this characteristic.

In the system shown in Fig. 1, battery 4 furnishes a constant potential for the anode 3. The portion 13 of this battery supplies the potential which is applied to the third electrode 11. When the system is connected in this way and the capacity and inductance are properly proportioned the current in inductance 2 will vary, becoming either an alternating current or a pulsating direct current. In either case an alternating current will flow in a circuit connected to inductance 14 which is coupled to inductance 2. The frequency of this current may be varied by varying the capacity or inductance. It is also dependent to some extent upon the resistance 2 and the value of the negative resistance. In order that the system may oscillate, the product of the two resistances should be numerically less than the ratio of inductance to capacity. The alternating current obtained in the manner which I have described may be utilized for any desired purpose; for example, inductance 14 might be connected to an antenna and by the use of suitable signal producing apparatus the current be employed for transmitting wireless signals. In the above description and in the claims which follow I have used such expressions as "current flow from cathode to third electrode" to designate the net electron current received by the third electrode, or the current which will flow in the external circuit between cathode and third electrode.

While I have shown and described the preferred embodiment of my invention, various modifications therein may be made without departing from the scope of the appended claims; for example, the capacity instead of being placed in parallel with the inductive resistance may equally well be connected in parallel with the negative resistance.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. Means for producing alternating currents comprising a circuit which includes capacity and inductance and a device having a plurality of electrodes inclosed in a receptacle evacuated to such a degree that the device is operable independently of gas ionization, and sources of potential of such values applied to the electrodes that the device has a working range over which the current flow therethrough increases and decreases inversely as the potential applied thereto.

2. Means for producing alternating currents comprising a circuit which includes capacity and inductance, and a device having an electron emitting cathode and electrodes coöperating therewith, and sources of potential of such values applied to the electrodes that the device has a working range over which the current flow therethrough varies inversely as the potential applied thereto, said device being [illegible] said working range independe[illegible] any gas ionization.

3. Means for producing alternating cur-

rents comprising a circuit which includes capacity and inductance and a device having an electron emitting cathode, an anode and a third electrode inclosed in a highly evacuated envelop, and sources of potential of such values applied between the cathode and other electrodes that the device has a working range over which the current flow from the cathode to the third electrode varies inversely as the potential applied thereto.

4. Means for producing alternating currents comprising a device having an electron emitting cathode, an anode and a third electrode inclosed in a highly evacuated envelop, and having a working range over which the current flow from cathode to third electrode varies inversely as the potential applied thereto, an external circuit between said cathode and third electrode comprising inductance and capacity and means for impressing a constant potential on said anode.

5. Means for producing alternating currents comprising a circuit which includes capacity, inductance and both positive and negative resistance, the negative resistance having a definite working range over which the current flow therethrough increases and decreases inversely as the potential applied thereto independently of any changes in temperature or gas ionization, and being so constructed that the current therethrough is carried entirely by the flow of negative electrons through an evacuated space.

6. Means for producing alternating currents comprising a circuit which includes capacity and inductance and a device having a definite working range over which the current flow therethrough increases and decreases inversely as the potential applied thereto independently of any changes in temperature or gas ionization, and which is so constructed that the current therethrough is carried entirely by the flow of negative electrons through an evacuated space.

7. Means for producing alternating currents comprising a circuit which includes capacity, inductance and both positive and negative resistance, the negative resistance having a definite working range over which the current flow therethrough increases and decreases inversely as the potential applied thereto independently of any changes in the temperature, the current through said negative resistance being carried entirely by the flow of negative electrons through an evacuated space, and the product of the two resistances being numerically less than the ratio of the inductance to the capacity.

8. Means for producing alternating currents comprising a device having an electron emitting cathode, an anode and a third electrode inclosed in a highly evacuated receptacle, means for impressing a constant positive potential upon said anode, means for impressing a smaller positive potential upon said third electrode of such value that the device has a working range over which the current flow from cathode to third electrode varies inversely as the potential applied thereto, and inductance and capacity included in an external circuit between said cathode and third electrode.

In witness whereof I have hereunto set my hand this 6th day of November, 1915.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 98.

A. W. HULL.
ELECTRON DISCHARGE APPARATUS.
APPLICATION FILED JUNE 9, 1919.

1,385,873

Patented July 26, 1921.
2 SHEETS—SHEET 1.

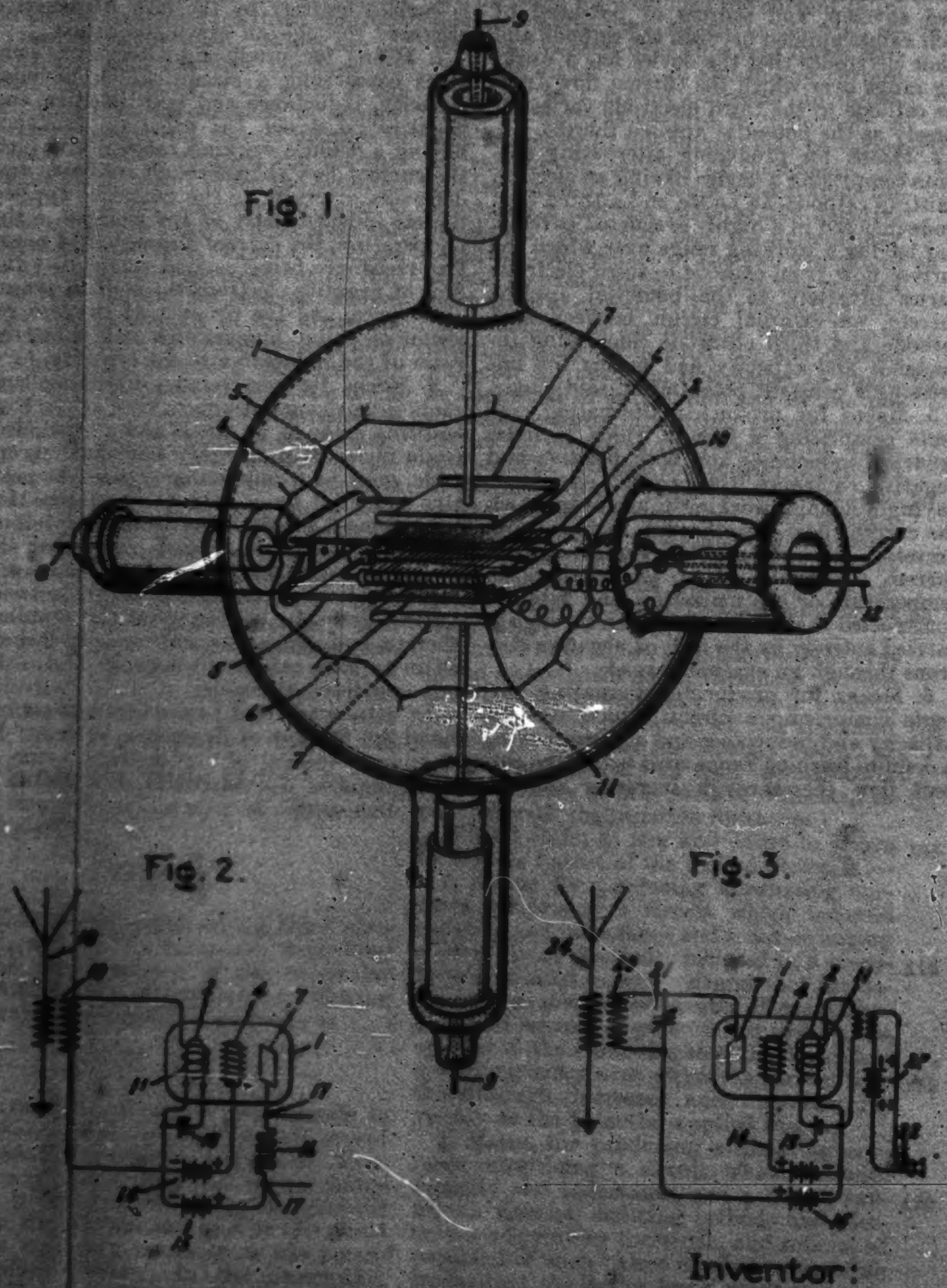

9
7
6
2
10
1
5
4
3
8
12
11
9
10
11
17
13
16
24
20
21
14
15

Fig. 1.

Fig. 2.

Fig. 3.

Inventor:
Albert W. Hull,
by Albert G. Davis
His Attorney.

A. W. HULL.
ELECTRON DISCHARGE APPARATUS.
APPLICATION FILED JUNE 3, 1918.

1,385,873. **Patented July 26, 1921.**
2 SHEETS—SHEET 2.

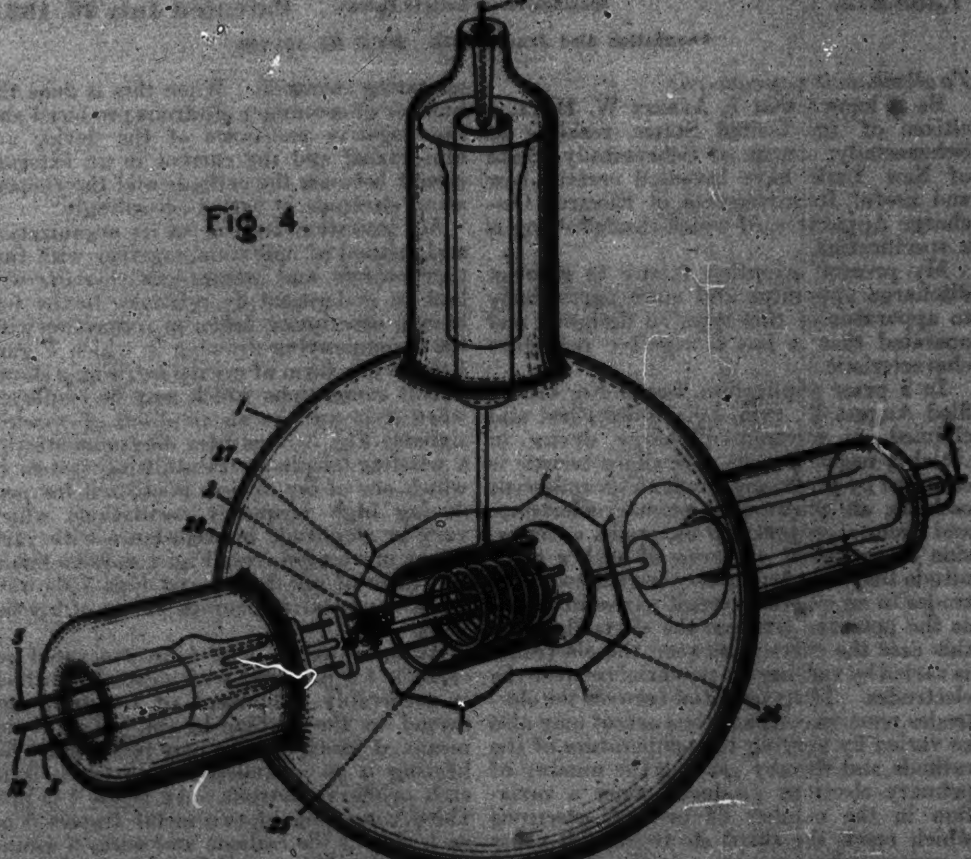

9
1
27
2
28
8
7
11
12
3
26
25

Fig. 4.

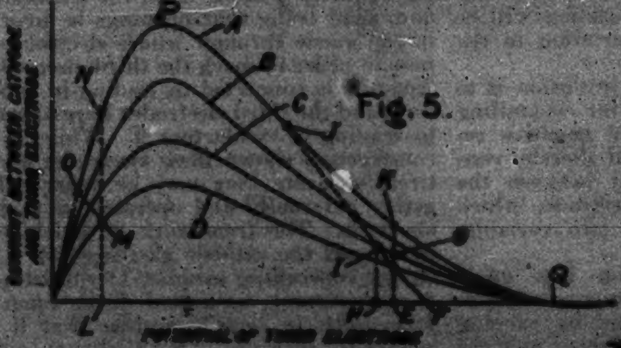


Fig. 5.

Inventor:
Albert W. Hull,
by
His Attorney

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS.

1,385,873. Specification of Letters Patent. Patented July 26, 1921.

Application filed June 6, 1916. Serial No. 101,789.

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus, of which the following is a specification.

My present invention relates to electron discharge apparatus and more particularly to apparatus of this type, so designed and operated that it has a negative resistance characteristic.

In a prior application, Serial No. 47,908, filed August 30, 1915, I have described and claimed an electron discharge device in which a negative resistance characteristic is obtained by producing, from an incandescent cathode, an emission of primary electrons, and from a coöperating electrode, an emission of secondary electrons of such a magnitude that the current between the two electrodes in an external circuit varies inversely as the potential between the electrodes. In this case the current between the electrodes is varied by varying the potential between the electrodes. If the potential between the electrodes remains constant the current may also be varied by varying the temperature of the cathode, and thereby varying the number of primary electrons produced, since a variation in the number of primary electrons which reach the third electrode will cause a corresponding variation in the number of secondary electrons emitted. In this case the value of the negative resistance will be varied, thereby causing a variation in the current.

The object of my present invention is to provide a convenient means for controlling or varying the value of the negative resistance in such a device and thereby controlling the flow of current between the cathode and coöperating electrode, which will be independent of the two variables above mentioned.

In carrying my invention into effect I provide a charge controlling member in proximity to the cathode and by varying the potential between this member and the cathode, vary the effective emission of primary electrons; that is, vary the number of primary electrons which will reach the coöperating electrode. When this is done the number of secondary electrons produced and the negative resistance of the device are also varied and the current in an external circuit between the cathode and the coöperating electrode is varied accordingly.

My invention both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 shows one form of my device; Fig. 2 shows circuit connections which may be employed when it is used as an amplifier of wireless signals; Fig. 3 illustrates diagrammatically a wireless telephone transmitting system in which one of my devices is utilized for producing high frequency oscillations which vary in amplitude in accordance with variations in sound waves; Fig. 4 shows a modified form of my device, and Fig. 5 shows a set of characteristic curves of one of my devices.

As indicated in Fig. 1 an evacuated receptacle 1 is provided with a cathode 2 which is preferably a filament of tungsten connected to the leading-in conductors 3 by means of which current may be supplied for heating it to incandescence to cause it to emit primary electrons. An anode 4 is provided consisting of two metal frames 5 on each side of the cathode and wires 6 wound upon these frames. Other forms of anode may equally well be used, the essential requirement being that openings be provided in the anode through which electrons may pass in order to reach the third electrodes 7. Anode 4 is connected to leading-in conductor 8 and the third electrodes 7 are connected to leading-in conductors 9. While in the construction shown these electrodes are entirely separate they may be connected together externally and operated as a single electrode. The framework 10 which serves to support the cathode also supports a discharge controlling member 11 consisting of a wire wound back and forth upon the framework in such a manner that it surrounds the cathode. This discharge controlling member is connected to leading-in conductor 12. The receptacle 1 is preferably exhausted to such a degree that with any

operating voltage which may be employed the flow of current between the electrodes is not accompanied by any visible manifestation of gas ionization such, for example, as blue glow.

In the operation of a device such as the one I have described a definite positive potential is applied to the anode 4, the cathode being considered as at zero or earth potential. If the cathode is heated to incandescence there will be a flow of electrons from cathode to anode. If the third electrode 7 is at the same potential as the cathode no electrons will be received thereby. If, however, a small positive potential is applied to the third electrode a portion of the electrons will pass through the anode and reach the third electrode. The velocity with which these electrons will strike the third electrode will depend upon the potential between it and the cathode. If this potential is increased the velocity will increase until the electrons striking the third electrode are able by their impact to liberate secondary electrons. These secondary electrons leaving the third electrode will be attracted to the more positive anode. As the potential is increased a point will be reached at which the number of secondary electrons leaving the third electrode increases faster than the number of primary electrons received and the current which will flow in the external circuit between the cathode and third electrode will begin to decrease. A point will finally be reached at which the number of secondary electrons leaving the third electrode is just equal to the number of primary electrons which strike it. That is, each electron that strikes liberates on an average one secondary electron. No current will then flow in an external circuit between the cathode and the third electrode. If the potential of the third electrode is further increased the number of secondary electrons given off becomes greater than the number of primary electrons received and as a result the current in the external circuit will reverse in direction, the third electrode supplying current to the anode instead of receiving current. Thus it will be apparent that the device has a working range through which it has a negative resistance characteristic; that is, over which the current in the external circuit between cathode and third electrode various inversely as the potential between the electrodes.

If, with any given potential upon the discharge controlling member, a constant potential is applied to the external circuit between cathode and third electrode and other conditions are constant there will be a constant flow of current in the external circuit. If, however, a variable potential is applied to the discharge controlling member 11 the number of electrons which leave the cathode and reach the third electrode will be varied accordingly and the current in the external circuit will be varied. That is, if the member 11 is made more positive the flow of electrons to the third electrode will increase and if member 11 is made more negative the flow of electrons will decrease. If the potential of the third electrode is adjusted so that the device has a negative resistance characteristic a small change in the potential of member 11 will be capable of producing a large change in the current between cathode and third electrode. When operated in this way my device has an advantage over devices such as the "audion" and "pliotron" which have positive resistance operating characteristics.

This advantage will be understood by reference to the set of curves shown in Fig. 5 in which curves A, B, C and D show the relation between current in an external circuit between cathode and the third electrode and the potential of the third electrode for different potentials upon the discharge controlling member. The beginnings of these curves where the current is increasing are similar in form to the current characteristics of previous electron discharge devices when operated in the customary manner. Those parts of the curves where the current decreases show the negative resistance characteristic of devices constructed and operated in accordance with my invention. Suppose now for example the device, of which the curves given are characteristic, has applied to its third electrode a potential corresponding to point E. Then if the discharge controlling member has a potential corresponding to curve D, current F will flow in the external circuit between cathode and third electrode. If now the potential of the discharge controlling member be changed to that corresponding to curve C the current will tend to increase to a value corresponding to point G on curve C. On account of the increased resistance drop in the external circuit, however, the potential of the third electrode will decrease to some new value as H and the current will rise to a value I considerably greater than the value corresponding to point G. When the potential of the discharge controlling member is changed to the value corresponding to curve A it may be found that the current has risen to a value J which is much greater than the value K which it would have reached if the potential of the third electrode had remained constant. If on the other hand the device were to be operated with a potential L on the third electrode where it has a positive resistance characteristic the effect will be entirely different. When the potential of the discharge controlling member changes from the value corresponding to curve D to that corresponding to curve A, the current instead of increasing from value M to value

N may only increase to a value O because of the decrease in potential of the third electrode with increase in current.

In Fig. 2 I have shown diagrammatically circuit connections which may be employed when my device is utilized as an amplifier of wireless signals. As here indicated a battery 13 is employed for heating the cathode 2 to incandescence, a battery 14 furnishes a constant positive potential for anode 4 and a third battery 15 supplies a positive potential to the third electrode 7 of such a value that the device will operate upon that portion of its current curve over which it has a negative resistance. For example, in case curve A of Fig. 5 represents the operating characteristic the device should be so adjusted that it will operate between the points P and Q of the curve. The external circuit connecting the cathode and third electrode includes a resistance 16. The signals which are to be amplified are received upon the antenna 18 and impressed upon the charge controlling member 11 by means of the inductive coupling 19. The potential variations thus produced upon the charge controlling member 11 will produce corresponding fluctuations in the current through the resistance 16, and since the drop through the resistance is proportional to the current there will be potential variations between the terminals 17 of this resistance corresponding to those impressed upon the member 11 but of much greater amplitude. These amplified potential variations may be utilized for the operation of another amplifier or suitable detecting apparatus. For the selective reception of signals the antenna or the circuit which includes member 11 may be tuned according to any of the usual well known methods.

I have found that if suitable values of capacity and inductance are provided in the circuit between cathode and third electrode, a device constructed and operated in accordance with my invention will serve as a generator of continuous high frequency oscillations. Such an arrangement is indicated in Fig. 3, in which case an inductance 20 and variable capacity 21 are included in the external circuit between cathode and third electrode. The frequency of the oscillations may be conveniently varied by varying the capacity 21. The amplitude of the oscillations may be varied by varying the potential of member 11. In the present case I have indicated a method of adapting my device for use as a wireless telephone transmitter, the potential of member 11 being varied in accordance with variations in sound waves in the transmitter 22 which is supplied with current by battery 23. The transmitting system is completed by coupling inductance 20 to the antenna 24.

In Fig. 4 I have shown one of my devices which operates in the same manner as the one shown in Fig. 1, but in which the construction is varied somewhat. In this case the cathode 2 instead of being supported upon a framework is made in the form of a spiral, self-supporting coiled filament. The anode consists of a heavy coil of wire 25 surrounding the cathode and supported upon the plate 26 which is connected to leading in conductor 3. The third electrode consists of a metal cylinder 27 surrounding the cathode and anode. The discharge controlling member consists of a rod 28 located within the coiled filament. The effect of potential variations of this member upon the current between cathode and third electrode is similar to that which occurs when the charge controlling member surrounds the cathode, only with the internal charge controlling member it will usually be found desirable to have a negative potential impressed thereon at all times. Under these conditions very little current will be taken by the control member. This feature is of special advantage when the device is used as an amplifier, as, for example in the arrangement shown in Fig. 2 as it permits of the use of a high ratio of potential transformation in the coupling 19.

While I have described only two modifications of my device and have illustrated but two organizations in which it may be employed, it will be apparent that many modifications of the specific structure of the device, as well as its application, may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means for producing an emission of secondary electrons from the third electrode sufficient in value to produce a negative resistance characteristic between cathode and third electrode, and means for applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

2. The combination in an apparatus of the class described of an evacuated receptacle containing a cathode adapted to be heated to incandescence, an anode, a third electrode and a discharge controlling member, said anode and third electrode being so constructed and related to each other that electrons may pass through openings in the anode and reach the third electrode, means for impressing a constant positive potential upon the anode, means for impressing a smaller positive potential upon the third electrode, and means for impressing a vari-

able potential upon the discharge controlling member.

3. The combination in a negative resistance device of means for producing an emission of primary electrons from a cathode to a coöperating electrode, an external circuit between said cathode and coöperating electrode, means for producing an emission of secondary electrons from said coöperating electrodes and a discharge controlling member for varying the effective emission of primary electrons to vary the emission of secondary electrons and thereby vary the current in said external circuit between the cathode and coöperating electrode.

4. The combination in an apparatus of the class described of an evacuated receptacle containing an electron-emitting cathode, an anode, a third electrode and a discharge controlling member, of means for supplying a definite positive potential to said anode, means for supplying a lower positive potential to the third electrode of such a value that the third electrode will emit a sufficient number of secondary electrons to produce a negative resistance characteristic between cathode and third electrode, and means for applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

5. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode external to said cathode and anode, and a discharge controlling member, means for applying a definite positive potential to the anode, means for applying a smaller positive potential to the third electrode, and means for applying a variable potential to the discharge controlling member.

6. The combination in an apparatus of the type described of an electron discharge device so constructed and organized that it has a negative resistance characteristic between an electron emitting cathode and a coöperating electrode, a discharge controlling member in proximity to the cathode adapted to vary the discharge between cathode and coöperating electrode and means for applying a variable potential to said discharge controlling member.

7. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode and a third electrode, means for producing an emission of secondary electrons from said third electrode and a discharge controlling member adjacent the cathode for varying the effective secondary electron emission from said third electrode.

8. The combination in an apparatus of the class described of an evacuated receptacle containing an electron-emitting cathode, an anode and a third electrode, means for impressing a constant positive potential upon the anode, means for producing an emission of secondary electrons from the third electrode, and a discharge controlling member adjacent the cathode for varying the effective secondary electron emission from said third electrode.

9. The combination in an apparatus of the class described of an evacuated receptacle containing an electron emitting cathode, an anode and a third electrode, means for impressing a constant positive potential upon said anode, means for impressing a lower positive potential upon the third electrode of such a value as to produce an emission of secondary electrons from said electrode, a discharge controlling member adjacent the cathode and means for impressing a variable potential thereon to vary the effective secondary electron emission from the third electrode.

10. The combination of an electron discharge device comprising a cathode, an anode, a third electrode and a discharge controlling member inclosed in an evacuated envelop, means for impressing a definite positive potential upon the anode, means for impressing a lower positive potential upon the third electrode, means for impressing a variable potential upon the discharge controlling member, the electrodes being so proportioned and related to each other and the potentials being so chosen that the current in an external circuit between cathode and third electrode varies inversely as the potential applied to the third electrode over a given working range and varies with variations in the potential on the discharge controlling member, increasing as that potential becomes more positive and decreasing as it becomes more negative.

11. The combination in an apparatus of the class described of a highly evacuated envelop having therein a discharge controlling member, a filamentary cathode surrounding said member, an anode having openings therein surrounding said cathode and a third electrode surrounding said anode.

12. The combination in an apparatus of the class described of a highly evacuated envelop having therein a discharge controlling member, a cathode in the form of a coiled filament surrounding said member, an anode having openings therein surrounding said cathode, a third electrode surrounding said anode, means for impressing a definite positive potential upon said anode, means for impressing a smaller positive potential upon the third electrode and means for impressing a variable potential upon the charge controlling member.

13. The combination in an apparatus of the type described of an evacuated envelop having therein a discharge controlling mem-

ber, a filamentary cathode, an anode and a third electrode, said anode being located between said third electrode and said cathode and said cathode being located between said anode and said discharge controlling member.

14. Means for amplifying electric currents comprising an evacuated receptacle containing a cathode adapted to be heated to incandescence, an anode, a third electrode and a discharge controlling member located adjacent said cathode, a circuit comprising the cathode and discharge controlling member, means for producing a flow of primary electrons from said cathode to said third electrode, and for producing an emission of secondary electrons from said third electrode to the anode and means for causing the currents to be amplified to flow in the circuit comprising the cathode and the discharge controlling member.

15. Means for amplifying potential variations comprising an evacuated receptacle containing a cathode adapted to be heated to incandescence, an anode, a third electrode and a discharge controlling member located adjacent the cathode, means for impressing a constant positive potential upon the anode, a circuit connection between cathode and third electrode which includes means for impressing a smaller positive potential upon the third electrode, means for impressing the potential variations which are to be amplified upon the discharge controlling member, and means included in the circuit connection between cathode and third electrode for utilizing the current variations in that circuit.

16. Means for amplifying potential variations comprising a negative resistance device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member inclosed in a highly evacuated envelop and having sources of potential connected in external circuits between cathode and anode and between cathode and third electrode of such values that the device has a working range over which the current flow in the external circuit between cathode and third electrode varies inversely as the potential applied thereto, and means for impressing the potential variations which are to be amplified upon the discharge controlling member.

17. The method of operating an electron discharge device which comprises a filamentary cathode adapted to be heated to incandescence independently of the operating current, a coöperating electrode and a discharge controlling member inclosed in an evacuated receptacle and which is so constructed and organized that it has a negative resistance characteristic between the cathode and coöperating electrode, which consists in varying the negative resistance of the device by applying a variable potential to the discharge controlling member.

18. The method of operating an electron discharge device which consists in producing an emission of primary electrons from a cathode to a coöperating electrode, producing an emission of secondary electrons from said coöperating electrode, and applying a variable potential to a discharge controlling member in proximity to the cathode and thereby varying the number of secondary electrons effectively emitted.

19. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode and applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

20. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode and a discharge controlling member which consists in supplying a uniform positive potential to said anode, supplying a lower positive potential to the third electrode of such a value that the third electrode will emit a sufficient number of secondary electrons to give the device a negative resistance characteristic between cathode and third electrode and applying a variable potential to the discharge controlling member to vary the number of secondary electrons emitted from the third electrode.

21. The method of varying the value of the negative resistance of a device comprising an electron emitting cathode, an anode, a third electrode, and means for causing an emission of secondary electrons from the third electrode, which consists in varying the number of primary electrons which may reach said third electrode with any given potential applied thereto and thereby varying the number of secondary electrons which will be effectively emitted therefrom.

22. The method of varying the value of the negative resistance of a device comprising an electron emitting cathode, an anode, a third electrode, a discharge controlling member and means for causing an emission of secondary electrons from the third electrode, which consists in applying a variable potential to said discharge controlling member and thereby varying both the number of primary electrons which may reach said third electrode with any given potential applied thereto and the number of secondary electrons which will be effectively emitted therefrom.

23. The method of controlling the value

of the negative resistance of a device comprising an electron emitting cathode, an anode, a third electrode, and means for causing an emission of secondary electrons from the third electrode, which consists in controlling the number of primary electrons which may reach the third electrode with any given potential applied thereto and thereby controlling the number of secondary electrons which will be effectively emitted therefrom.

24. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode external to said cathode and anode, and a discharge controlling member which consists in applying a definite positive potential to the anode, applying a smaller positive potential to the third electrode, applying a variable potential to the discharge controlling member and utilizing the resultant variable current between cathode and third electrode to give an indication of the variable potential applied to the discharge controlling member.

25. The method of amplifying a variable electric current which consists in producing an emission of primary electrons from a cathode to a coöperating electrode both of which are inclosed in a highly evacuated receptacle, producing an emission of secondary electrons from the coöperating electrode sufficient to give the device a negative resistance characteristic between cathode and coöperating electrode, causing the electric current to be amplified to flow in a circuit comprising the cathode and a discharge controlling member adjacent the cathode and thereby causing a current of greater magnitude but having corresponding variations to flow in a circuit comprising the cathode and coöperating electrode.

26. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, and varying the amplitude of the oscillations thus produced by applying a variable potential to the discharge controlling member.

27. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, and varying the negative resistance of said device by applying to the discharge controlling member a potential which varies periodically at an audible frequency.

28. The method of transmitting signals in a system comprising a transmitting circuit and an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, varying the amplitude of the oscillations thus produced by applying a signaling potential to the discharge controlling member, and supplying to the transmitting circuit the oscillations of varying amplitude.

29. The method of transmitting signals in a system comprising a transmitting circuit and an electron discharge device comprising an electron emitting cathode, an anode, a third electrode, and a discharge controlling member, which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic between cathode and third electrode, producing high frequency oscillations by means of said device, varying the negative resistance of said device by applying to the discharge controlling member a potential which varies periodically at an audible frequency, and supplying to the transmitting circuit the oscillations produced.

30. The combination in an apparatus of the type described, of means for producing alternating currents comprising an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means including an external circuit between cathode and third electrode for producing an emission of secondary electrons from the third electrode sufficient in value to produce a negative resistance characteristic between cathode and third electrode, said external circuit between cathode and third electrode comprising an inductance and a capacity and means for varying the negative resistance of said device comprising a source of variable potential and means for applying a variable potential from said source to the discharge controlling member.

31. The combination in an apparatus of the type described, of means for producing high frequency alternating currents comprising an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means including an external circuit between cathode and third electrode for producing an emission of secondary elec-

trons from the third electrode sufficient in value to produce a negative resistance characteristic between cathode and third electrode, said external circuit between cathode and third electrode, comprising an inductance and a capacity and means for applying to the discharge controlling member a potential which varies periodically at an audible frequency.

32. The combination in a signaling system of a transmitting circuit, means for producing high frequency currents comprising an evacuated receptacle containing an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means including an external circuit between cathode and third electrode for producing an emission of secondary electrons from the third electrode sufficient in value to produce a negative resistance characteristic between cathode and third electrode, said external circuit between cathode and third electrode comprising an inductance and a capacity and means for supplying to the discharge controlling member a potential which varies in accordance with variations in sound waves, and means for supplying the high frequency currents produced in said external circuit to said transmitting circuit.

33. The combination in an apparatus of the class described of a highly evacuated receptacle having therein an electron emitting cathode, an anode, a third electrode and a discharge controlling member, means including external circuits between cathode and anode and between cathode and third electrode for producing a negative resistance characteristic between cathode and third electrode, and means for applying to the discharge controlling member a variable potential and thereby varying the current in the external circuit between cathode and third electrode.

In witness whereof I have hereunto set my hand this 2nd day of June, 1916.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 90.

A. W. HULL.

NEGATIVE RESISTANCE.

APPLICATION FILED AUG. 30, 1915.

1,387,984. **Patented Aug. 16, 1921.**

Fig. 1.

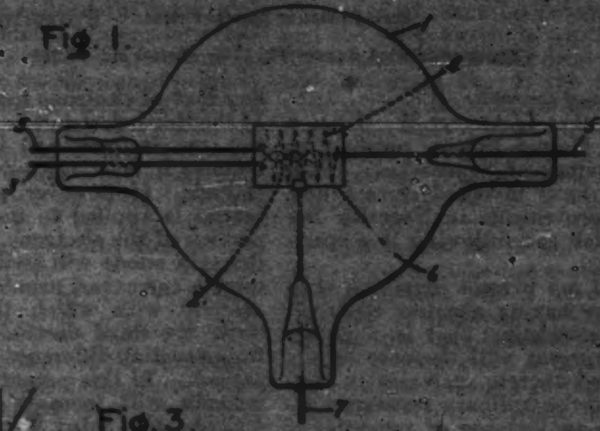


Fig. 3

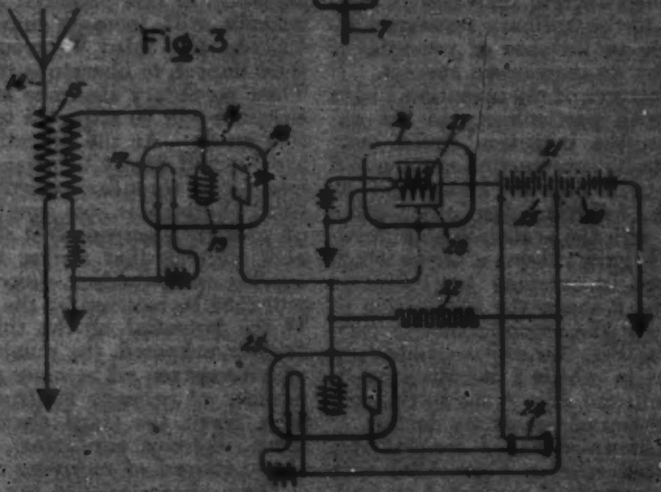

14
15
16
17
18
19
26
27
21
25
20
28
22
23
24

Fig. 2.

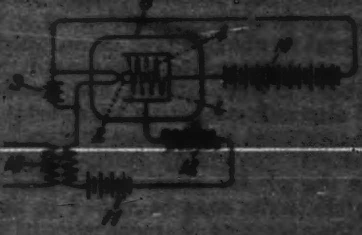
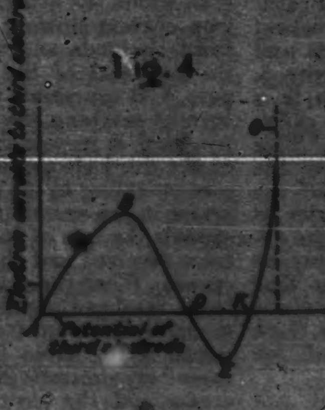

8
3
4
10
5
2
12
13
11

Fig. 4.



Inventor:
Albert W. Hull,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

NEGATIVE RESISTANCE.

1,387,984. Specification of Letters Patent. Patented Aug. 16, 1921.

Application filed August 30, 1915. Serial No. 47,[illegible].

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Negative Resistance, of which the following is a specification.

The object of my present invention is to provide a device having negative electrical resistance characteristics; that is, a device in which the current will decrease as the potential applied thereto increases in contradistinction to the ordinary resistance devices in which an increase of potential is accompanied by an increase in current.

The novel features of my invention I have pointed out with particularity in the appended claims, the invention itself, however, both as to its construction and method of operation, will best be understood by reference to the following description taken in connection with the accompanying drawing, in which Figure 1 shows a device which may be utilized in carrying my invention into effect; Fig. 2 shows the application of my invention for the amplification of variable potentials; Fig. 3 shows a wireless receiving system in which a negative resistance is utilized, and Fig. 4 shows the current characteristics of one of my devices.

The device shown in Fig. 1 consists of a highly evacuated envelop 1 provided with a filamentary cathode 2 connected to leading-in conductors 3 for supplying current for heating it to incandescence. This cathode is preferably surrounded by a helical wire grid 4 which serves as an anode and which is connected to a leading-in wire 5. Surrounding the cathode and anode is a third electrode consisting of a metal cylinder 6 connected to a leading-in wire 7. This cylinder is preferably fairly close to the anode though the relative positions of the three electrodes may be varied in order to vary the operating characteristics of the device. The envelop 1 should preferably be exhausted to such a degree of vacuum that when potentials of the magnitude desired for operation are applied to the electrodes there will be no visible manifestations of gas ionization such as blue glow.

If the cathode is connected to earth and heated to incandescence and a positive potential impressed upon the anode, there will be a flow of electrons from cathode to anode. If the third electrode is also at earth potential, no electrons will be received thereby because it is at the same potential as the cathode. If, however, a small positive potential is applied to the third electrode, a portion of the electrons which pass through the grid anode will strike it and it will receive a current of negative electricity. The velocity with which these electrons will strike the third electrode will depend upon the potential difference between it and the cathode. If this potential is increased, the velocity will increase until the electrons striking the third electrode are able, by their impact, to liberate secondary electrons. These secondary electrons leaving the third electrode will be attracted to the more positive anode. As the potential is increased, a point will finally be reached at which the number of secondary electrons leaving the third electrode is just equal to the number of primary electrons that strike it, that is each electron that strikes liberates on the average one secondary electron. No current will then be received by the third electrode. If the potential of the third electrode is further increased, the number of secondary electrons given off becomes greater than the number of primary electrons received and as a result the third electrode loses electrons, thereby supplying current to the anode instead of receiving current.

These characteristics can best be understood by reference to the curve shown in Fig. 4, in which the ordinates represent the electron current flowing to or away from the third electrode and the abscissæ represent the potential of the third electrode. The part A B represents the increasing electron current reaching the third electrode as the potential is increased. When the potential of the third electrode increases beyond that corresponding to the point B, the rate of increase in the emission of secondary electrons exceeds the rate of increase in primary electrons received and the current begins to decrease. When the potential of the third electrode reaches the point D, it loses as many electrons as it receives, and the current becomes zero. From D to E the number of secondary electrons given off continues to increase and the electron current from the third electrode to the anode increases. The point E is finally reached, however, at which the potential of the third electrode so closely approaches that of the anode that the number of secondary electrons lost by the third electrode begins to decrease because of the fact that the difference of potential between anode and third electrode is not great enough to attract as many electrons to the anode as before. This continues until the point F is reached, where the number of secondary electrons which leave the third electrode and do not return is equal to the number of primary electrons which strike it, and the current again becomes zero. From this point the electron current received by the third electrode increases with increase in its potential. Dotted line G represents the potential of the anode. The part B E of the current curve is approximately straight and may be represented by the equation

$$I = I_0 - \frac{E}{R}$$

where E is the potential of the third electrode, I_0 and R are constants depending upon the characteristics of the particular device and I is the electron current flowing to or away from the third electrode as

$$I_0 - \frac{E}{R}$$

is positive or negative. R corresponds to the resistance of an ordinary circuit except that in this case it is a negative resistance. Thus it will be seen that there is a certain range through which the device may be operated in which the current received by the third electrode will decrease as the potential applied thereto increases. In the description which follows and in the claims the term "negative resistance" is used to designate a device having negative resistance characteristics.

It is not at all essential in the operation of my device that the portion B E of the current curve should extend below the axis and in case it does extend below the axis, as in the example given, it is immaterial whether the normal electron current comes upon the portion B D or the portion D E of the curve.

In Fig. 2 I have illustrated a system in which a negative resistance device such as I have described above may be utilized to amplify potential variations. The negative resistance 8 here indicated is constructed as shown in Fig. 1. A battery 9 provides current for heating the filamentary cathode 2 and battery 10 is employed to impress a constant positive potential upon the anode 4. A battery 11 is also employed with a resistance 12 in series therewith to impress a positive potential upon the third electrode of such a value that the device will operate at a point on the portion B E of the current curve. Transformer 13, the primary winding of which is connected to the source of potential variations which it is desired to amplify, will impress a variable potential upon the circuit. When the connections are made in this way and no potential is supplied by the transformer 13, a certain definite current will flow in the circuit. When current is flowing there will be a drop of potential through the resistance 12 and the difference of potential between the cathode and the third electrode will be equal to the difference between this drop and the potential of battery 11. If the resistance 12 is greater than the constant R of the negative resistance and if the additional potential supplied by transformer 13 is in the same direction as that supplied by battery 11, the first effect of the additional potential will be to increase the drop in potential through resistance 12 and cause the third electrode to become less positive with respect to the cathode. As a result more current will flow in the circuit. With more current flowing the drop across resistance 12 increases and the third electrode becomes still less positive causing a further increase in the current. When a point has finally been reached at which the current becomes stable the change in the potential difference across the resistance will be much greater than the potential applied by transformer 13. The degree of amplification or the rate of change in potential across the resistance 12 with changes in the potential applied to the circuit depends upon the ratio of resistance 12 to the difference between resistance 12 and the constant R. The closer these are to each other in value the greater will be the degree of amplification. If the resistance 12 is less than the constant R the same will hold true and the action will be like that just described, but the effect of the additional potential will be to decrease the drop through resistance 12 and decrease the current flow. While in the above explanation the current has been considered as reaching its stable value by a series of gradations, it actually reaches that value immediately and responds to all voltage variations no matter how short their duration. If the extra potential supplied by transformer 13 is in the opposite direction to that of battery 11 the action will be just the reverse of that above described, that is when resistance 12 is greater than R the current will decrease and when resistance 12 is less than R the current will increase. I have indicated the resistance 12 as an ordinary ohmic resistance but it will of course be understood that it may equally well be any other device possessing positive resistance characteristics.

In Fig. 3 I have illustrated the use of a negative resistance device to increase the degree of amplification of a wireless receiving system. The receiving system here shown comprises an antenna 14 which is coupled by means of transformer 15 to the grid circuit of an electron discharge amplifier 16. This device comprises a filamentary cathode 17, a coöperating anode 18 and an interposed discharge controlling grid 19 inclosed in a highly evacuated envelop. The operation of devices of this nature is too well known to require further explanation. The plate circuit of this amplifier is supplied with current by the portion 20 of battery 21 and includes a resistance 22 which is connected in the grid circuit of a second amplifier 23 similar in structure to the first. The plate circuit of this amplifier which includes the telephone receiver 24 is supplied by the portion 25 of battery 21. Negative resistance device 26 has its anode 27 supplied with a constant positive potential by battery 21 and its third electrode 28 connected to one terminal of resistance 22.

When signals are received by the antenna 14 the potential of grid 19 is varied and the current flowing in the plate circuit of amplifier 16 varies accordingly. If for the moment the effect of the negative resistance is neglected these changes in current will produce corresponding potential variations across the terminals of resistance 22 and thus vary the potential of the grid of amplifier 23 and cause a corresponding variation in the current through the telephone receiver 24. The current flowing in the plate circuit of amplifier 16 depends upon the potential of grid 19 and upon the difference of potential between its electrodes. As the current through resistance 22 increases the drop of potential therethrough increases and the difference of potential between the electrodes of amplifier 16 decreases. Hence the current flowing through amplifier 16 will not increase to the value which it would reach if this potential remained constant. This effect however is compensated for by the negative resistance which acts in this respect in a manner directly opposite to that of the amplifier. The negative resistance in this case is in parallel to the positive resistance 22 and it is therefore evident that potential variations between the terminals of positive resistance 22 and negative resistance 26 will be exactly equal to the potential variations between the cathode and anode of amplifier 16 only in the reverse direction. The effect of these potential variations upon the two resistances is not the same, however. The change in this potential which is applied to the two resistances will produce a change in current in one direction in the negative resistance and in the opposite direction in the positive resistance. Hence, it will be apparent that the effect of applying the potential mentioned to the two resistances will be to produce a current which circulates between the two resistances and which does not flow through amplifier 16. The currents through the two resistances, however, will not be equal as the current in the resistance in which the current flows in the same direction as that in the amplifier 16 will be greater than the current in the other resistance by an amount equal to that in amplifier 16. The current through one of the resistances may be considered as being made up of two parts, one part which flows through the amplifier 16 and one part which flows through the other resistance while the current in the other resistance will be merely the current which circulates between the two resistances and does not pass through amplifier 16. As a result the current in resistance 22 may be much greater than that flowing through amplifier 16 and the potential variations across resistance 22 will be greater than the potential variation which can be produced by amplifier 16 alone. In other words the amplification may be made much greater than would be possible without the negative resistance. In practice it will be found that the best results are obtained when the negative resistance is given such a value as to compensate as closely as possible for the resistance both of the amplifier 16 and the resistance 22.

I have indicated a convenient construction for my negative resistance in Fig. 1, but many variations therein may be made without changing the principle of its operation. In general the third electrode should be placed near the anode and in such position that some of the electrons from the cathode will strike it even when it is less positive in potential than the anode; and the relative positions should also be such that secondary electrons given off by the third electrode can readily reach the anode.

In the above description and in the claims which follow I have used such expressions as "current flow from cathode to third electrode" to designate the net electron current received by the third electrode, or the current which will flow in the external circuit between cathode and third electrode.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A negative resistance device comprising a plurality of electrodes inclosed in a highly evacuated receptacle and having sources of potential applied to said electrodes in such a way that the device has a working range over which the current flow between two of said electrodes increases and decreases inversely as the potential applied between said two electrodes.

2. A negative resistance device comprising an electron emitting cathode adapted to be heated to incandescence independently of the current passing through the device and electrodes coöperating therewith and having sources of potential applied to said electrodes in such a way that the device has a working range over which the current flow

between said cathode and one of the other electrodes varies inversely as the potential applied between said cathode and said other electrode.

3. A negative resistance device comprising an electron emitting cathode, an anode and a third electrode inclosed in a highly evacuated envelop and having sources of potential applied to said electrodes in such a way that the device has a working range over which the current flow from the cathode to the third electrode varies inversely as the potential applied thereto.

4. In combination, a device comprising an electron emitting cathode, an anode and a third electrode and sources of potential applied to said electrodes in such a way that the device has a working range over which the current flow from the cathode to the third electrode varies inversely as the potential applied thereto, said third electrode being located near the anode and so positioned with respect to the cathode and anode that it will receive electrons from the cathode when it is more positive than the cathode, and that secondary electrons given off from the third electrode can readily reach the anode.

5. In combination, a device comprising an electron emitting cathode, an anode, and a third electrode, said third electrode being located near the anode and so positioned with respect to the cathode and anode that it will receive electrons from the cathode when it is more positive than the cathode, and that secondary electrons given off from the third electrode can readily reach the anode and sources of potential applied to said electrodes of such value that the number of electrons received and retained by the third electrode over a given working range will vary inversely as the potential applied thereto.

6. A negative resistance device comprising an electron emitting cathode, an anode and a third electrode, said anode being interposed between cathode and third electrode and having openings therein through which electrons can reach the third electrode when it is more positive than the cathode, and sources of potential applied to said electrodes of such value that the number of electrons received and retained by the third electrode over a given working range will vary inversely as the potential applied thereto.

7. The combination of a negative resistance device comprising an electron emitting cathode, an anode and a third electrode inclosed in an evacuated envelop, means for directly producing by impact an emission of secondary electrons from said third electrode and means for varying the secondary electron emission from said third electrode, the envelop being exhausted to such a degree that with the potentials necessary for producing the secondary electron emission applied to the electrodes the device will operate without any appreciable gas ionization.

8. The combination of a negative resistance device comprising an electron emitting cathode, an anode and a third electrode inclosed in an evacuated envelop, means for impressing constant positive potential upon the anode, means for directly producing by impact an emission of secondary electrons from the third electrode, and means for varying the secondary electron emission from said third electrode, the envelop being exhausted to such a degree that with the potentials necessary for producing the secondary electron emission applied to the electrodes the device will operate without any appreciable gas ionization.

9. The combination of a negative resistance device comprising an electron emitting cathode, an anode and a third electrode inclosed in an evacuated envelop, means for impressing a constant positive potential upon said anode, means for impressing a positive potential upon the third electrode of such a value as to directly produce by impact an emission of secondary electrons from said electrode, and means for impressing a variable potential upon said third electrode to vary the secondary electron emission therefrom, the envelop being exhausted to such a degree that with the potentials necessary for producing the secondary electron emission applied to the electrodes the device will operate without any appreciable gas ionization.

10. The combination of an electron discharge device comprising a cathode, an anode and a third electrode inclosed in a highly evacuated envelop, means for impressing a definite potential upon the anode and means for impressing a variable potential upon the third electrode, the electrodes being so proportioned and related to each other that the current to the third electrode varies inversely as the potential applied thereto over a given working range.

11. Means for amplifying potential variations comprising a positive resistance and a negative resistance device in series therewith, the two resistances being approximately equal to each other in value, said negative resistance device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle, and being operable as a negative resistance by electron currents independently of any appreciable gas ionization.

12. Means for amplifying potential variations comprising a device having positive resistance characteristics, and a negative resistance device in series therewith, the resistance of the two devices being approximately equal to each other in value, said negative resistance device comprising an electron

emitting cathode and coöperating electrodes in an evacuated receptacle, and being operable as a negative resistance by electron currents independently of any appreciable gas ionization.

13. Means for amplifying potential variations comprising a positive resistance, a negative resistance device of substantially the same value in series therewith, and means for supplying a constant potential to said resistances, said negative resistance device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle and being operable as a negative resistance by electron currents independently of any appreciable gas ionization.

14. Means for amplifying potential variations comprising a negative resistance device, a positive resistance of substantially the same value, and means for supplying the potential variations which are to be amplified to the two resistances in series, said negative resistance device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle and being operable as a negative resistance by electron currents independently of any appreciable gas ionization.

15. Means for amplifying potential variations comprising a negative resistance device, a positive resistance, means for supplying a constant potential to said resistance in series and means for supplying the potential variations which are to be amplified to the two resistances in series, said negative resistance device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle and being operable as a negative resistance by electron currents independently of any appreciable gas ionization.

16. Means for amplifying potential variations comprising a negative resistance device having a working range over which the current flow therethrough increases and decreases inversely as the potential applied thereto, a positive resistance of a value substantially equal to that of the negative resistance device and means for supplying the potential variations which are to be amplified to the two resistances in series, said negative resistance device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle and being operable as a negative resistance by electron currents independently of any appreciable gas ionization.

17. Means for amplifying potential variations comprising a negative resistance device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle and operable as a negative resistance by electron currents independently of any appreciable gas ionization and having a working range over which the current flow therethrough increases and decreases inversely as the potential applied thereto, a positive resistance of a value substantially equal to that of the negative resistance device, means for supplying a constant potential to said resistance in series, and means for supplying the potential variations which are to be amplified to the two resistances in series.

18. Means for amplifying potential variations comprising a negative resistance device having an electron emitting cathode and having a working range over which the current flow therethrough varies inversely as the potential applied thereto, said device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle and being operable over such a range by means of electron currents independently of gas ionization, a positive resistance of a value substantially equal to that of the negative resistance device and means for supplying the potential variations which are to be amplified to the two resistances in series.

19. Means for amplifying potential variations comprising a negative resistance having an electron emitting cathode, an anode, and a third electrode inclosed in a highly evacuated envelop and having a working range over which the current flow from the cathode to the third electrode varies inversely as the potential applied thereto, a positive resistance having a value substantially equal to that of the negative resistance and means for supplying the potential variations which are to be amplified to the two resistances in series.

20. Means for amplifying potential variations comprising a negative resistance having an electron emitting cathode, an anode and a third electrode inclosed in a highly evacuated envelop and having a working range over which the current flow from the cathode to the third electrode varies inversely as the potential applied thereto, a positive resistance having a value substantially equal to that of the negative resistance, means for supplying a constant potential to said resistances in series, and means for supplying the potential variations which are to be amplified to the two resistances in series.

21. Means for amplifying potential variations comprising a negative resistance having an electron emitting cathode, an anode and a third electrode near the anode and so positioned with respect to the cathode and anode that it will receive electrons from the cathode when it is more positive than the cathode and that secondary electrons given off from the third electrode can readily reach the anode, a positive resistance and

means for supplying the potential variations which are to be amplified to the two resistances in series.

22. Means for amplifying potential variations comprising a negative resistance device comprising an electron emitting cathode and coöperating electrodes in an evacuated receptacle and being operable as a negative resistance by electron currents independently of any appreciable gas ionization, a positive resistance and means for supplying potential variations which are to be amplified to the two resistances in series, the two resistances being approximately equal to each other in value.

23. Means for amplifying potential variations comprising an electron discharge device having an electron emitting cathode, an anode and a third electrode, means for directly producing by impact an effective emission of secondary electrons from said third electrode and means for varying the secondary electron emission from said third electrode.

24. Means for amplifying potential variations comprising a device having positive resistance characteristics, a negative resistance and a positive resistance in series with said device and said negative resistance, said negative resistance having such a value as to compensate as closely as possible for the other resistance in the circuit.

25. Means for amplifying potential variations comprising an electron discharge amplifier, a negative resistance and a positive resistance in series with said amplifier and said negative resistance, said negative resistance having such a value as to compensate as closely as possible for the resistance of the amplifier and the positive resistance.

26. The combination in a wireless signaling system of a negative resistance and a device having positive resistance characteristics in series therewith, said negative resistance having such a value as to compensate as closely as possible for the positive resistance in the circuit.

27. The combination in a wireless receiving system of a device having positive resistance characteristics, a negative resistance and a positive resistance in series with said device and said negative resistance, said negative resistance having such a value as to compensate as closely as possible for the positive resistance of the circuit.

28. The combination in a wireless receiving system of an electron discharge amplifier, a negative resistance and a positive resistance in series with said amplifier and said negative resistance, said negative resistance having such a value as to compensate as closely as possible for the positive resistance of the circuit.

29. A negative resistance device comprising an electron emitting cathode, an anode and a third electrode inclosed in an envelop evacuated to such a degree that with any operating potentials which may be applied to the electrodes the device will operate independently of any gas ionization, and sources of potential applied to said electrodes in such a way that the device has a working range over which the current flow between cathode and third electrode varies inversely as the potential applied between said cathode and third electrode.

30. The method of operating an electron discharge device comprising an electron emitting cathode, an anode and a third electrode which consists in producing an emission of secondary electrons from the third electrode sufficient to give the device a negative resistance characteristic and applying a variable potential to said third electrode to vary the number of secondary electrons emitted therefrom.

31. The method of operating an electron discharge device comprising an electron emitting cathode, an anode and a third electrode which consists in applying a constant positive potential to the anode and applying a positive potential to the third electrode of such a value as to produce an emission of secondary electrons therefrom sufficient to give the device a negative resistance characteristic.

32. The method of operating an electron discharge device comprising an electron emitting cathode, an anode, and a third electrode which consists in applying a constant potential to the anode, applying a smaller positive potential to the third electrode to produce an emission of secondary electrons therefrom and varying the positive potential of the third electrode to vary the secondary electron emission.

33. The method of operating an electron discharge device comprising an electron emitting cathode, an anode and a third electrode which consists in applying constant positive potential to the anode and applying a positive potential to the third electrode of such a value as to give the device a negative resistance characteristic.

34. A negative resistance device comprising an electron emitting cathode, an anode and a third electrode inclosed in an evacuated envelop, said anode being interposed between said cathode and third electrode, and sources of potential applied to said electrodes in such a way that the device has a working range over which the current flow from the cathode to the third electrode varies inversely as the potential applied thereto.

35. A thermionic amplifier having a cathode and two coöperating electrodes and means for directly producing by impact an effective emission of secondary electrons from one of said coöperating electrodes by

1124

reason of a bombardment thereof by a stream of primary electrons emanating from the cathode.

36. A thermionic amplifier having a cathode and two coöperating electrodes and means for directly producing by impact an effective emission of secondary electrons from one of said coöperating electrodes by reason of a bombardment thereof by an electronic stream emanating from the cathode.

37. An electron discharge device comprising a cathode, an anode and a third electrode, and means for maintaining the anode and third electrodes at different potentials with respect to the cathode, said third electrode being rendered electronically active by bombardment by an electronic stream emanating from the cathode.

38. An electron discharge device comprising a cathode, an anode and a third electrode, and means for maintaining the anode and third electrode at different potentials with respect to the cathode, said third electrode being rendered electronically active by bombardment by a thermionic stream emanating from the cathode.

In witness whereof, I have hereunto set my hand this 28th day of August, 1915.

ALBERT W. HULL.

[Note: For Defendant's Exhibits Nos. 100 to 278, Inclusive, See Interference Record.]

(No Defendant's Exhibit No. 279.)

DEFENDANT'S EXHIBIT No. 280.

S. DUSHMAN.
PROTECTIVE DEVICE.
APPLICATION FILED MAY 20, 1915.

1,172,961. **Patented Feb. 22, 1916.**

Fig. 1.

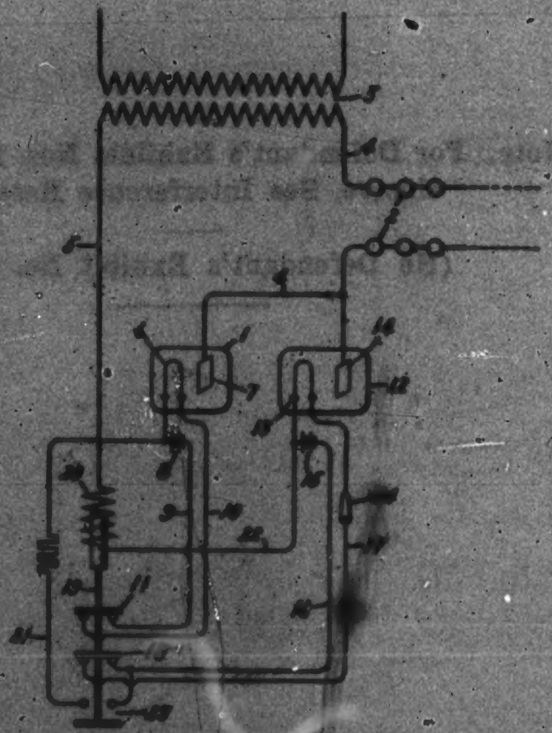
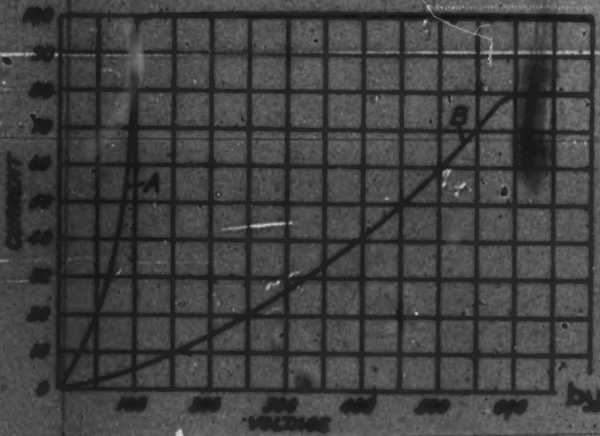

5
4
3
2
6
8
7
14
12
15
20
9
10
22
11
16
17
21
13
23

Fig. 2.



Inventor:
Saul Dushman,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

SAUL DUSHMAN, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

PROTECTIVE DEVICE.

1,172,961. Specification of Letters Patent. Patented Feb. 22, 1916.

Application filed May 28, 1915. Serial No. 30,452.

To all whom it may concern:

Be it known that I, SAUL DUSHMAN, a subject of the King of Great Britain, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Protective Devices, of which the following is a specification.

My invention relates to the protection against overload of devices passing a substantially constant current with a variable impressed voltage, such, for example, as incandescent cathode devices, which when operating in series with a load device are liable to injury or destruction should the load device or devices be short-circuited or in any other way consume less voltage and thereby cause an excessive voltage across the constant current device.

Although my invention is of general application it may be better understood by a consideration of the electric characteristics of incandescent cathode electron discharge devices. When such a device is so highly exhausted that its current is a pure electron discharge, relatively large amounts of energy may be transmitted. Over a given range, varying with the geometric relation in space of the parts of the discharge device, the distance between the electrodes and other factors, the current varies with the 3/2 power of the voltage and then at higher voltages the current becomes substantially constant with a variable impressed voltage. When the voltage impressed is greater than this critical value, the resistance of the external load may be varied without affecting the current. The latter then depends only upon the temperature of the source of electron discharge. During normal operation only a small part of the voltage of the source is consumed in the tube, the rest of the voltage being consumed in the load. Should the load be short-circuited all of the voltage, and hence all of the energy of the system, would be consumed in the tube, and unless some safety device were provided the tube would be destroyed. Ordinary protective devices would not protect the tube under these circumstances. In the first place, since the current remains constant, an excess current device would not operate. Secondly, an excess voltage device could not be used since the full voltage that occurs across the tube when current is flowing on short-circuit exists in normal operation on every other half cycle while current has ceased to flow because of the unidirectional conductivity of the tube. This high voltage that exists normally while current is not flowing does no harm to the tube since it represents no energy, but it makes impossible the utilization of the usual excess-voltage devices to protect the tube.

In accordance with my invention I utilize the increase in voltage drop across the device to be protected to effect an increase of current passed by an auxiliary electron discharge apparatus when the current is of a polarity to cause a rise of energy in the main device. This auxiliary device is constructed to require a high voltage to pass an appreciable current, and in which the current under normal operating conditions is considerably below the saturation value at which any further increase in voltage produces no further current. This increase of current in the auxiliary device actuates any known form of current relay to deënergize the main discharge device, and also deënergizes the auxiliary discharge device.

My invention will be better understood by reference to the following description taken in connection with the accompanying drawing in which—

Figure 1 illustrates my invention diagrammatically in connection with a series load circuit supply by half wave rectifiers, and Fig. 2 illustrates by curves the relation of the voltage and the current in the main and the auxiliary devices.

Referring to the drawing the main electron discharge device 1, which in this case is shown as supplying the load 2 with rectified current is connected to the secondary of a transformer 3, by the conductors 4, 5. The discharge device contains an incandescent cathode 6, and an anode 7. The electrodes are so completely freed from gas and the space in the envelop evacuated to a pressure so low that transmission of energy occurs by pure electron conduction substantially without gas ionization. With this end in view the bulb is first evacuated by approved lamp exhaust methods, the last portions of gas being removed by the Gaede molecular pump or any other means capable of removing vapors of oil and water as well as gases. When the evacuation has proceeded to such a high degree that an electron discharge of considerable magnitude may be sent through the device without destructive positive ionization, the cathode is heated, to incandescence and a high potential, for example, 5000 volts and higher, impressed upon the electrodes. The bombardment of the anode by the electron discharge liberates therefrom ionizable gas. As soon as a blue glow is observed the discharge is discontinued and pumping continued until a high vacuum has been restored, when the process is repeated. When the electrodes have been thus sufficiently freed from gas to operate at high voltages without giving off gases and the space within the tube has been exhausted to a vacuum of about .05 microns (0.00005 m. m. of mercury) or lower, the tube is sealed off from the pump. The cathode 6 is heated to incandescence by a battery 8 connected to the cathode by the conductors 9, 10, having in circuit a switch 11, the object of which will be presently explained. The electrodes of the device are spaced closely together so as to decrease the voltage drop and consequent energy loss. The effect of this is to lower the voltage limit above which the device operates with a constant current with a variable impressed voltage.

As explained by Dr. Irving Langmuir in the *Physical Review* for December 1913, the electrostatic and magnetic influence of each electron in a given space on every other electron in the space between the electrodes of the device is known as the "space charge" effect. Owing to this space charge effect the electron current varies over a given range with the impressed voltage, providing the temperature of the filament is so high that there is no limitation owing to the inability of the cathode to supply electrons. At voltages above this range the current remains substantially constant. As noted above, the range of space charge voltage depends on the geometrical relations of the parts of the device. The device 1 is constructed to operate with a low "space charge" voltage to reduce to a minimum the loss of energy in the tube. For example, as shown in Fig. 2, the electrical characteristic of the device may be represented by the curve A, the ordinates being current value in milliamperes, and the abscissæ voltage values. In this particular device with the filament at a given temperature the current increases with the 3/2 power of the voltage up to 100 volts when all the electrons which the filament is capable of emitting at that temperature are utilized; at voltages exceeding 100 volts the current remains constant.

Connected across the terminals of the rectifier 1 is a second rectifying device 12, also having an electron-emitting cathode 13 and which the current varies with the voltage is very greatly increased, the range of voltage accompanied by a variable current including the working range of voltage drop across the terminals of the device 1.

Again referring to Fig. 2, the electrical characteristics of the device 12 may be represented by the curve B. The current increases with the 3/2 power of the voltage multiplied by a constant depending on the electron emission up to nearly 600 volts, and then becomes substantially constant at 80 milliamperes, the electron emission being somewhat less than in the device 1, for example, because of a lower filament temperature.

The battery 15 heating the cathode 13 has included in its circuit conductors 16, 17, and a switch 18 connected to the same shaft 19 as the switch 11. In series with the device 12 is the winding of an electromagnet 20 having its core connected to the shaft 19. Under normal operating conditions the space charge voltage across device 1, and consequently across device 12, is so low that the current passing through the device 12 is so small that it is insufficient to operate the magnet 20. On the other hand, when a short circuit or sudden decrease in resistance of the load occurs, the voltage across both the devices 1 and 12 becomes so high that the current through device 12 becomes sufficiently great to cause the magnet 20 to raise its core, opening the switches 11 and 18, and closing the switch 23. In the given case this tripping current might be set at 40 milliamperes. The effect of this is to deënergize the heating circuits of the cathodes of both the devices 1 and 12 by opening the switches 11 and 18 and to connect the winding of the magnet 20 across the battery 15 by the conductors 16, 21. and 22 by the closure of a switch 23. When the disturbing conditions have been corrected the switches 11 and 13 may be closed and the switch 23 opened in any suitable way, for example, by opening a switch 24 in the circuit 16.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination of a source of alternating current, an electron discharge device, conducting a constant current with a variable impressed voltage exceeding a predetermined value, connected to said source, a load connected in series with said device, an auxiliary electron discharge device conducting a variable current at an impressed voltage exceeding the predetermined operating voltage of the first device, and means responsive to a predetermined rise of cur-

having an electron-emitting cathode and being evacuated to a pressure so low that conduction of energy occurs substantially without positive ionization, a load connected in series with said device, a source of alternating current connected to supply current to said device and said load at a voltage exceeding the voltage at which the current of said device becomes substantially constant, a second pure electron-discharge device connected in parallel with the first device constructed to operate with a variable current over a voltage range exceeding the range of voltage over which the current is variable in the first device, and means responsive to a predetermined rise of current in said second device to deënergize both of said devices.

3. The combination of an electrical discharge device operating with a substantially constant current over a variable range of impressed voltage exceeding a predetermined value, a load in series with said device, rectifying means connected in parallel with said device, transmitting current of the same polarity as said discharge device, the current being variable with the voltage above the voltage value at which the current in said device is substantially constant and an electroresponsive device operatively connected to said means for deënergizing said discharge device upon a predetermined rise of current in said rectifying means.

4. The combination of a rectifier operating with a substantially pure electron discharge and having electrodes spaced closely to keep the energy loss due to space charge voltage drop at a low value, a second rectifier operating with a substantially pure electron discharge having electrodes spaced more widely apart to give a high space charge voltage, and connected to corresponding electrodes of the first rectifier, a source of electrical energy supplying said rectifiers, a load in series with both said rectifiers and an electroresponsive device operatively connected to said second rectifier for deënergizing both said rectifiers upon a predetermined rise of current.

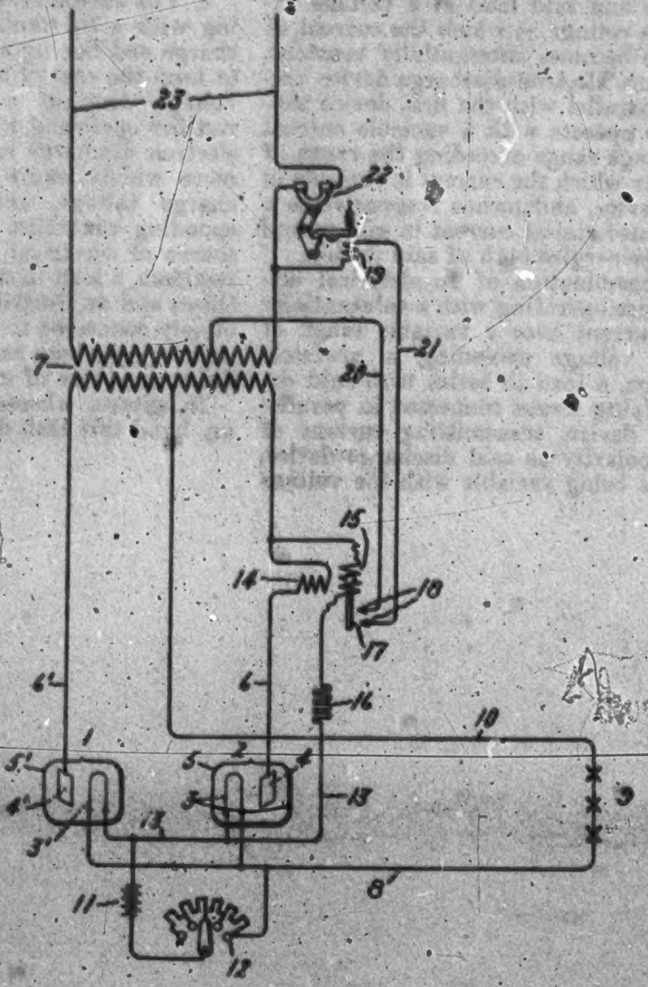
In witness whereof, I have hereunto set my hand this 18th day of May, 1915.

SAUL DUSHMAN.

DEFENDANT'S EXHIBIT No. 281.

L. A. HAWKINS.
PROTECTIVE DEVICE.
APPLICATION FILED JULY 7, 1914.

1,172,990. **Patented Feb. 22, 1916.**


23
22
19
21
20
7
15
14
18
17
16
6
6'
10
1
2
5'
4'
3'
5
4
3
13
13
9
8
11
12

Witnesses:
Anthony Marr
J. Ellis Glen

Inventor:
Laurence A. Hawkins,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

LAURENCE A. HAWKINS, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

PROTECTIVE DEVICE.

1,172,990. Specification of Letters Patent. Patented Feb. 22, 1916.

Application filed July 7, 1914. Serial No. [illegible].

To all whom it may concern:

Be it known that I, LAURENCE A. HAWKINS, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Protective Devices, of which the following is a specification.

My invention relates to the protection against overload of hot-cathode vacuum tubes or other devices having a similar volt-ampere characteristic, and is particularly applicable to hot-cathode rectifiers.

When a hot cathode tube so highly exhausted that its current is a pure electron discharge, is operated as a rectifier, current passes in one direction only, since such a tube has what may be termed "unidirectional conductivity", and that current, furthermore, is substantially constant in amount, regardless of the voltage of the source and the resistance of the load. In practice, such a tube is so designed with reference to the voltage and current required in the load circuit, that in normal operation only a small part of the voltage of the source is consumed in the tube while the current is passing. For instance, assume a load circuit requiring a quarter of an ampere at 40,000 volts. The tube might be so designed to have from 200 to 400 volts drop when the current is passing so that the normal energy in the tube would be from 50 to 100 watts, while the rest of the 10 kilowatts would be consumed in the load circuit. But if while the tube were thus operating, the load circuit should be accidentally short-circuited, the current through the tube would remain practically constant, but the voltage across the tube would rise to 40,000 and the full 10 kilowatts would then be consumed in the tube itself and would quickly destroy the tube. Now ordinary protection devices would not protect the tube under these circumstances. In the first place, since the current remains constant, an excess current device would not operate. Secondly, an excess-voltage device could not be used, since the same 40,000 volts that occurs across the tube when current is flowing on short-circuit, exists in normal operation on every other half cycle while current has ceased to flow because of the unidirectional conductivity of the tube. This high voltage that exists normally while current is not flowing does no harm to the tube since it represents no energy, but it makes impossible the use of an excess-voltage device to protect the tube.

By my invention I utilise, for the protection of the tube, the fact that the dangerous condition involves the existence of the high voltage at the same instant current is flowing, or in other words, of high voltage in phase with the current, and my invention consists in providing a protective device depending for its operation on the coöperation of current and of high voltage in phase therewith.

The accompanying drawing illustrates my invention diagrammatically in a system for rectifying alternating current by means of incandescent cathode devices. The electron discharge devices 1, 2 each comprise a filamentary cathode 3 adapted to be heated and a coöperating anode 4, these electrodes being contained in a sealed envelop 5. The space within the envelop is evacuated to such low pressure, for example, one-tenth of a micron of mercury or less, and the envelop and the electrodes are so completely freed from gas that positive ionization of residual gas by collision is substantially absent as described in an application filed by Irving Langmuir, Serial No. 795,610, filed Oct. 16, 1913. Such devices may be used to carry relatively heavy currents with a voltage drop as low as about 100—200 volts. The voltage of the circuit may be very much greater, for example, one-hundred thousand volts or more, the voltage drop in the rectifier representing only a small fraction of the circuit voltage. The anodes 4, 4′ are connected by conductors 6, 6′ to the terminals of the secondary of the transformer 7. The cathodes 3, 3′ are both connected to a conductor 8 which is connected to the load 9, the circuit being completed by a conductor 10 to a neutral point on the transformer secondary. The cathodes 3, 3′ are both heated by a battery 11, connected in series with variable resistance 12 across the conductors 8 and 13, or in any other convenient manner.

The current coil 14 connected in series with the anode conductor 6 and the voltage coil 15 connected respectively to the cathode 3 and the anode 4 of the electron discharge device in series with a very high resistance 16, are respectively the current and voltage coils of a wattmeter type relay. A flow of current coincidently through both coils causes a movement of the pivoted armature 17 in the well-known manner, bridging the contacts 18, and completing the circuit of a circuit breaker controlling magnet 19 connected by conductors 20 and 21 across a section of the primary of the transformer 7, or any other convenient source of current. When a short circuit occurs across any part of the load 9 the voltage across the device 2 will be greater proportionately when the load current is passing than normally when all the load is in circuit, as has been heretofore explained. That is, a short circuit in the load will cause a proportionate increase of voltage in the coil 15 coincident with the passage of current through the coil 14 and will energize the magnet 19 thereby unlatching the circuit breaker 22 and opening the primary circuit 23 of the transformer. Of course, in the same manner a resistance can be inserted in the supply circuit instead of completely opening the circuit. I wish it also to be understood that a similar protective device may be provided for the discharge device 1 but this is not absolutely necessary as the circuit will be opened in any event during the succeeding half wave if the short circuit happens to occur while current is being passed by device 1.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination of a source of alternating current, a discharge device having unidirectional conductivity and passing a substantially constant current with a variable impressed voltage, a load connected in series with said device and means responsive to an abnormal increase of energy in said device for deënergizing said device.

2. The combination of a source of alternating current, an electron discharge device having asymmetric conductivity, a load connected in series with said device and means for disconnecting said source in response to an abnormal rise of energy in said discharge device.

3. The combination of a source of current, a device supplied by said source having unidirectional conductivity and transmitting a substantially constant current with a variable voltage, a load connected in series with said device and means for deënergizing said device responsive to an abnormal voltage across the terminals of said device coincidently with a passage of current through said device.

4. The combination of a source of alternating current, a rectifying device operating with a pure electron discharge, a load circuit in series with said device and said source, and circuit controlling means for controlling the energy supply responsive to a passage of current through said rectifying device and increase of voltage in phase therewith across the terminals of said device above a predetermined value.

5. The combination of a source of alternating current, an incandescent cathode device operating with a substantially pure electron discharge, a load circuit fed from said source through said device, and means for deënergizing said device responsive to an increase of energy in said device above a predetermined value.

In witness whereof, I have hereunto set my hand this 6th day of July, 1914.

LAURENCE A. HAWKINS.

Witnesses:

M. F. Beckett,

Helen Orford.

DEFENDANT'S EXHIBIT No. 252.

G. S. MEIKLE.

RECTIFIER AND THE METHOD OF OPERATING THE SAME.

APPLICATION FILED OCT. 9, 1914.

1,182,290. Patented May 9, 1916.

Fig. 1.

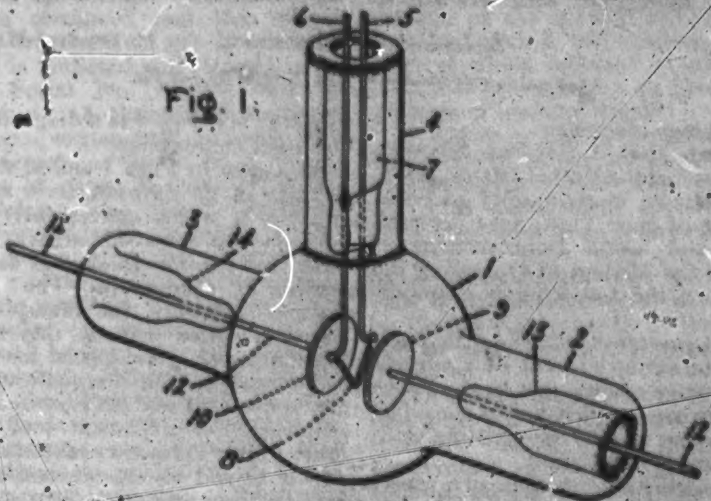

6
5
4
7
3
14
1
9
13
2
12
12
10
8
12

Fig. 2.

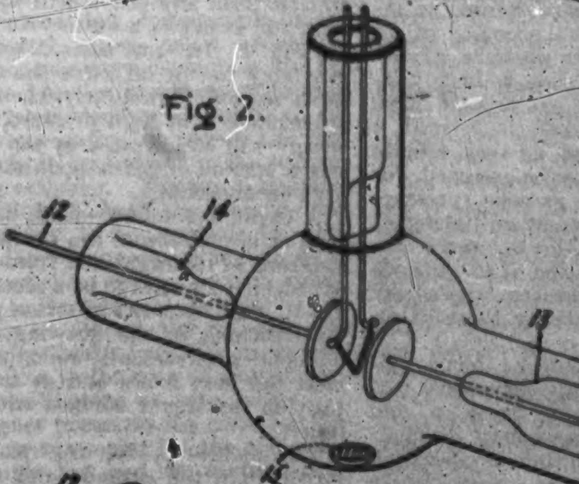
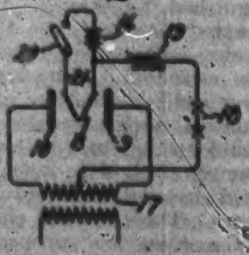

12
14
13
12
15

Fig. 4.


14
15
10
8
9
17

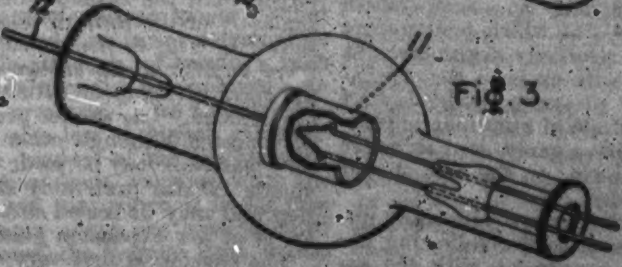


Fig. 3.

Witnesses:
George W. Tilden
[illegible]

Inventor:
George S. Meikle.
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

GEORGE S. MEIKLE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RECTIFIER AND THE METHOD OF OPERATING THE SAME.

1,182,290. Specification of Letters Patent. Patented May 9, 1916.

Application filed October 9, 1914. Serial No. 865,886.

To all whom it may concern:

Be it known that I, GEORGE STANLEY MEIKLE, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Rectifiers and the Method of Operating the Same, of which the following is a specification.

The present invention relates to the rectification of alternating current of a current and voltage range comparable to the range of the mercury arc rectifier, and is embodied in a device having an electron-emitting cathode, and an anode or anodes.

My device is distinguished in one aspect from various prior devices containing an incandescent cathode by the presence of an inert gas at a considerable pressure, as distinguished, for example, from the highly attenuated residual trace of gas present in an envelop exhausted to what is termed a "hard vacuum." Although no very definite lower limit of pressure can be assigned, for practical purposes the gaseous pressure should not be much below one millimeter of mercury as at very much lower pressures a rapid electrical disintegration of the cathode occurs. The electrical characteristics of my new rectifier are substantially those of an electric arc.

My invention is embodied in a device containing a cathode of highly refractory material, such, for example, as tungsten, and an anode or anodes having a heat dissipating capacity enabling continuous operation at a given rated capacity at a temperature below about 727° C., at which temperature electron emission is relatively negligible, this device being filled with an inert gas of relatively appreciable pressure, preferably of the order of magnitude of atmospheric pressure. Electro-negative gases, such as water vapor, oxygen, chlorin, or the like should be carefully excluded.

My invention will be more completely understood by reference to the following description taken in connection with the accompanying drawings, of which—

Figure 1 illustrates a device embodying my invention containing an inert gas noncondensable at room temperature; Fig. 2 illustrates a modification in which a mercury atmosphere is employed; Fig. 3 illustrates one particular form of a half-wave rectifier; and Fig. 4 is a diagram of suitable electrical connections.

As shown in Figs. 1 and 2, the full wave rectifier in its simplest form comprises an envelop 1, which conveniently consists of glass and has three side arms 2, 3 and 4 provided for the convenience of sealing in the leading in conductors. The cathode conductors 5, 6 may, for example, consist of tungsten sealed directly into a stem 7 of low-expansion glass, such, for example, as sodium-magnesium boro-silicate, although any convenient seal may be used. The cathode comprises a filament 8 of tungsten, or other highly refractory material. The cathode is heated to incandescence during operation from any convenient source of current, for example, a battery as indicated at 16, Fig. 4. In some cases, the heating current may be cut off after the discharge or arc is started, particularly when the gaseous atmosphere is at high pressure, and enough energy will be liberated by the arc to maintain a portion of the cathode at a sufficiently high incandescence.

A clean, refractory metal, such as tungsten, at incandescence is a primary source of electrons as distinguished from a refractory oxid which appears to be a secondary source due to some obscure ionization phenomenon. As indicated in the drawing, the cathode filament is conveniently coiled so as to minimize the heat losses and at the same time provide maximum surface within a given space.

The anodes 9, 10, are relatively much larger than the cathode and may be conveniently of the form of disks, although, as shown in Fig. 3, the anode 11 in the half wave rectifier to advantage may have been the form of a cup or cylinder surrounding the cathode. The anodes preferably consist of tungsten although other highly refractory materials may be used. The anode terminals 12 also preferably consist of tungsten and may be sealed directly into stems 13, 14 of low expansion glass.

The envelop is first very carefuly evacuated and baked out at as high a temperature as the glass will stand without softening so as to remove residues of air and water vapor. Unless the anodes have been freed from gas previous to mounting, for example, by heating to a high incandescence in a vacuum, they should be freed from deleterious gases in the tube by electron bombardment by impressing between the cathode while at incandescence and the anode to be purified a voltage high enough to cause an electron current to flow but insufficient to produce appreciable positive ionization. Deleterious gases are thereby driven out of the anode. The evacuation may then be continued and the voltage progressively increased as gas is removed. This method is disclosed and claimed in an application, Serial No. 795,610 filed by Irving Langmuir. A quantity of inert gas, such as nitrogen, argon, neon, krypton, or a globule of mercury, as shown at 15, Fig. 2, or a mixture of gases, is then introduced into the envelop. The gas is preferably at a relatively considerable pressure, for example, at a pressure varying from about one centimeter of mercury pressure upward to atmospheric pressure. No definite lower limit of pressure can be assigned, but the pressure should be high enough to largely suppress electrical disintegration of the cathode by the bombardment of ions. When the cathode operates in mercury vapor lower pressures are permissible than when the cathode is operating in a gas, such as argon or nitrogen. When the gaseous pressure is low, for example, in the case of mercury vapor, below about one centimeter of mercury, depending on the voltage, it is practically necessary to provide for greater electron emission at the cathode than necessary to convey the current, for example, by increasing the temperature of the cathodes. Thereby a negative field is established about the cathode, and the bombardment of the cathode by positive ions, and its disintegration is reduced by the presence of these electrons which apparently return to the cathode. In this manner it is possible to operate the cathode with a commercially fairly long life in gaseous pressures as low in the case of mercury vapor as one millimeter or even below.

At the higher pressures the electrical disintegration, or sputtering, of the cathode is correspondingly less and the useful life of the device is correspondingly longer, so that a high electron emission is not necessary to give a long life although, of course, a high electron emission may also be employed even at higher gas pressures. The thermal disintegration is also less at higher gas pressures. As the pressure of the gas increases beyond a certain limit varying with the nature of the gas, and which is in the case of mercury vapor about one centimeter of mercury pressure, the voltage drop in the tube increases. In most cases, however, it is desirable to operate at a gas pressure substantially above the region of minimum voltage drop in order to secure a fair life. However, when currents of low voltage are to be rectified and the highest efficiency is desired, the voltage drop permissible may make it desirable to sacrifice life to efficiency to some extent and, therefore, to operate at the pressure of minimum voltage drop, but ordinarily this is not desirable.

When mercury vapor is used as the ionizable gas it should be understood that the size of the envelop should be so proportioned that it will operate at a temperature at which sufficient quantities of mercury will be vaporized to give the desired pressure of mercury vapor.

As shown in Fig. 4, the anodes 9, 10 may be connected to the terminals of a source of alternating current, such as the secondary of a transformer 17, the cathode 8 being connected to an intermediate point of potential in series with a load 18, and a series resistance 19. The device is started after suitable connections have been made by closing the switch 20 in the heating circuit 21 and heating the cathode to incandescence.

The anodes should be made of such size that heat will be dissipated from them at such rate that they will remain below the temperature at which appreciable electron emission occurs so as to prevent passage of current in the reverse direction when the anode is negative.

With a rectifier constructed as illustrated and above described, currents of many amperes depending on the size of the apparatus can be rectified without discharge of any current in the reverse direction with a low voltage drop, which in mercury vapor is about 8 to 15 volts, and which varies somewhat dependent upon the nature of the gas filling, temperature of the cathode, pressure of the gas, and similar conditions. When the current to be rectified has a voltage up to several hundred volts, the cathode and anodes are located relatively close together, as indicated in the drawing, but when the voltage is substantially higher than this the distance between the cathode and the anodes should be correspondingly increased.

The discharge is normally confined to a relatively narrow zone between the cathode and the anode, and has the general appearance of an ordinary open air arc. The electrical characteristics of the device are those of an arc, that is, an increase of current produces little appreciable instantaneous change of voltage. However, inasmuch as an increase of current will also increase the gas pressure, an increase of current is accompanied by an increase of voltage drop if sufficient time has elapsed for an adjustment of pressure. The instantaneous value of the voltage across the terminals must be lowered by an increase of current, as two rectifiers can not be operated in parallel without some provision being made to divide the load.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. A rectifier comprising the combination of an envelop, a tungsten cathode, an anode of refractory material having a heat dissipating capacity great enough to operate below the temperature at which appreciable electron emission occurs, and an atmosphere of mercury vapor in which electro-negative gaseous impurities are absent at a pressure high enough to substantially prevent the electrical disintegration of the cathode.

2. A low voltage rectifier comprising the combination of an envelop, a tungsten cathode, an anode having a heat dissipating capacity great enough to operate below the temperature at which appreciable electron emission occurs, means for heating said cathode, and a quantity of mercury in said envelop which at the normal operating temperature of the device will have a pressure at which the electrical discharge is contracted into a comparatively restricted zone between the electrodes and said discharge has the electrical characteristics of an arc.

3. A rectifier comprising the combination of an envelop, a refractory cathode operable at a temperature of at least about 2000° C., an anode operable continuously below about 737° C. and a filling of gas inert with respect to the cathode at high temperatures, the pressure of said gas being substantially between the limits of about a centimeter of mercury and atmospheric pressure.

4. A rectifier comprising the combination of an envelop, a cathode consisting of conducting material operable without melting at a temperature in excess of about 2000° C., an anode large enough to operate below the temperature at which appreciable electron emission occurs, and an atmosphere of gas in said envelop inert with respect to the cathode at high temperature at a pressure high enough to substantially suppress electrical disintegration of the cathode.

5. A rectifier comprising the combination of an envelop, an electron emitting cathode, an anode having sufficient heat dissipating capacity to enable it to operate continuously below the temperature at which appreciable electron emission occurs, and an atmosphere of inert gas in said envelop at a pressure of at least about one millimeter of mercury at the operating temperature.

6. The method of reducing the disintegration of an electron-emitting incandescent cathode operating in a gaseous pressure low enough to permit considerable electrical disintegration of said cathode, which consists in increasing the temperature of the cathode to a value higher than necessary to convey the operating current whereby a negative electric field is established about said cathode by free electrons.

7. A rectifier comprising the combination of an envelop, a cathode of refractory material operable at incandescence above a temperature of about 2000° C., an anode having a heat-dissipating capacity great enough to be operable below the temperature at which appreciable electron emission occurs, and a filling of dry gas having at the operating temperature of the device a pressure of at least about one centimeter of mercury, said gas being inert with respect to the electrodes at the operating temperature.

8. A rectifier comprising the combination of a sealed envelop, a tungsten cathode, an anode having a heat dissipating capacity great enough to be operable below the temperature at which appreciable electron emission occurs, and a filling of gas inert with respect to the cathode when at incandescence and having at the operating temperature of the device a pressure materially above one millimeter of mercury, whereby electrical disintegration of the cathode during operation is substantially suppressed.

In witness whereof, I have hereunto set my hand this 8th day of October, 1914.

GEORGE S. MEIKLE.

Witnesses:
BENJAMIN B. HULL,
HELEN ORFORD.

DEFENDANT'S EXHIBIT No. 283.

G. S. MEIKLE.
RECTIFIER.
APPLICATION FILED JAN. 15, 1916.

1,266,517. Patented May 14, 1918.

Fig. 1.

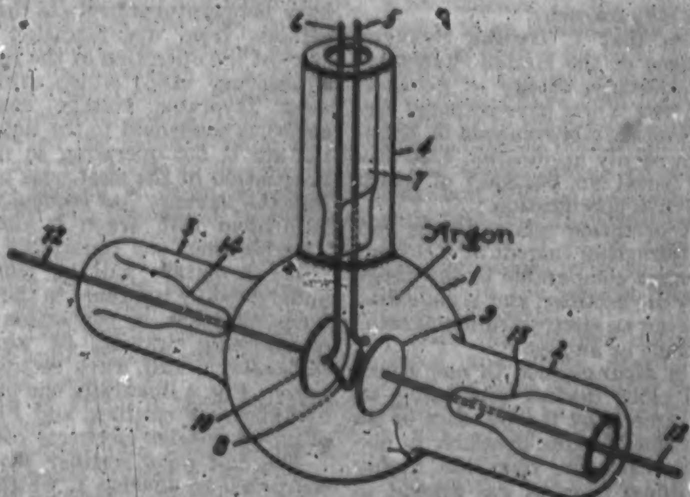

6
5
4
7
Argon
1
3
12
3
14
9
13
2
10
8
12

Fig. 2.

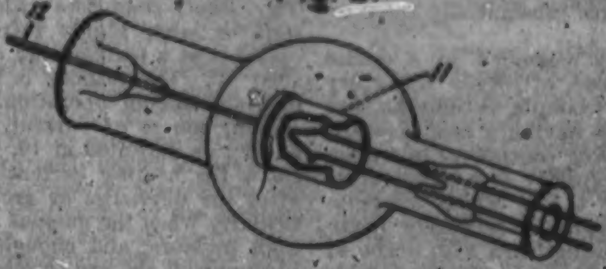
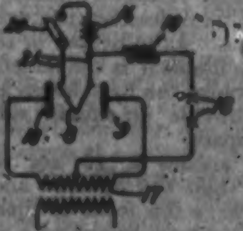


Fig. 3



Inventor:
George S. Meikle,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

GEORGE STANLEY MEIKLE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RECTIFIER.

1,266,517. Specification of Letters Patent. **Patented May 14, 1918.**

Original application filed October 9, 1914, Serial No. 865,836. Divided and this application filed January [illegible] 1916. Serial No. 72,[illegible].

To all whom it may concern:

Be it known that I, GEORGE STANLEY MEIKLE, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Rectifiers, (division of my application filed October 9, 1914, Serial No. 865,836,) of which the following is a specification.

The present invention relates to the rectification of alternating current of a current and voltage range comparable to the range of the mercury arc rectifier, and is embodied in a device having an electron-emitting cathode, and an anode or anodes.

My device is distinguished in one aspect from various prior devices containing an incandescent cathode by the presence of an inert gas at a considerable pressure, as distinguished, for example, from the highly attenuated residual trace of gas present in an envelop exhausted to what is termed a "lamp vacuum." Although no very definite lower limit of pressure can be assigned, for practical purposes the gaseous pressure should not be much below one millimeter of mercury as at very much lower pressures a rapid electrical disintegration of the cathode occurs. The electrical characteristics of my new rectifier are substantially those of an electric arc.

My invention is embodied in a device containing a cathode, of highly refractory material, such, for example, as tungsten, and an anode or anodes having a heat dissipating capacity enabling continuous operation at a given rated capacity at a temperature below about 727° C., at which temperature electron emission is relatively negligible, this device being filled with argon of relatively appreciable pressure, preferably of the order of magnitude of atmospheric pressure. Water vapor should be carefully excluded.

In the parent application, above identified, I have enumerated various inert gases which may be introduced into a rectifier. Among these gases argon possesses several marked advantages. For example, an arc in argon exhibits a very low voltage drop. Under favorable conditions the difference in potential across the electrodes between which the arc is operating is only about one to two volts. Argon being gaseous at ordinary temperatures protects the incandescent cathode from disintegration at the very start of the operation of the rectifier, whereas mercury vapor which exhibits the next most favorable voltage consumption to argon, is condensed to the liquid state when the arc is not operating so that some disintegration of the electrodes takes place before the mercury has become vaporized. A bulb filled with argon is also more transportable than one containing mercury.

My invention will be more completely understood by reference to the following description taken in connection with the accompanying drawing of which Figure 1 illustrates a full wave rectifier containing argon; Fig. 2 illustrates one particular form of half wave rectifier, and Fig. 3 is a diagram of suitable electrical connections.

The full wave rectifier shown in Fig. 1 comprises an envelop 1, which conveniently consists of glass and has three side arms 2, 3 and 4, provided for the convenience of sealing in the leading-in conductors. The cathode conductors 5, 6 may, for example, consist of tungsten sealed directly into a stem 7 of low-expansion glass, such, for example, as sodium-magnesium boro-silicate, although any convenient seal may be used. The cathode comprises a filament 8 of tungsten, or other highly refractory material, operable at a temperature of at least about 2000° C. The cathode is heated to incandescence during operation from any convenient source of current, for example, a battery as indicated at 16, Fig. 3. In some cases, the heating current may be cut off after the discharge or arc is started, particularly when the gaseous atmosphere is at high pressure, and enough energy will be liberated by the arc to maintain a portion of the cathode at a sufficiently high incandescence.

A clean, refractory metal, such as tungsten, at incandescence is a primary source of electrons. As indicated in the drawing, the cathode filament is conveniently coiled so as to minimize the heat losses and at the same time provide maximum surface within a given space.

The anodes 9, 10 are relatively much larger than the cathode and may conveniently have the form of disks, as shown in Fig. 1, or may consist of a cup, or cylinder in a half wave rectifier as shown at 11, Fig. 2. The anodes preferably consist of tungsten although other highly refractory materials may be used. The anode terminals 12 also preferably consist of tungsten and may be sealed directly into stems 13, 14 of low expansion glass.

The envelop is first very carefully evacuated and baked out at as high a temperature as the glass will stand without softening so as to remove residues of air and water vapor. Unless the anodes have been freed from gas previous to mounting, for example, by heating to a high incandescence in a vacuum, they should be freed from deleterious gases in the tube by electron bombardment by impressing between the cathode while at incandescence and the anode to be purified a voltage high enough to cause an electron current to flow but insufficient to produce appreciable positive ionization. Deleterious gases are thereby driven out of the anode. The evacuation may then be continued and the voltage progressively increased as gas is removed. This method is disclosed and claimed in an application, Serial No. 795,610 filed by Irving Langmuir.

A quantity of argon is then introduced into the envelop. The gas is preferably at a relatively considerable pressure, for example, at a pressure varying from about one centimeter of mercury pressure upward to atmospheric pressure. No definite lower limit of pressure can be assigned, but the pressure should be high enough to largely suppress electrical disintegration of the cathode by the bombardment of ions.

When the gaseous pressure is low it is practically necessary to provide for greater electron emission at the cathode than necessary to convey the current, for example, by increasing the temperature of the cathode. Thereby a negative field is established about the cathode, and the bombardment of the cathode by positive ions, and its disintegration is reduced by the presence of these electrons which apparently return to the cathode.

At the higher pressures the electrical disintegration, or sputtering, of the cathode is correspondingly less and the useful life of the device is correspondingly longer, so that a high electron emission is not necessary to give a long life although, of course, a high electron emission may also be employed even at higher gas pressures. The thermal disintegration is also less at higher gas pressures. As the pressure of the gas increases beyond a certain limit varying with the nature of the gas, and which as in the case of argon is somewhat less than one centimeter of mercury pressure, the voltage drop in the tube increases. In most cases, however, it is desirable to operate at a gas pressure substantially above the region of minimum voltage drop in order to secure a fair life. However, when currents of low voltage are to be rectified and the highest efficiency is desired, the voltage drop permissible may make it desirable to sacrifice life to efficiency to some extent, and therefore, to operate at the pressure of minimum voltage drop, but ordinarily this is not desirable.

As shown in Fig. 3, the anodes 9, 10 may be connected to the terminals of a source of alternating current, such as the secondary of a transformer 17, the cathode 8 being connected to an intermediate point of potential in series with a load 18, and a series resistance 19. The device is started after suitable connections have been made by closing the switch 20 in the heating circuit 21 and heating the cathode to incandescence.

The anodes should be made of such size that heat will be dissipated from them at such rate that they will remain below the temperature at which appreciable electron emission occurs so as to prevent passage of current in the reverse direction while the anode is negative.

With the rectifier constructed as illustrated and above described, currents of many amperes depending on the size of the apparatus can be rectified without discharge of any current in the reverse direction with a low voltage drop, which in argon is about 1 to 2 volts, and which varies somewhat dependent upon the temperature of the cathode, pressure of the gas, and similar conditions. When the current to be rectified has a voltage up to several hundred volts, the cathode and anodes are located relatively close together, as indicated in the drawing, but when the voltage is substantially higher than this the distance between the cathode and the anodes should be correspondingly increased.

The thermionic discharge is normally confined to a relatively narrow zone between the cathode and the anode, and has the general appearance of an ordinary open air arc. The electrical operating characteristics of the device are those of an arc, that is, an increase of current produces little appreciable instantaneous change of voltage. However, inasmuch as an increase of current will also increase the gas pressure, an increase of current is accompanied by an increase of voltage drop if sufficient time has elapsed for an adjustment of pressure. The instantaneous value of the voltage across the terminals must be lowered by an increase of current, as two rectifiers cannot be operated in parallel without some provision being made to divide the load.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. A rectifier comprising the combination of a sealed envelop, a refractory cathode operable at a temperature of at least about 2000° C., an anode having a heat-dissipat-

ing capacity great enough to be operable below the temperature at which appreciable electron emission occurs, and a filling of argon having at the operating temperature of the device a pressure materially above one millimeter of mercury.

2. A rectifier comprising the combination of a sealed envelop, a tungsten cathode, means for heating said cathode to incandescence, an anode having a heat-dissipating capacity great enough to be operable below the temperature at which appreciable electron-emission occurs, and a filling of argon having at the operating temperature of the device a pressure of at least about one centimeter of mercury.

3. A rectifier comprising the combination of a sealed envelop, a refractory cathode adapted to emit electrons, an anode having a heat-dissipating capacity great enough to be operable below the temperature at which appreciable electron emission occurs, and a quantity of argon in said envelop having at the operating temperature of the device a pressure sufficiently high to give to an electrical discharge emanating from the cathode when at incandescence the characteristics of an electric arc.

4. A rectifier comprising the combination of a sealed envelop, a tungsten cathode, means for heating said cathode to incandescence, a tungsten anode of materially greater heat-dissipating capacity than said cathode, and a quantity of argon gas within said envelop, at a pressure permitting a discharge having a voltage drop of a few volts with the cathode at incandescence.

In witness whereof, I have hereunto set my hand this 14th day of January 1916.

GEORGE STANLEY MEIKLE.

DEFENDANT'S EXHIBIT No. 284.

I. LANGMUIR.

FILM CONDUCTOR AND THE METHOD OF MAKING THE SAME.

APPLICATION FILED JUNE 8, 1914. RENEWED MAY 1, 1917.

1,273,628. Patented July 23, 1918.

Fig. 1.

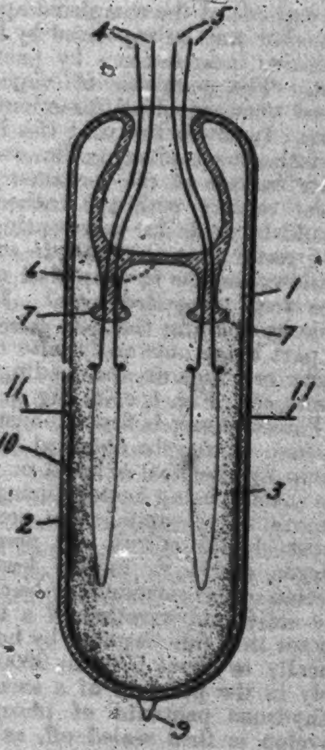
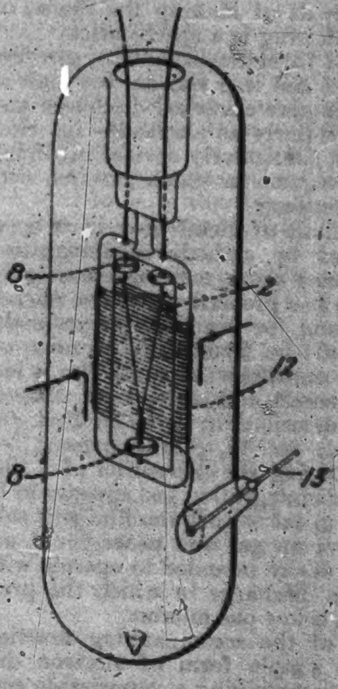


Fig. 2.



Witnesses:

Helen O. [illegible]

Margaret E. Woolley

Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

FILM CONDUCTOR AND THE METHOD OF MAKING THE SAME.

1,273,628. Specification of Letters Patent. Patented July 23, 1918.

Application filed June 6, 1914, Serial No. 843,869. Renewed May 1, 1917. Serial No. 165,796.

To all whom it may concern:

Be it known that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Film Conductors and the Methods of Making the Same, of which the following is a specification.

The present invention comprises gas-free metal films formed in a vacuum too high to permit a disruptive electrical discharge and suitable particularly as electrodes for electrical devices, particularly devices requiring a very high vacuum in which gas-free electrodes are necessary.

Adherent films of metal have been heretofore formed by cathodic disintegration but in this case there must necessarily be present a gas at a pressure above one micron of mercury and for practical purposes the pressure should be from 20 to 30 microns. Under these conditions the metal film is less strongly adherent and consists of discrete particles as described in detail in *Zeit. fur Elektrochemie*, vol. 18, (1912), pages 373—419—837. During the deposition of a film by cathodic disintegration gas appears to be fixed on the metal so that the film will subsequently give up gas and hence could not be used in a device intended to operate with pure electron discharge in which the pressure must be below one micron.

Figure 1 of the accompanying drawing illustrates a simple form of electron discharge device containing a vaporizable conductor for preparing a film anode and Fig. 2 is a modification in which the vaporized metal is furnished by the cathode.

As disclosed and claimed by me in my Patent No. 1,237,210, issued August 14, 1917, an extremely high vacuum may be produced by incandescing a refractory metal conductor, such as tungsten in a partial vacuum to a temperature elevated enough to actively vaporize the refractory metal. This vaporized metal is deposited on the walls of the evacuated container as a hard strongly adherent film which even when so thin as to be transparent is a good electrical conductor and capable of carrying relatively heavy currents.

Referring to Fig. 1 the envelop 1, consisting of glass, quartz, or similar non-conducting material, is provided with two vaporizable conductors 2, 3, consisting of tungsten, tantalum or molybdenum and provided, respectively, with leading-in conductors 4, 5 sealed into a stem 6 in the usual manner. One of these filaments 2, 3 may be used for the cathode of the completed apparatus and the other may be vaporized by heating it to intensive incandescence by passage of current. The particles of vaporized metal travel outward in all directions in straight lines. In order to avoid the formation of a continuous conducting film over the entire inner surface of the container and in electrical contact with the cathode provision should be made for intercepting the vaporized metal near the cathode so as to "cast shadows" on the envelop wall which will be free from deposited metal. This may be done by shaping the stem 6 so that it will in part bulge outwardly, also by providing knobs or rings on the leading-in wires as shown at 7, Fig. 1, or 8, Fig. 2.

The container is first exhausted to a good vacuum as may be obtained by means of a pump by chemical exhaust or other means, the envelop being heated during pumping to remove water vapor. The preliminary exhaust should reduce the pressure to one micron (0.001 m. m.) or less. The completion of the vacuum may be carried out by the active vaporization of a tungsten conductor in a side chamber by heating it electrically to about 2700 to 2900° C., preferably in the presence of a small amount of anhydrous pentoxid of phosphorus. The envelop is then sealed off, as indicated at 9, and one of the refractory conductors, for example, the filament 3 is heated to about 2700° to 2900° C. by passage of current, thereby depositing the desired gas-free film as indicated at 10. Contact is made to the film 10 of vaporized metal by sealed-in wires 11, two being provided to insure a good contact. This film is gas-free and so hard and coherent that even when no more than 10^{-6} m. m. in thickness it can only with the greatest difficulty be scratched off the glass with a knife.

The device shown in Fig. 1 may be used as a rectifier when the cathode 2 is maintained incandescent and the film of deposited metal is used as the anode. Similar devices of this nature may be used as relays by providing a discharge controlling grid 12, Fig. 2 connected to a leading-in conductor 13. In the device shown in Fig. 2 no separate conductor for producing the anode film has been provided, as the cathode 2 may itself serve to provide the vaporized metal without serious damage when an extra heavy filament has been provided to serve as cathode.

The films produced in this manner may be easily made about 10^{-5} to 10^{-6} c. m. in thickness and in apparatus such as described will readily receive currents of about 100 milliamperes or more.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. As an article of manufacture, a solid body and an adherent, gas-free film of metal produced by the vaporization of said metal in a vacuum having a residual gas pressure below about one-thousandth of a millimeter of mercury.

2. An electrical discharge apparatus having an anode consisting of a gas-free film of metal produced by vaporization in a vacuum in which the residual gas is at a pressure too low to permit a disruptive discharge therein.

3. An electrical discharge apparatus having an envelop of non-conducting material and a gas-free layer of metal thereon produced by vaporization of said metal in a vacuum having a residual gas pressure below about one-thousandth of a millimeter of mercury.

4. The method of producing a gas-free, adherent metallic film upon a solid body which consists in exposing said body to metal vapor in a vacuum having a residual gas pressure below one-thousandth of a millimeter of mercury.

5. The method of depositing gas-free conductive films upon insulating surfaces which consists in heating a highly refractory metal to a temperature near its melting point in vacuum too high to permit of the passage of a disruptive discharge and exposing the surface upon which a film is desired to said vapors.

6. An electrical discharge device comprising the combination of a glass envelop, an incandescing cathode, and an anode consisting of a dense, coherent film of tungsten deposited on the wall of said envelop by vaporization in a vacuum too high to permit a disruptive electrical discharge at high voltages.

7. The method of depositing a gas-free conductive film of refractory metal upon non-conducting surfaces which consists in incandescing a refractory metal conductor at the vaporizing temperature of the metal constituting said conductor in a vacuum so high that electrical discharges may be produced therein without positive ionization.

8. An article of manufacture comprising an envelope of non-conducting material and a layer of metal thereon produced by the vaporization of said metal in a vacuum having a residual gas pressure below about 1/1000 of a millimeter of mercury, said metal being sufficiently hard and coherent to resist abrasion.

9. The method which consists in vaporizing metal in a vacuum having a residual gas pressure below 1/1000 of a millimeter of mercury, and receiving said vaporized metal upon a solid body, thereby producing a coherent, gas-free deposit of metal.

In witness whereof I have hereunto set my hand this 5th day of June, 1914.

IRVING LANGMUIR.

Witnesses:

Benjamin B. Hull,

William G. Gartner.

DEFENDANT'S EXHIBIT No. 285.

I. LANGMUIR.
ELECTRON DISCHARGE APPARATUS.
APPLICATION FILED APR. 23, 1919.

Reissued Jan. 31, 1922. **15,278.**

Fig.1.

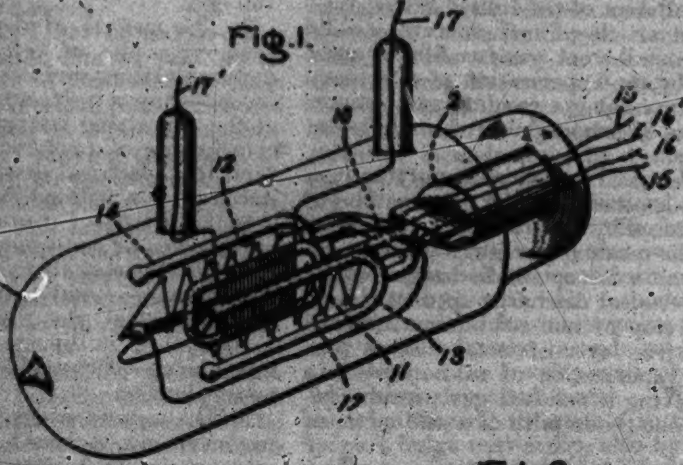

17
17'
2
10
12
14
15
16
16
15
1
13
11
19

Fig.3.

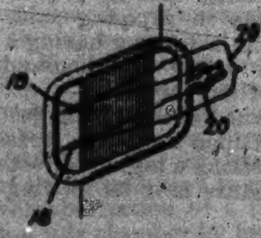


Fig.2.

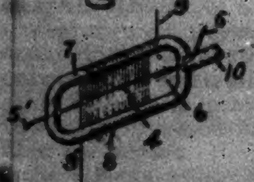

9
6
7
10
5
6
4
3
8

Fig.4.

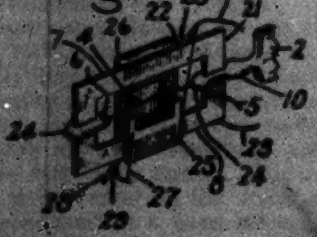
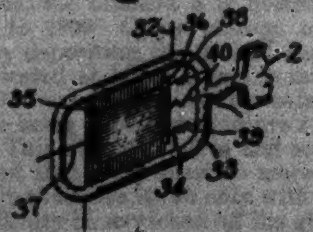

22
23
40
21
26
7
4
6
2
10
5
24
28
25
8
24
18
27
29

Fig 5.


32
36
38
40
2
35
39
33
37
34

Inventor:
Irving Langmuir.
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS.

15,278. Specification of Reissued Letters Patent. Reissued Jan. 31, 1922.

Original No. 1,273,787, dated July 23, 1918, Serial No. 795,609, filed October 16, 1913. Renewed March 14, 1916, Serial No. 84,241. Application for reissue filed April 23, 1919. Serial No. [illegible].

To all whom it may concern:

Be it known that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Apparatus, of which the following is a specification.

The present invention relates to electron discharge devices, for example, discharge tubes having an incandescent cathode.

Devices of this nature as described and broadly claimed in a copending application, Serial No. 795,610, filed October 16, 1913, are provided with an electron-emitting cathode, an anode, and a conducting body or auxiliary electrode, commonly termed a grid consisting ordinarily of an electrical conductor located between cathode and anode for statically controlling the electrical discharge conditions of the tube. Electron discharge devices as described in the above application may be operated at exceedingly high voltages and have a high load capacity. This new apparatus is suited for use in a much wider field than former devices of this nature which were limited to low voltages and very feeble currents.

The present invention comprises various structural features of novelty which coöperate to increase the range and capacity of a device of this type. For example, in accordance with my invention the grid is supported on a supporting frame-work in such manner that mechanical displacement of the grid by static strains or by mechanical shocks cannot easily occur. Other features of novelty are pointed out with particularity in the claims.

In the accompanying drawings various forms of apparatus are shown illustrative of my invention. Figure 1 illustrates an electron discharge tube with its parts assembled, and Figs. 2 to 5 inclusive, show alternative forms of electrode and grid constructions.

As shown in Fig. 1, the various parts of the apparatus may be mounted in an inclosing envelop or globe 1 upon a pedestal or press 2 similar to the mount employed for incandescent lamps. The cathode construction is shown in Fig. 2. It consists of a substantially straight filament 4 consisting of highly refractory material, preferably tungsten, and provided with terminals 5, 5′. The filament 4 is mounted, preferably attached to a light spring 6, between two oppositely disposed parallel rod supports or arbors 7 and 8 constituting a frame work, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this frame-work is wound a wire 9 in the form of a flattened helix, which has such a small diameter or section that it is too yielding to retain without the aid of the framework a desired position or configuration. The turns of conductor are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. The conductor 9, which may be very fine and extends in the forms illustrated transversely across the space between the cathode and the anode, constitutes a grid which by means of applied potential exerts an electrostatic control upon the electron discharge.

The supporting frame-work for the cathode and grid is attached to a rod or arbor 10, mounted upon the stem of the tube. Adjacent to the cathode and grid is the anode or plate 11 which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks 12 upon fork-shaped supports 13 and 14 but it is not necessary that it should assume this particular form. As indicated, the anode also may consist of a conductor or wire which has such small section that it is not self-supporting and, therefore, is carried upon a framework which is upheld by the support which carries the grid framework, and as will be described in connection with Fig. 4, the second framework may be placed upon the first-mentioned framework carrying the grid conductor. Both anode and grid preferably consist of tungsten, but other gas-free refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 15, 15′. The cathode terminals 5, 5′ are supplied with current through leading-in wires 16, 16′. Although it is not necessary for all purposes to provide connections for each end of the grid it is desirable to do so when the potential applied to the grid is small and in the case of a straight or linear cathode the potential gradient along the grid may to advantage be the same as that on the filament. In this manner the potential drop from grid to cathode is the same along its length. The grid is indicated in Fig. 1 as being attached to leading-in conductors 17, 17′ at opposite ends.

In some cases it is desirable to use a V-shaped incandescing conductor for the cathode and to attach to its bight a spring as shown at 18, 19 in Fig. 3. In this manner contact of the conductor with the grid by sagging when the metal is expanded at high temperature is prevented. In Fig. 3 a plurality of loops are used in order to increase the amount of cathode surface. The filaments are connected in parallel by means of conductors 20, 20′.

In Fig. 4 the cathode 4 has been shown as being mounted in a frame 21, consisting of ferrochrome, tungsten, or other suitable metal upon which the wire 22 constituting the grid is wound in the form of a flattened helix. As the grid wire is thus wound upon a conductive frame its turns are in parallel and electrical contact may be made directly to the frame 21 which constitutes a part of the grid electrode by conductor 23. The leading-in conductors 5, 6 for the cathode are insulated from the frame by glass supports 24 as indicated.

Upon the frame 21 are placed mica sheets 25 and 26 which serve to insulate the wire 27 which is wound in the form of a flattened helix constituting the anode or plate from the grid. The leading-in conductors 28, 28′ to which the ends of the wires are anchored may be attached to glass beads 29 fused upon the frame 21.

In Fig. 5 not only the grid 32 is wound upon the frame 33 but also the cathode wire 34 is wound upon stout straight metallic conductors or wires 35, 36, consisting preferably of tungsten in such a way as to form a flattened helix. The conductors 35, 36 are attached respectively to an anchoring wire 37 and to two springs 38 and 39 serving to hold taut the turns of the tungsten wire constituting the cathode and to prevent them from coming into contact with the grid wire 32. A stranded copper conductor 40 may be used to conduct current to the cathode.

In preparing the apparatus, the preliminary exhaust is carried out by the most improved methods such as used in incandescent lamp manufacture. The anodes or plates are then subjected to an electron discharge or bombardment by impressing a suitable voltage between the cathode and anode. When the anode consists of a conductor such as wire 11, Fig. 1, it is preferably heated by passage of current either before or during the bombardment. When the anode is plate-shaped the heating may form a part of the treatment by electron bombardment, the discharge current being made heavy enough to heat the anode, but heating is not essential. The removal of the gas from the anode is not due to heat alone, but is due to electrical effect. The voltage should be so chosen at the beginning of the electron discharge treatment that blue glow is absent in the tube as this indicates that ionization of the residual gas by collision of gas molecules with electrons is taking place and under these conditions disintegration of the cathode is apt to take place. The discharge voltage is progressively increased, the gas being removed as fast as evolved, preferably by a Gaede molecular pump. This treatment is ordinarily continued until the discharge voltage is higher than the voltage at which the device is normally operated but this rule will not hold true when the operating voltage is very high as substantially all the gas may be removed before the operating voltage is exceeded. Evacuation of the device should preferably be carried to a pressure as low as a few hundredths of a micron or even lower although no definite limits may be assigned. In any event evacuation should be so low that no appreciable gas ionization takes place during normal operation. When the cathode and anode are very close together and the discharge is confined to a direct path, a greater gas pressure is permissible than when the opposite is true.

An electron discharge tube may be used in various electrical systems, for example, as in receiving systems for radio-telegraphy. The passage of electron current across the evacuated space between cathode and anode is controlled by the potentials impressed upon the grid. A tube prepared as above described may be used to transmit currents limited in potential only by the dielectric strength of the glass, quartz or other material of the tube and the mechanical strength of parts subjected to static forces.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electrical vacuum discharge apparatus comprising a highly evacuated envelop, a cathode adapted to be heated, a coöperating anode, a rigid framework, an unheated conductor, constituting a grid, wound back and forth on said frame-work with closely adjacent turns and located between cathode and anode, and external connections for said electrodes and said grid.

2. The combination of a highly evacuated envelop, a cathode, a coöperating anode, rods spaced apart and adjacent said cathode, a grid conductor having too small a diameter to be self-supporting wound over said rods with closely adjacent turns and having a plurality of sections transverse to said rods, and external connections for said electrodes and said grid.

3. An electron discharge apparatus comprising an evacuated envelop, an electron-emitting cathode, a coöperating anode, a frame-work spaced about said cathode, and a conductor wound about said framework closely adjacent said cathode.

4. An electron discharge apparatus comprising an evacuated envelop, a refractory conductor, connections for transmitting energy to incandesce said conductor, bars located on opposite sides of said conductor, a wire wound with closely adjacent turns on said bars to constitute a grid, but out of contact with said incandescing conductor, a second set of bars closely adjacent to the first set but insulated therefrom and a conductor constituting an anode mounted thereon in a plane substantially parallel to said grid, and leading-in conductors to said grid and anode.

5. A vacuum discharge tube comprising a highly evacuated envelop, a cathode adapted to be heated, a cooperating anode, a framework located adjacent thereto, a conductor mounted thereon, and having turns inclosing said cathode, and external connections for said electrodes and said conductor.

6. The combination of a gas-tight highly evacuated envelop, a filamentary conductor adapted to be heated, constituting a cathode, a frame consisting of conductive material spaced about said conductor, a conductor wound on said frame with closely adjacent turns surrounding said cathode and constituting a grid, insulating supports adjacent said grid, a second conductor constituting an anode wound upon said supports, and external current connections for said electrodes and grid.

7. An electrical device comprising the combination of an inclosing envelop, a cathode, means for causing said cathode to emit electrons, an anode, a self-supporting framework located between said electrodes, and an electrical conductor mounted on said framework and extending transversely to the direct path between said electrodes.

8. An electrical apparatus comprising the combination of a cathode adapted to emit electrons independently of the operating current, an anode, a supporting framework, a wire mounted on said framework, said wire having too small a cross-section to be self-supporting, constituting a charge-receiving grid, an inclosing evacuated envelop, and electrical connections for said electrodes and grid.

9. An electrical apparatus comprising the combination of a cathode, adapted to independently emit electrons, a supporting framework, a conductor having too small a section to be self-supporting mounted thereon, a second framework adjacent the first, a second conductor mounted on said second framework insulated from said first-named conductor, an inclosing envelop, and external connections for said elements.

10. An electrical apparatus comprising the combination of a cathode adapted to emit electrons, supporting bars located on opposite sides of said cathode, a wire wound on said bars to constitute a grid, a second set of self-supporting bars adjacent said first set but insulated therefrom, a second wire wound on said second set of bars, constituting an anode, an inclosing envelop, and external electrical connections for said cathode, grid and anode.

11. An electrical apparatus comprising the combination of an evacuated envelop, a supporting framework therein, a cathode mounted on said framework, an unheated conductor positioned to control an electrical discharge emitted by said cathode and extending transversely to a direct path between said cathode and anode, said conductor being also mounted on said framework, and a cooperating anode within said envelop.

12. An electrical apparatus comprising the combination of an evacuated gas-tight envelop, a supporting framework therein, a cathode carried by said framework, a discharge-controlling conductor also carried by said framework and surrounding said cathode and a cooperating anode within said envelop.

13. An electrical device comprising the combination of a supporting stem, framework carried thereby, a filamentary cathode of refractory material supported by said framework, a discharge-controlling conductor having too small a section to be self-supporting wound on said framework about and in close proximity to said cathode, a second framework also carried by said stem, an anode supported by said second framework, an inclosing evacuated envelop, and electrical leading-in conductors joined respectively to said cathode, said discharge-controlling conductor and said anode.

14. An electrical apparatus comprising the combination of an evacuated envelop, a supporting framework therein, a cathode mounted on said framework adapted to be operated at incandescence, a discharge-controlling conductor also mounted on said framework and extending transversely across the direct path between said cathode and anode, said conductor being of such small cross-section as to be unable to maintain a desired configuration without the framework, and a cooperating anode.

15. An electrical device comprising the combination of a supporting stem, a framework carried thereby, a cathode mounted on said framework, a discharge-controlling conductor also mounted on said framework, a second framework also carried by said stem, an anode supported by said second framework, an inclosing evacuated envelop,

and electrical leading-in conductors sealed in said envelop [illegible] joined respectively to said cathode, said discharge-controlling conductor and said [illegible].

16. An electrical device comprising the combination of a supporting stem, a framework upheld thereby, a cathode of refractory material, a discharge-controlling conductor, both said cathode and conductor being carried by said framework and having such small section as to be too yielding to be self-supporting, a second framework also carried by said stem, an anode conductor too small in diameter to be self-supporting, carried by said second framework, an inclosing evacuated envelop and electrical leading-in conductors sealed into said envelop and each joined respectively to said cathode, said discharge-controlling conductor and said anode.

17. An electrical device comprising the combination of a framework, a filamentary cathode of tungsten supported by said framework, a tungsten wire wound with closely adjacent turns on said framework constituting a discharge controlling grid, a second framework closely adjacent the first framework, a second tungsten wire mounted on said second framework but out of electrical contact with the cathode and grid, a common support for both frameworks, an inclosing envelop evacuated to such low pressure that conduction of energy can occur therein substantially independently of positive gas ionization, and electrical leading-in conductors sealed into said envelop and connected respectively to said cathode, said grid and said anode.

18. An electrical device comprising the combination of a cathode, an anode, a framework having a plurality of arms spaced apart, a discharge-controlling conductor extending from one of said arms to another arm, transverse to a direct path between said cathode and anode, an inclosing envelop, and external connections for said electrodes and said conductor.

19. An electrical device comprising the combination of a refractory cathode, an anode, means for heating said cathode independently of a discharge between said cathode and anode, a framework located between said electrodes and an unheated conductor mounted on said framework and surrounding one of said electrodes, and an inclosing enevelop into which electrodes and said unheated conductor are sealed.

20. An evacuated envelop containing three electrodes one of which is a filament adapted to be heated, another a charge receiving anode, a self-supporting framework spaced about one of said electrodes, and a third electrode consisting of a wire mounted on said framework and located transversely to the space between said electrodes.

21. A thermionic device having a plurality of electrodes in immediate proximity to each other, and one supported by but held out of electrical contact with another electrode by an interposed dielectric.

22. A space current device comprising a plurality of electrodes, one of which is insulatingly supported by another electrode.

23. In an evacuated vessel, an electrode, insulating material supported by said electrode and another electrode supported by said insulating material.

24. A vacuum tube device of the audion type comprising an output electrode, a cathode and a control electrode, one of said electrodes being insulatingly supported by another of said electrodes.

25. A vacuum tube device of the audion type comprising a pair of plate electrodes with a filamentary electrode and an auxiliary electrode located between the electrodes of said pair, said filamentary electrode being insulatingly supported by another of said electrodes.

26. A vacuum tube device of the audion type comprising a pair of plate electrodes with a filamentary electrode and an auxiliary electrode located between the electrodes of said pair, said filamentary electrode being insulatingly supported by said auxiliary electrodes.

27. An evacuated vessel comprising an arbor, a pair of plate electrodes laterally disposed from said arbor and supported thereby, an electrode between said plate electrodes.

28. An evacuated vessel comprising an arbor, a pair of plate electrodes laterally disposed from said arbor and supported thereby, and cathode and control electrodes located between the members of said pair.

29. A vacuum tube device comprising a press, a pair of spaced parallel rods arising from said press, and more than two electrodes including a cathode located between said rods and supported thereby.

30. A vacuum tube device of the audion type comprising a plurality of electrodes, one of which is supported by another.

31. A vacuum tube comprising an arbor, an electrode supported thereby, and another electrode supported by said first mentioned electrode.

32. A vacuum tube device comprising anode and control electrodes, and a filamentary cathode insulatingly supported by one of said electrodes.

33. A vacuum tube device comprising anode and control electrodes, and a filamentary cathode insulatingly supported by said control electrode.

34. A thermionic device comprising a helical filamentary cathode, anode surfaces at opposite sides of said cathode, and a control electrode between said anode surfaces and adjacent said cathode.

35. An evacuated vessel containing a press,

a straight wire supported above said press, a helical electrode supported by said wire, and a cooperating anode.

36. An evacuated vessel containing a press, a straight wire supported above said press, a helical cathode supported by said wire, and an anode associated with said cathode.

37. An evacuated vessel containing a press, a straight wire supported above said press, a helical cathode surrounding said wire and supported thereby, and a cooperating anode.

38. A thermionic device comprising an evacuated vessel, a pair of parallel plate electrodes surfaces, a plurality of parallel wires therebetween, and a helical electrode mounted on said wires.

39. An evacuated vessel comprising a press, a plurality of parallel wires supportingly connected to said press, a helical electrode mounted on said wires, anode surfaces at opposite sides of said electrode, and lead wires in said press for said electrodes.

40. A thermionic device comprising a plurality of helical electrode sections, one of which surrounds another.

41. A thermionic device comprising a cathode, an anode surrounding said cathode, a control electrode between said cathode and said anode, a single press within said tube, and supporting connections for said electrodes extending beyond said press.

In witness whereof, I have hereunto set my hand this 17th day of April, 1919.

IRVING LANGMUIR.

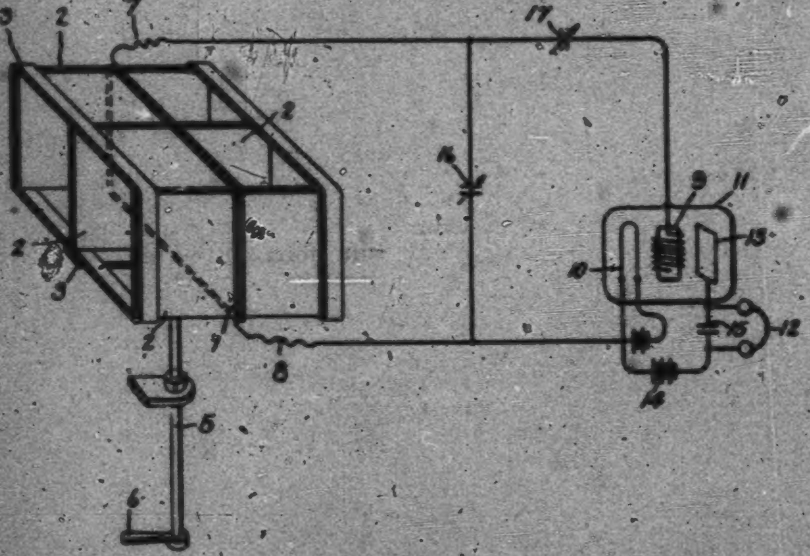
DEFENDANT'S EXHIBIT No. 286.

E. J. BERG.

WIRELESS RECEIVING APPARATUS.

APPLICATION FILED FEB. 13, 1917.

1,352,242. Patented Sept. 7, 1920.


3
2
7
17
2
16
9
11
13
10
15
12
14
2
3
4
2
9
8
5
6

Inventor:
Ernst J. Berg.
by Albert G. Davis
His Attorney

UNITED STATES PATENT OFFICE.

ERNST J. BERG, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

WIRELESS RECEIVING APPARATUS.

1,352,242. Specification of Letters Patent. Patented Sept. 7, 1920.

Application filed February 13, 1917. Serial No. 148,[illegible]

To all whom it may concern:

Be it known that I, Ernst J. Berg, a citizen of the United States, residing at Schenectady, county of Schenectady, in the State of New York, have invented certain new and useful Improvements in Wireless Receiving Apparatus, of which the following is a specification.

My present invention relates to wireless signaling systems and more particularly to means for receiving signals produced by electromagnetic waves radiated from a distant point.

The object of my invention is to provide a simple, cheap and efficient receiving apparatus which will not require the use of the large and expensive antenna ordinarily used for this purpose.

A further object of my invention is to provide a receiving apparatus which will be capable of receiving signals from a certain desired direction to the exclusion of signals and "strays" coming from other directions.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and mode of operation will best be understood by reference to the following description when taken in connection with the accompanying drawing in which I have indicated, partly in diagram, one embodiment of my invention.

As indicated in the drawing my receiving apparatus comprises a coil 1 made up of a large number of turns of insulated wire. Within this coil and at right angles to the plane of the coil I place a number of sheets of copper 2, or other metal having good conductivity. These metal sheets are supported in a framework 3 which is mounted upon the rotatable standard 5 having a handle 6 upon its end whereby the entire structure may be rotated in a horizontal plane. I have shown the coil 1 as being supported directly by the copper sheets 2 but the turns of this coil may be mounted upon a separate form if desired, the only essential feature of the construction being that it shall be positioned at a right angle to the copper sheets. The terminals 7 and 8 of the coil 1 are connected to the grid 9 and cathode 10 of a receiving device 11 of the audion type and the signals to be received will cause a response in the telephone receiver 12 which is included in a circuit which comprises the cathode 10, anode 13 and a local battery 14. The telephone receivers are preferably shunted by a condenser 15 which serves as a by-path for the radio frequency component of the current flowing in the circuit. A variable condenser 16 serves to tune the receiving circuit to the frequency of the waves to be received and a condenser 17 in series with the grid 9 may be employed to assist the device 11 in its action as a detector.

The operation of my receiving apparatus is as follows: If the signal which is to be received comes from a direction in the plane of the coil 1 there will at any given instant be a certain phase difference between the waves cutting the two sides of the coil. Because of this a resultant electromotive force will be set up in the coil, which electromotive force will be applied to the grid of the receiving device and will produce an indication in the telephone receiver. If a wave comes from a direction at right angles to the plane of the coil the waves cutting the two sides of the coil will always be in phase and no resultant electromotive force will be set up in the coil. It will be apparent that if the coil is rotated from a position where it is at right angles to the direction of the received waves toward a position where it is parallel to their direction that an electromotive force will be produced in the coil which increases in magnitude as the phase difference between the waves cutting the two sides of the coils increases until the point is reached where this phase difference is greatest and that this condition will occur when the coil is parallel to the direction of the received waves. Hence by rotating the coil until the point is reached where the received signals are strongest it will be possible to determine with a considerable degree of accuracy the direction from which the received signals come.

The metal sheets 2 are in effect short circuited coils of low impedance, and in fact if desired may be replaced by actual coils of low impedance. Electromagnetic waves coming from the desired direction will pass through these sheets without producing any currents therein, since they are at right angles to the direction of the waves and hence without any loss of energy. Signals or strays coming from other directions, how-

1152

ever, will produce currents in these sheets. They will also of course tend to produce currents in coil 1. Because of the comparatively low impedance of the sheets, and the high impedance of coil 1 for any waves except those for which it is tuned, most of the energy of the undesirable waves will be dissipated in the sheets and their effect in the coil 1 will be so small that it will not interfere with the reception of the desired waves.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. The method of directive receiving of wireless signals by means of a receiving coil which consists in utilizing said coil as a receiving antenna, rotating the coil in a horizontal plane until the response in receiving apparatus connected thereto is a maximum for the desired signals and at the same time absorbing the energy of undesirable impulses of all frequencies in such a way that they will produce substantially no effect in the receiving coil.

2. The method of directive receiving of wireless signals by means of a receiving coil which consists in utilizing said coil as a receiving antenna, rotating the coil in a horizontal plane until the response in receiving apparatus connected thereto is a maximum for signals coming from a desired direction and at the same time absorbing the energy of signal impulses of all frequencies coming from other directions in such a way that they will produce substantially no effect in the receiving coil.

3. The method of directive receiving of wireless signals by means of a receiving coil which consists in utilizing said coil as a receiving antenna, rotating the coil in a horizontal plane until the response in receiving apparatus connected thereto is a maximum for signals coming from a desired direction and at the same time absorbing the energy of signal impulses of all frequencies coming from other directions in low impedance circuits which are so located that they are substantially unaffected by the desired signals.

In witness whereof I have hereunto set my hand this 12th day of February, 1917.

ERNST J. BERG.

DEFENDANT'S EXHIBIT No. 287.

W. C. WHITE.
RADIORECEIVING SYSTEM.
APPLICATION FILED OCT. 11, 1917.

1,365,576. Patented Jan. 11, 1921.

Fig.1.

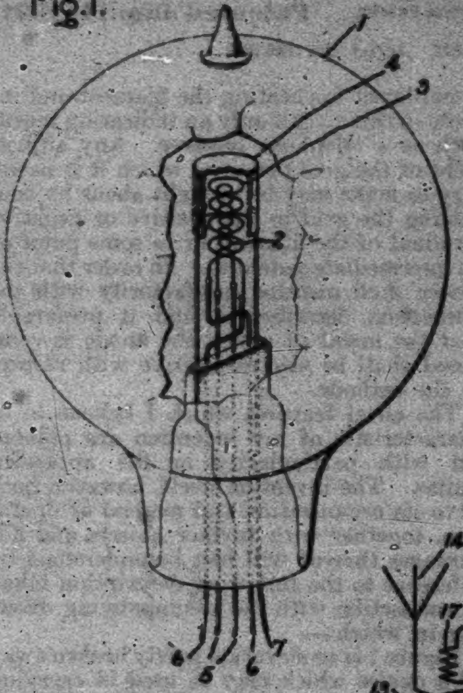


Fig.2.

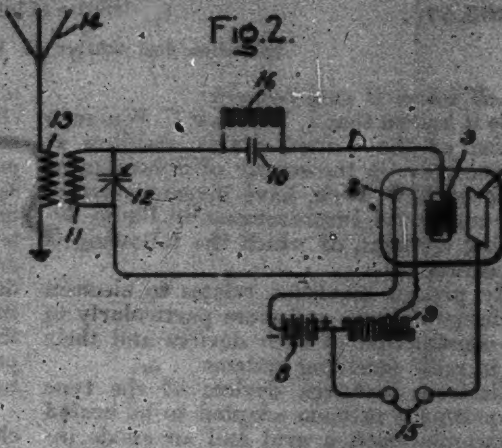

14
16
13
10
12
11
3
2
4
9
8
15

Fig.3.

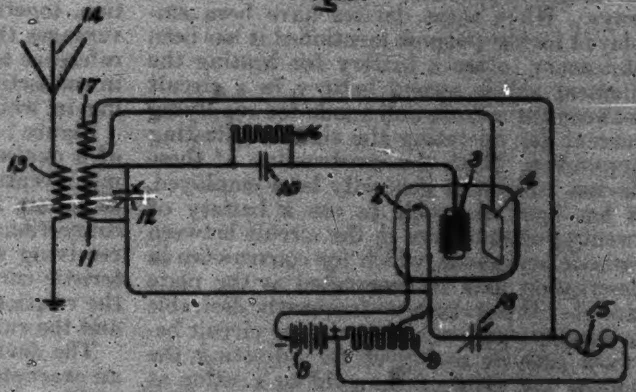
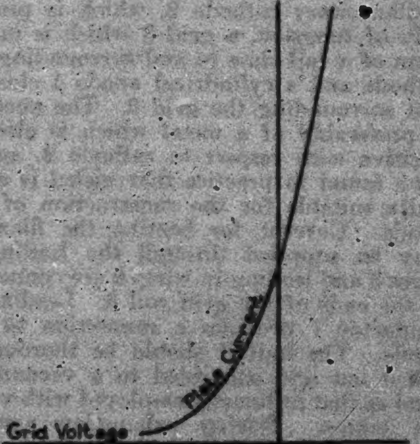

14
17
16
13
10
12
11
3
2
4
18
15
9
8

Fig.4.



Inventor:
William C. White,
by Albert G. Davis
His Attorney.

1154

UNITED STATES PATENT OFFICE.

WILLIAM C. WHITE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIO-RECEIVING SYSTEM.

1,365,576. Specification of Letters Patent. **Patented Jan. 11, 1921.**

Application filed October 11, 1917. Serial No. 196,051.

To all whom it may concern:

Be it known that I, William C. White, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Radio-Receiving Systems, of which the following is a specification.

My present invention relates to electron discharge devices, and more particularly to the construction of such devices and their use in radio receiving systems.

Electron discharge devices of the type comprising a cathode adapted to be heated to incandescence, a grid and an anode inclosed in an evacuated envelop, have been commonly employed in the past as detectors or receivers for radio signals in various ways. When these devices have been employed for the purpose mentioned it has been customary to use a battery for heating the filament and a second battery in a circuit between the cathode and anode for supplying current for operating the signal indicating apparatus. With the construction of these devices which has generally been employed, it has been necessary to use a battery of twenty volts or more in the circuit between cathode and anode, which for convenience in description may be designated as the plate circuit. It has also been frequently desirable to employ another battery in the circuit between cathode and grid for adjusting the normal potential of the grid to a value at which the device will operate most satisfactorily.

The object of my invention is to provide a device which may be used as a radio detector or receiver, as well as for other purposes in which a single battery of a few volts potential may be employed for fulfilling all of the functions carried out by the three batteries mentioned above. In carrying my invention into effect I construct the electron discharge device in such a way that the cathode and grid are separated by as small a distance as possible without danger of their actually touching each other, during the operation of the device and with the anode spaced from the grid by a distance which may be slightly greater than the spacing between cathode and grid but which will in any case be very small. In using this device as a radio detector I connect the anode directly to the positive terminal of the battery which is employed for heating the filament and include in this circuit only an indicating means such as a telephone receiver. Any adjustment of the grid potential which it is necessary to make may be brought about by connecting the grid to the positive or negative terminal of the filament or to some point of an intermediate potential. In order that the device shall operate satisfactorily with the connection described, I find it preferable that the metal of which the anode is composed shall be electro-positive with respect to the cathode.

The novel features which I believe to be characteristic of my invention are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof will best be understood by reference to the following description taken in connection with the accompanying drawing in which:—

Figure 1 is an elevation partly broken away of a device which may be used in carrying my invention into effect: Figs. 2 and 3 are diagrams illustrating two different circuit connections which may be employed in radio receiving systems, and Fig. 4 is a characteristic curve of one of my devices showing the relation between the voltage of the grid and the current in the plate circuit.

The device illustrated in Fig. 1 comprises an evacuated envelop 1, in which is inclosed a filamentary cathode 2, which is preferably of tungsten, a grid 3 which is in the form of a coil close to and surrounding the cathode and a cylindrical anode 4 close to and surrounding the grid 3. The anode 4 is preferably of a metal which is electro-positive with respect to cathode 2, and I have found in practice that nickel is especially suitable for the construction of the anode. Current for heating the filament may be supplied through the leading-in wires 5 and leading-in wires 6 are connected to the ends of the grid coil 3. Leading-in conductor 7 provides a connection to the anode. The bulb 1 should be thoroughly baked out and exhausted to a vacuum as good as that ordinarily employed with vacuum lamps. During exhaustion current should be passed through the device to heat the anode in order to expel any impurities or oxids which there may be at or near the surface. This is of special importance as I have found that in order to obtain the most satisfactory operation the anode surface should be made as clean as possible. I find it convenient to make the grid 3 of tungsten and to use this as a cathode during exhaustion. By this expedient sufficient current may be passed through the device to heat the anode to the desired degree without any danger of injury to the cathode.

In Fig. 2 I have shown a circuit arrangement which may be employed with my device when used as an ordinary detector of radio signals. In this case the battery 8 which may be of about six volts, or even less, furnishes heating current for the cathode 2, variable resistance 9 being inserted in series with this battery in order to adjust the current through the cathode to the desired amount. The grid circuit of this device comprises the condenser 10, the usual inductance 11 and variable capacity 12 for tuning the circuit, the inductance 11 being coupled with the inductance 13 in circuit with the antenna 14. The anode 4 is connected to the positive terminal of battery 8 through the usual telephone receiver 15. In practice I also usually find it most convenient to bring the grid connection to the positive terminal of the cathode 2.

It has been demonstrated that the operation of a device of this sort with the circuit arrangement shown depends upon the gradual building up of a negative potential upon the grid by reason of the charging of the condenser 10 by successive radio frequency impulses received and the leakage of this charge during the interval between successive signals. In order for the device to operate most efficiently it is desirable that the normal grid potential should be such that a small variation in its potential will produce a large variation in the current between the cathode and anode. In practice this relation may conveniently be expressed in terms of milliamperes change in plate current per volt change in grid potential. In Fig. 4 I have shown a curve which represents this relation in one of my devices, which is constructed in the manner described. It will be seen from an inspection of this curve that when no signals are being received and the grid is therefore at substantially zero potential with respect to the cathode, the device will operate upon that portion of the curve which is practically straight and which is also substantially the steepest portion. The maximum degree of amplification will also be obtained when operating upon this portion of the curve. If the normal grid potential is positive the current taken by the grid will be much greater than when the grid is at zero potential or negative, and as a result the changes in grid potential produced by the signals will not be as great as when the potential of the grid is zero or negative. It will therefore be evident that no extra battery is necessary in the grid circuit to adjust the device for most efficient operation. In order that the negative charge upon the grid which is accumulated thereon during the receipt of a signal may leak off after the signal has been received and before the succeeding signal is impressed upon the grid circuit, it is desirable to employ a high resistance 16 shunting the condenser 10.

I have also found that in the operation of such a device in the manner indicated in Fig. 2 there is a tendency for the grid to assume a negative potential with respect to the cathode when no signals are being received especially if the grid is connected to the negative terminal of the filament. To avoid this it is usually desirable to connect the grid to the positive terminal of the filament as indicated in order that there may be at all times a slight leakage current between the grid and cathode.

By the use of a cathode of tungsten I am able to obtain an advantage over other forms of cathodes in that the cathode may safely be operated at a high enough temperature to give the electrons emitted an appreciable initial velocity. This initial velocity of the electrons will be great enough to cause a current flow between cathode and anode without any source of potential in the external circuit. By reason also of the fact that the material of the anode is electro-positive with respect to that of the cathode there will be a greater flow of current between the two than there would be if both were of the same material. There will also usually be a slight drop of potential through the resistance 9 and this drop of potential will cause the anode to be slightly positive with respect to the most positive end of the filament and thus assist the action of the device. It is evident of course that with the connection shown the anode is positive with respect to the negative end of the cathode by an amount equal to the potential of the battery 8.

In Fig. 3 I have indicated a modification of my invention which is adapted to receive continuous wave signals by the heterodyne method. In this case the plate circuit of the electron discharge device includes an inductance 17 which is coupled with the coil 11 in such a way that local oscillations will be produced which are of slightly different frequency from the received oscillations and which will combine with the received oscillations to produce beats in the telephone receiver 15. A variable condenser 18 is employed as a shunt to the telephone receiver 15 in order that the high frequency component of the current in the plate circuit may not be compelled to pass through the receiver. In order that a device of the type described may be operated as an oscillator it is necessary that it should be adjusted to a point where it will act as an amplifier to such a degree that the energy which may be returned from the plate to the grid circuit is greater than the energy losses of the circuits, and previous devices of this type have required a separate source of potential in the plate circuit to bring them to a point where their energy amplification would be great enough to produce oscillations.

While I have illustrated and described the preferred embodiments of my invention it is by no means limited to the precise construction or circuit arrangement shown as many variations in the structural details as well as the manner in which it is used may be made without departing from the scope thereof as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electron discharge amplifying device comprising a metallic cathode adapted to be heated to incandescence, a grid and an anode inclosed in an evacuated receptacle, said anode being composed of a metal which is electro-positive with respect to the metal of the cathode and the parts being so proportioned and so close to each other that the maximum degree of amplification of which the device is capable may be obtained with the grid normally at substantially zero potential with respect to the cathode and with a single source of energy of a potential as low as six volts for supplying current for heating the cathode and for the operation of the device as an amplifier.

2. The combination in a radio receiving system of an electron discharge device having a filamentary cathode of tungsten, a grid and an anode of nickel inclosed in an evacuated envelop, a single battery of not over six volts for supplying current for heating the cathode and for operating signal indicating means, the two terminals of said battery being connected to the terminals of said cathode, means for impressing received signals upon said grid and a connection from the anode to the positive terminal of said battery, said connection including signal indicating means.

3. An electron discharge device comprising a filamentary cathode of tungsten, a grid and a nickel anode inclosed in an evacuated receptacle, the parts being so proportioned and so close to one another that the device is capable of operating to produce oscillations from a direct current source of a potential as low as six volts.

In witness whereof, I have hereunto set my hand, this 10th day of October, 1917.

WILLIAM C. WHITE.

DEFENDANT'S EXHIBIT No. 288.

J. B. PRATT.

DEGASIFYING PROCESS.

APPLICATION FILED MAR. 15, 1920.

1,374,679. **Patented Apr. 12, 1921.**

Fig. 1.

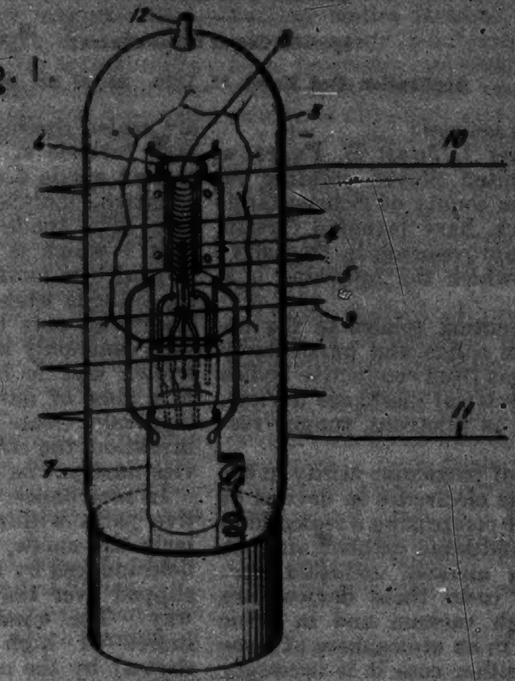
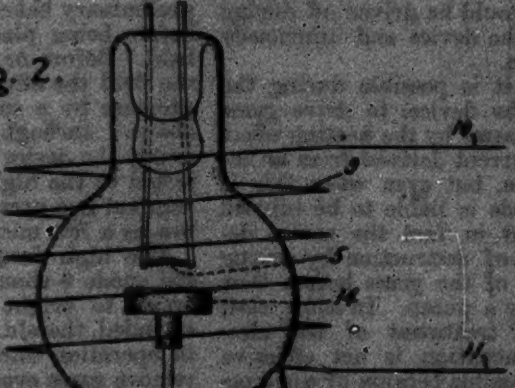

12
8
6
3
10
4
5
9
11
7

Fig. 2.


10
9
5
14
11
12
13
To Pump

Inventor:
John B. Pratt,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

JOHN B. PRATT, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

DEGASIFYING PROCESS.

1,374,679. Specification of Letters Patent. Patented Apr. 12, 1921.

Application filed March 15, 1920. Serial No. [illegible].

To all whom it may concern:

Be it known that I, JOHN B. PRATT, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Degasifying Processes, of which the following is a specification.

The present invention relates to the removal of gas from solids and particularly to the removal of gas from conductive bodies or electrodes in electrical discharge devices, such for example, as pliotrons, tungar rectifiers, or the like.

My invention is of particular utility in the pretreatment of the electrodes in devices of the thermionic type comprising a sealed bulb containing an incandescent cathode and one or more relatively massive unheated electrodes. In some cases these devices are operated in a high vacuum and in other cases are operated in an atmosphere of some selected gas. In either case it is necessary to pretreat the electrodes to remove gases which otherwise would be driven off during the operation of the device and injuriously affect its operation.

In many cases it is possible during the manufacture of the device, to drive gases out of electrode masses by the heating effect of an operating current derived from an incandescent cathode, but even when this is possible the cathode is liable to be injured by sputtering and in fact the entire device is in danger of destruction by arcing due to ionization of the gases before they can be removed by a pump. In some cases such preliminary treatment of the electrodes during evacuation is not effective and may not be possible because of some peculiar structural features of the device.

In accordance with my invention, conductive masses are rendered free from gas by subjecting them, preferably in a maintained vacuum, to a magnetic field of sufficiently high frequency and intensity to heat these bodies to a desired temperature.

I have shown diagrammatically in the accompanying drawing a high frequency induction heater applied in Figure 1 to the preparation of a vacuum tube, and in Fig. 2 to the preparation of a gas-filled arc device.

The electron discharge device shown in Fig. 1 comprises a glass envelop 3 into which are sealed conductors leading to a filamentary cathode 4, mounted on a support 5, and an anode 6 consisting, for example, of tungsten, molybdenum, platinum, or the like. The anode 6 is mounted upon a support 7 which is sealed into the container. A grid 8 is located between the anode and the cathode whereby the electron current in the device may be controlled. As this device, commonly known as a pliotron, is well known and is here shown as illustrative of a class of devices which may be advantageously treated in accordance with my invention, the structural features of the device need not be described in greater detail.

In accordance with my invention, conductive parts within the bulb 3 and particularly the anode, are heated by a magnetic field induced by a winding 9, which may be slipped over the device in any convenient way. The winding 9 is connected to a source of high frequency current (not shown) by the conductor 10, 11.

The pliotron preferably is given the usual preliminary bake-out to remove water vapor before being placed in the high frequency field. Before or during the application of the field the envelop is exhausted to a low pressure by a suitable vacuum pump (not shown) through a tubulature 12. Preferably the device to be exhausted is not subjected to the high frequency field until the residual gas pressure in the envelop 3 is as low as a few microns, or even lower.

The high frequency current induced in the anode 6 should be sufficient to heat the anode to bright redness and envelop gas occluded therein. The pump is continued in operation during this heat treatment to remove gases evolved from the anode. This degasifying treatment is continued until no more gases are evolved. In many cases, the deleterious gases are effectually removed in a few minutes. In other cases, the high frequency field may be applied advantageously for half an hour, or even longer.

The device shown in Fig. 2 is adapted for operation with an arc-like discharge in suitable gases, such, for example as nitrogen, argon, hydrogen, mercury vapor, or the like. A form now in general use in installations for charging batteries is known as the tungar rectifier. The bulb 13 likewise is connected to a pump (not shown) by a tube 12. The anode 14 in this case usually consists

1159

of graphite, but may consist of various other conductive materials.

The bulb is baked out and exhausted in the usual manner, and when the residual gas pressure has been reduced to a low value, say, a few microns or less, the anode and other conductive bodies within the bulb are heated by a high frequency magnetic field, pumping being continued as described in connection with Fig. 1. After substantially all occluded gases have been removed, the high frequency coil is removed and a desired gaseous filling is introduced into the bulb 13, which is finally sealed.

My invention is applicable not only to the treatment of electrodes in vacuum tubes, but is equally applicable to heat any conductive body in an envelop rendering the usual methods of heating difficult or impossible. It is important in many cases to prevent the slow evolution of gas from conductive parts in vacuum tubes which are not ordinarily traversed by enough electric current to heat them to a high temperature. In other cases, it may be desired to heat or even to vaporize metal not connected in any way to an electric circuit but sealed within an envelop. This may readily be done by my improved method.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The method of removing gas from electrically conducting masses which consists in materially reducing the gaseous pressure in the environment of said masses and heating said masses to an elevated temperature by electric induction at sufficiently high frequency to make interlinkage with a magnetic core unnecessary.

2. The method of removing gas from conducting bodies inclosed within an envelop which consists in subjecting said bodies to a high frequency variable magnetic field of sufficient strength to heat said bodies sufficiently to eliminate said gas.

3. The method of preparing electric discharge devices having conducting bodies inclosed within an envelop which consists in heating said bodies by a high frequency magnetic field to remove gas therefrom, removing said gas from said envelop and sealing said envelop.

4. The method of preparing thermionic devices to be operable with a substantially pure electron discharge which consists in evacuating said devices at an elevated temperature, heating conductive masses in said device, such as an anode, to a high temperature with a high frequency magnetic field while continuing the evacuation to remove gas evolved from said masses, and sealing said devices while highly evacuated.

In witness whereof I have hereunto set my hand this 12th day of March, 1920.

JNO. B. PRATT.

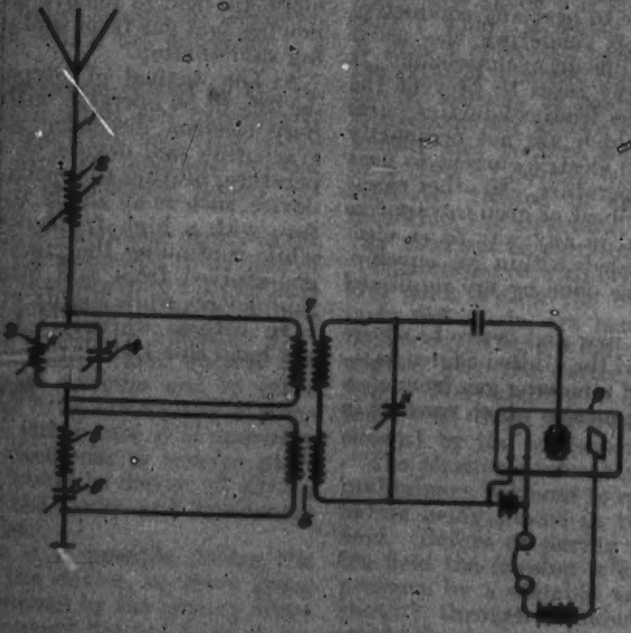
DEFENDANT'S EXHIBIT No. 289.

Dec. 11, 1923. 1,477,413

E. F. W. ALEXANDERSON

RADIO RECEIVING SYSTEM

Filed June 24, 1921



Inventor:
Ernst F. W. Alexanderson,
by Albert G. Davis
His Attorney.

Patented Dec. 11, 1923. **1,477,413**

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIO RECEIVING SYSTEM.

Application filed June 24, 1921. Serial No. [illegible].

To all whom it may concern:

Be it known that I, ERNST F. W. ALEXANDERSON, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Radio Receiving Systems, of which the following is a specification.

My present invention relates to radio receiving systems, and more particularly to means for preventing interference in such systems with the reception of desired signals.

The object of my invention is to provide in a radio receiving system a means for preventing interference with the reception of desired signals from a near-by transmitting station having a different wave length.

In carrying my invention into effect I provide in connection with a receiving antenna means for impressing upon the receiving circuit two equal and opposing potentials produced in the antenna by the interfering wave. This means is so arranged that it will also impress upon the receiving circuit two potentials produced by the desired signaling waves, but these two potentials will be of different magnitude and of the same phase or will have such phase relation to each other that they will add in the receiving circuit and will not neutralize one another.

The novel features which I believe to be characteristic of my invention are set forth in the appended claims. The invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have indicated diagrammatically one way in which my invention may be carried into effect.

As indicated in the drawing, I provide in connection with the receiving antenna 1 in addition to the ordinary antenna tuning coil 2, two special tuned circuits, one being a multiple tuned circuit made up of inductance 3 and capacity 4 and the other being a series tuned circuit made up of inductance 5 and capacity 6. These two circuits are adjusted so that they are both in resonance for the signal which it is desired to suppress. The inductances and capacities of these two circuits are selected so that the multiple tuned resistance of the first circuit is substantially equal to the series tuned resistance of the second circuit. Each of the circuits has the character of a non-inductive resistance at the frequency to which they are tuned, hence the voltage drops between the terminals of each of these two circuits are equal and in phase. The voltage drop across the first tuned circuit is impressed by means of the coupling transformer 7 upon a receiving circuit and the voltage drop across the second tuned circuit is also impressed by means of the coupling transformer 8 upon the receiving circuit which is associated with a detector 9 of the audion type. The couplings 7 and 8 are so arranged that the potentials of a frequency equal to that of the waves to be suppressed oppose each other in the receiving circuit and their effect is thus neutralized. Thus no signal will be received or detected of the frequency for which the two circuits are tuned. If, however, the frequency of the signal to be received is only slightly greater than the frequency for which these two circuits are tuned the multiple tuned circuit assumes the character of a capacity and the series tuned circuit assumes the character of an inductance. Thus the phase of the voltage drops produced by the desired signal across the two circuits is shifted in opposite directions. By properly proportioning the circuits the voltage drops produced across these circuits by the desired signal may be made to be substantially opposite in phase so that they will add in the receiving circuit. The magnitude of the voltage drop across the multiple tuned circuit will also be less than the voltage drop across the series tuned circuit.

It will thus be apparent that the signal which has a frequency only slightly different from that of the interfering wave may be received with practically full intensity at the same time that the interfering wave is neutralized.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. Means for eliminating disturbing effects in a radio receiving system comprising a receiving antenna, a multiple tuned circuit connected to said antenna which is resonant to the frequency of the disturbing effect to be eliminated, a series tuned circuit connected to said antenna which is also

resonant to the frequency of the disturbing effect to be eliminated, a receiving circuit and means for impressing upon the receiving circuit electromotive forces derived from both of said resonant circuits.

2. Means for eliminating disturbing effects in a radio receiving system comprising a receiving antenna, a multiple tuned circuit connected to said antenna which is resonant to the frequency of the disturbing effect to be eliminated, a series tuned circuit connected to said antenna which is also resonant to the frequency of the disturbing effect to be eliminated, the multiple tuned resistance of the first circuit being substantially equal to the series tuned resistance of the second, a receiving circuit and means for impressing upon the receiving circuit electromotive forces derived from both of said resonant circuits.

3. A receiving system for radio signals comprising a receiving antenna and means for deriving from said antenna and impressing upon a receiving circuit two radio frequency electromotive forces of equal intensity and opposite sign produced by undesired waves of definite frequency in said antenna, said means being arranged to impress upon the receiving circuit two electromotive forces produced in said antenna by desired signaling currents and which will add in the receiving circuit.

In witness whereof, I have hereunto set my hand this 23rd day of June, 1921.

ERNST F. W. ALEXANDERSON.

DEFENDANT'S EXHIBIT No. 290.

Aug. 26, 1924. 1,506,468

W. C. WHITE

ELECTRON DISCHARGE DEVICE

Filed Oct. 28, 1920

Fig. 1.

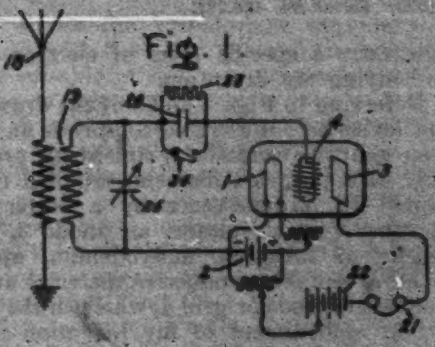

18
19
23
24
25
4
1
3
2
22
21

Fig. 2.

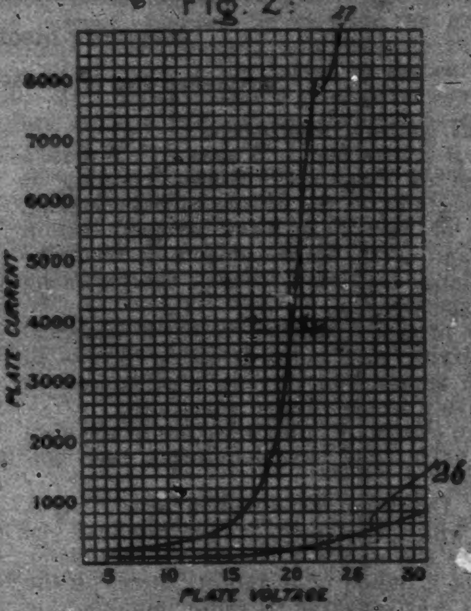


Fig. 5.

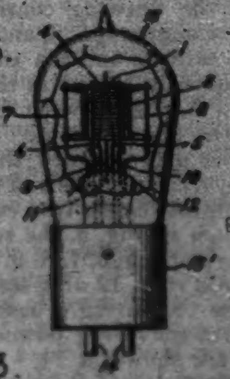

4
17
1
8
9
7
6
5
10
11
12
13
14

Fig. 4.

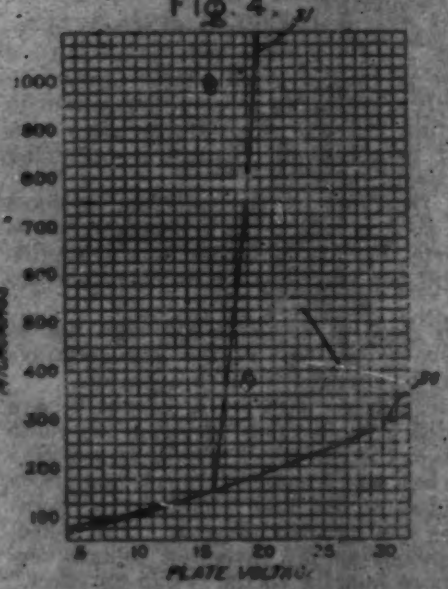
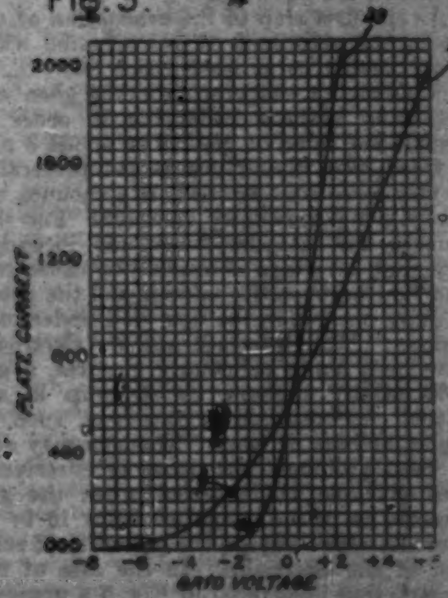


Fig. 3.



Inventor:
William C. White,
by Albert G. Davis
His Attorney.

Patented Aug. 26, 1924. 1,506,468

UNITED STATES PATENT OFFICE.

WILLIAM C. WHITE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE DEVICE.

Application filed October 28, 1920. Serial No. 420,221.

To all whom it may concern:

Be it known that I, WILLIAM C. WHITE, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Devices, of which the following is a specification.

My present invention relates to electrical amplifying and radio detecting devices in which an electron current is controlled by relatively feeble voltage variations.

Two classes of radio detectors of the electron valve type have heretofore been employed.

(1) Detectors of the audion, or soft valve, type which contained enough residual gas to give the device a critical characteristic, that is, a region of instability at which the device was sensitive to radio impulses due to gas ionization.

This class of detectors were erratic in behavior. A given impressed voltage did not always produce a given effect. Tubes apparently identical in construction varied in operating characteristics and a given tube would progressively change in operating characteristics.

(2) Detectors of the pliotron, or hard valve, type in which the evacuation was so complete that gas ionization was negligible and did not affect the operation of the device.

This class of detectors although not so sensitive as the best of the first class are regular and reproducible in operation.

In accordance with my invention, I have provided a "soft valve" detector for radio signals or the like which is fully as sensitive as the best gas detectors formerly constructed, and as regular and reliable in its operation as the vacuum detector. The detectors embodying my invention contain certain gases immune to the "clean-up effect," particularly the gases of the "rare" or noble gas group, such as argon, helium, neon, and even nitrogen. They are steady and reproducible in operation.

The accompanying drawing shows in Fig. 1 a radio receiving system containing a detector illustrative of the class of devices embodying my invention; Figs. 2, 3 and 4 are diagrams showing electrical characteristics of my improved detector, and Fig. 5 illustrates a specific form of electron tube as embodying my invention.

Referring to Figs. 1 and 5 of the drawing, the device here illustrated comprises an electron emitting cathode 1, consisting preferably of a tungsten filament, adapted to be heated to incandescence by a battery 2, or other suitable means, an anode 3, consisting of tungsten, molybdenum, nickel, or other suitable conductive material and a control electrode or grid 4, which in the particular embodiment of my invention illustrated in the drawing consists of a wire wound over supports 5, 6, and is located between the cathode and the anode. The anode is frequently known as the "plate" and the current flowing between the cathode and anode as the plate current. It is the function of the grid to vary the electrostatic field between the cathode and the anode, and thereby control the electron current. In the device shown in Fig. 5, the supporting and conducting wires 5, 6, 7, 8, 9, 10 and 11 are sealed into a stem 12 of a sealed glass bulb or envelope 13, having a base 13′ provided with current-conveying terminals, only two of which are shown at 14.

As the first step to the evacuation of the device the glass bulb 13 is evacuated while being heated to at least about 360° C., in fact, as high a temperature as the glass will withstand without collapsing in order to denude the same of gas. The anode 3 also is freed from disengageable gas, preferably by electronic bombardment in a vacuum, the pump being constantly operated. For this purpose the cathode is rendered incandescent and a voltage is applied to cause current flow between the cathode and the anode to drive out gas in the now well-understood manner. When the bulb and the electrodes have been made sufficiently gas-free, a gas substantially immune to clean-up is admitted, for example, a rare gas, such as argon, helium, or neon. Nitrogen may also be used although not quite so effectively. The envelope 13 is sealed when the gas pressure is in the range of about 15 to 75 microns, depending on the geometrical relation of the electrodes. In the case of the construction illustrated in Fig. 5 a pressure of about 20 to [illegible] microns is preferred.

The tube [illegible] be operated as a detector in the usual way in a radio system, for example, as illustrated in Fig. 1. The grid 4 receives signals from the antenna 18, for example, by being connected to the secondary winding of a transformer winding 19 in series with a condenser 20. The other terminal of the secondary winding is connected to the cathode 1. An ohmic resistance 23 may be connected in shunt to the condenser 20, a switch 24 being provided to short-circuit both the condenser and resistance. An adjustable condenser 25 may be connected across the transformer secondary. In circuit with the cathode 1 and the anode 3, some suitable receiving instrument, as for example, a telephone receiver 21, is connected in series with a suitable source of current, for example a battery 22.

Preferably the voltage of the battery 22 in the anode or plate circuit is adjusted somewhere above ionization voltage, but materially below the voltage at which the ionization of gas in the detector becomes so intense that there is a tendency for a blue glow to form. Preferably, the operating plate voltage is about 18 to 23 volts. Under these conditions the detector exhibits a markedly superior sensitivity to the vacuum detector of the pliotron type. In practice, the plate voltage and the filament current are varied until a maximum response is obtained in the receiver and the optimum settings thus obtained are maintained during operation over a considerable period of time.

Apparently this sensitivity is due to certain critical conditions of the tube which may be explained at least in part by reference to the grid and plate characteristics, as illustrated in a conventional manner in Figs. 2, 3 and 4. In Fig. 2 I have shown plotted for illustrative purposes a representative set of readings of plate currents plotted as ordinates and plate voltages as abscissae. The currents obtained with different impressed volatges in a device evacuated so highly that the ionization of residual gas is negligible is represented by the curve 26, which over a short region, say, above about 10 to 15 volts, substantially obeys the 3/2 power law of pure electron conduction. In other words, the currents obtained with different impressed voltages vary directly with the 3/2 power of the voltage. In a tube constructed in accordance with my invention and containing ionizable gas, the increase of current with rising voltages varies with a higher and constantly increasing power causing the characteristic to be more steeply curved, as illustrated by the curve 27.

Related intimately to this plate circuit characteristic is the grid-voltage, plate-current characteristic as illustrated in Fig. 3. When in a given tube different steady voltages are applied to the plate circuit, and the grid voltage is varied below and above zero, a series of corresponding plate currents are obtainable. In Fig. 3 the curve 28 represents the relation of grid voltage of a vacuum tube above and below zero to current in the plate circuit with a steadily applied plate voltage of 40 volts. In a tube embodying my invention, the change of current obtained by varying the grid voltage with a steadily applied plate voltage of 20 volts is illustrated by the curve 29. This curve is steeper even at the lower plate voltage and not as straight as the curve 28.

The slope of the curve thus obtained is usually designated as rho. In other words, the value of rho represents the relation of the change of current in the plate circuit in micro-amperes to the change of voltage in the grid circuit in volts. This value is also known as the conductance of the tube and is usually expressed in microhms.

Fig. 4 illustrates the conductance of the tube at different plate voltages. The conductances are plotted in microhms as ordinates, and the plate voltages are plotted as abscissae. It will be observed that the curve 30 expressing the conductance of a high vacuum or hard tube has a gentle uniform slope. On the other hand, the curve 31 expressing the conductance of a soft tube embodying my invention, follows very closely the curve of the vacuum tube up to a value of about 16 volts, and then very sharply bends upward and becomes almost vertical. In other words, at and above the ionization voltage of the gas filling in the tube, the conductance of the tube varies very rapidly with different plate voltages. In fact, results indicate that at some voltages in a range above and in the neighborhood of the ionization the conductance varies even more abruptly than indicated by the conventional curve shown in the diagram. When a tube embodying my invention is operated as a detector with a plate potential above ionization voltage, say, at 18 to 23 volts, which is well below the voltage at which the ionization becomes so intense as to produce a glow, the rate of change of conductances is high and therefore the rate of change of current in a receiver circuit is correspondingly great. As a result the device is very sensitive to feeble variations of voltage in the grid circuit, such, as for example, produced by weak radio signals.

In the soft tubes formerly produced this condition of sensitivity was extremely variable and erratic due to the continual variation of the gas content of the tube. This variation was apparently due to the liberation of gas from the parts of the tube, particularly the bulb, and the simultaneous clean-up of gas was due to chemical and physical action within the tube. In a detector tube embodying my invention these sources of variation are removed, the bulb and working parts of the tube having been freed from disengageable gas and the gas filling being substantially immune to clean-up effects. Whatever may be the correct explanation, the characteristics of my device are steady and reproducible, as contrasted with the unsteady and non-reproducible characteristic of soft tubes heretofore known. The device is so exceedingly sensitive in its operation that it is probable that the operation of the same involves phenomena not at present apprehended.

While I have described the operation of my improved detector as involving the ionization of the low pressure gaseous filling therein, I do not wish to be limited by this theory of operation as the benefits of my invention may be obtained independently of any particular theory of operation.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. An electron discharge device comprising a sealed container, a cathode adapted to operate at incandescence, an anode, a charge-receiving member or grid for controlling a current in said device, the container and parts of said device being substantially deprived of disengageable gas, and a filling of gas substantially immune to clean-up effects at a pressure of about 15 to 75 microns in said container.

2. An electron discharge device comprising a sealed container, a cathode adapted to emit electrons, an anode, means for varying the electrostatic field about said electrodes, the walls of said container and the electrodes being substantially deprived of disengageable gas, and a gas filling substantially immune to clean-up effects and non-condensible at ordinary temperatures sufficient in amount to produce at a given voltage between said cathode and anode by a progressive change of the electrostatic field in the positive direction, a corresponding regular increase of current between said electrodes which is greater than the increase under the same conditions in a similar device in which the residual gas is negligible, said gas content being insufficient to produce blue glow under operating conditions.

3. A radio detector comprising a sealed container, a filamentary cathode adapted to be heated to incandescence, an anode, a grid located intermediate said electrodes and a quantity of rare gas at a pressure of about 15 to 75 microns of mercury, said container and electrodes being deprived of disengageable gas, said device being capable of operation at voltages impressed on said electrodes above ionization voltage and below a luminosity producing voltage.

4. A radio detector comprising the combination of a cathode adapted to emit electrons by incandescence, an anode, means for varying the electric field between said electrodes, an enclosing envelope, said envelope and working parts of said electrodes being denuded of gas and a quantity of gas substantially immune to clean-up effects in said envelope, the quantity of gas being sufficient to render the device capable of operation with impressed voltages above the ionization voltage of said gas and below luminosity voltage with corresponding currents varying with the voltage at a rate materially greater than the $3/2$ power of the voltage, the pressure of said gas being insufficient to enable an arc-like discharge to occur therein.

5. A radio detector comprising the combination of a cathode adapted to emit electrons by incandescence, an anode, a discharge controlling grid, an enclosing envelope, a filling of argon gas therein at a pressure of about 15 to 75 microns of mercury, a source of current having a voltage above ionization voltage but insufficient to produce a luminous discharge in said gas in circuit with said cathode and anode, the quantity of said gas filling being sufficient to cause the current in said circuit to vary with variations of voltage over a working range at a rate materially greater than the $3/2$ power of the voltage but being insufficient to permit an arc-like discharge to occur therein at the voltage of said source.

6. A radio detector comprising a sealed container, a cathode operable at incandescence, an anode or plate, a charge-controlling electrode or grid and a filling of gas at a pressure of about 20 to 60 microns of mercury, said container and electrodes being deprived of gas, the conductance of said detector increasing more rapidly with rise of plate voltage above the ionization voltage of said gas filling than would be the case in said device were the residual gas at materially lower pressure.

7. A detector for radio signals comprising the combination of a sealed bulb, a cathode therein adapted to emit electrons, a plate or anode, the bulb, walls and contained members being substantially free from disengageable gas, a filling of attenuated gas which is substantially immune to electrical clean-up effects, a source of current connected in circuit with said cathode and anode having a voltage above and adjacent to the ionization voltage of said gas, the pressure of gas in said bulb being so related to the voltage of said source that the variation of conductance of said detector with variation of plate potential is materially greater than when gas ionization is negligible.

8. A detector for radio signals comprising the combination of a sealed bulb, a cathode operable at incandescence, an anode and a grid therein, the parts of said device

being substantially free from disengageable gas, a rare or noble gas therein at a pressure of about 15 to 75 microns of mercury, and a source of potential of about 18 to 23 volts connected between said cathode and anode.

9. An electrical discharge device comprising a container, an attenuated gas therein which is substantially immune to clean-up effects, a cathode operable at incandescence, means for heating said cathode, an anode, a control electrode, said container and electrodes being deprived of disengageable gas, and a source of current at a voltage of about 18 to 23 volts connected between said cathode and anode, the pressure of the gaseous filling being so chosen that the current between cathode and anode varies more abruptly with variations of potential of the control electrode than when the residual gas pressure is so low the ionization effects are negligible.

10. A radio detector apparatus comprising a sealed container, a filamentary cathode of refractory material, an anode, a grid, said container and electrodes being deprived of gas, a filling of argon at a pressure of about 20 to 60 microns, a source of current at a voltage of about 18 to 23 volts connected between said cathode and anode and means for impressing radio signals on said grid.

In witness whereof, I have hereunto set my hand this 27th day of October 1920.

WILLIAM C. WHITE.

DEFENDANT'S EXHIBIT No. 291.

Jan. 20, 1925. 1,523,776

A. W. HULL

ELECTRIC DISCHARGE DEVICE

Filed Jan. 29, 1920 2 Sheets-Sheet 1

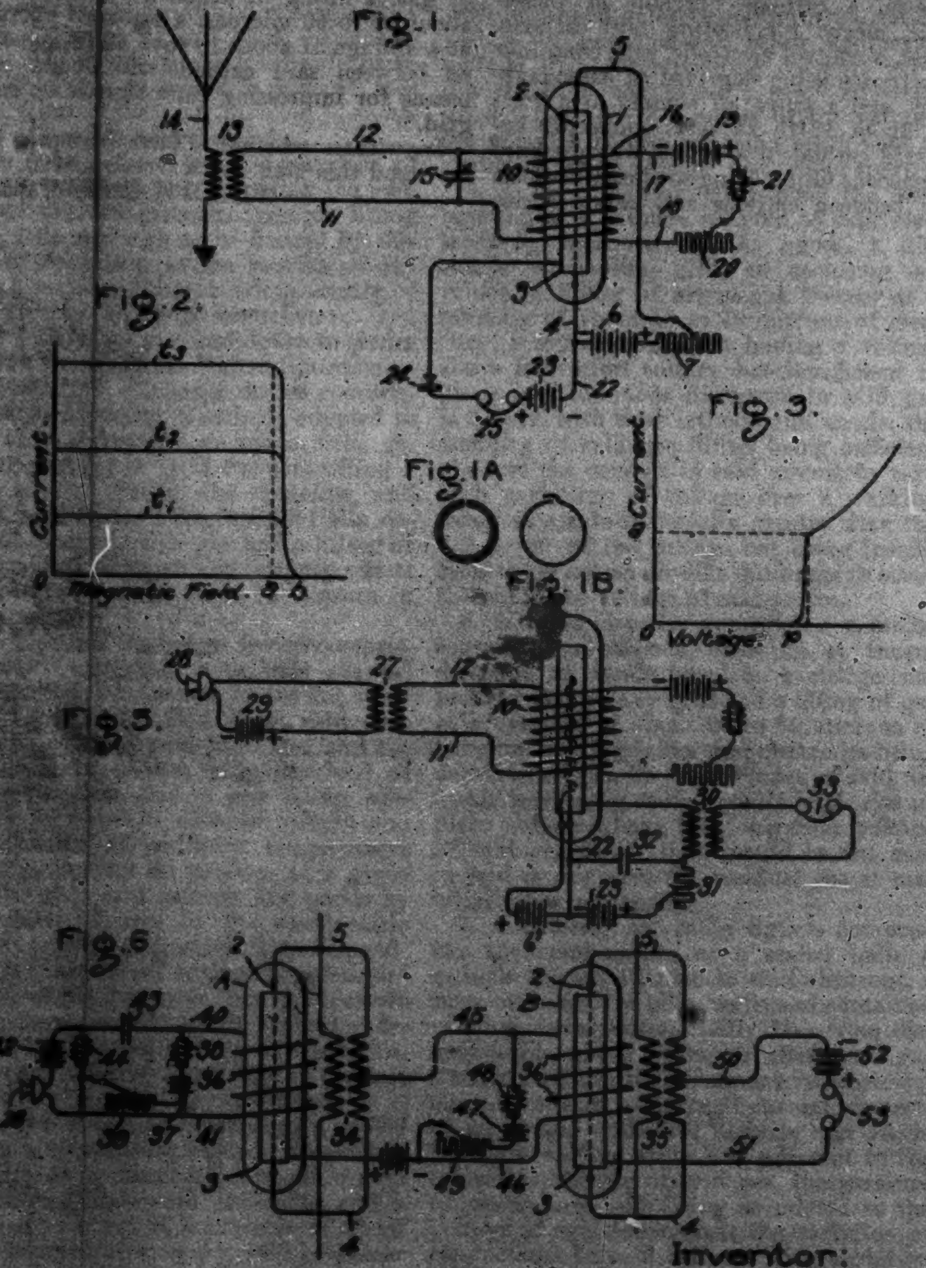


Fig. 1.
5
2
16
19
14
13
12
15
10
21
17
18
11
20
3
4
6
7
24
23
22
25
Fig. 2.
t_3
t_2
t_1
Current.
0
Magnetic Field.
a
b
Fig. 3.
Current.
a
0
Voltage.
p
Fig. 1A
Fig. 1B.
Fig. 5.
28
29
27
12
10
11
33
30
22
32
23
31
6
Fig. 6
2
5
A
43
40
42
44
38
36
28
39
37
41
34
3
4
45
2
B
48
47
49
46
35
50
52
53
51

Inventor:
Albert W. Hull,
by
His Attorney.

Jan. 20, 1925 1,523,776

A. W. HULL

ELECTRIC DISCHARGE DEVICE

Filed Jan. 29, 1920 2 Sheets-Sheet

Fig. 7.

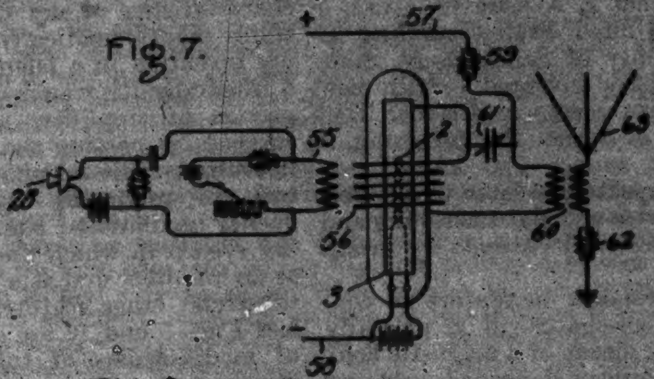

+
57
59
2
61
63
55
28
56
60
62
3
–
58

Fig. 8.

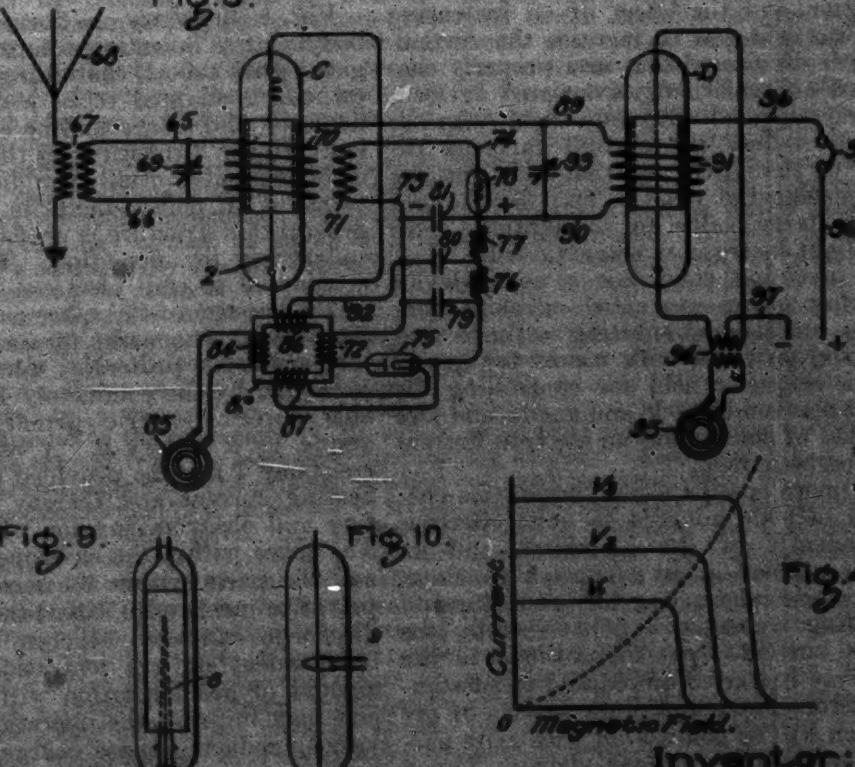

68
67
65
69
66
C
70
74
71
73
81
78
+
80
77
76
79
2
82
84
86
72
75
83
87
85
D
89
94
93
91
96
90
97
98
–
+
95

Fig. 9.

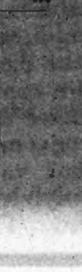
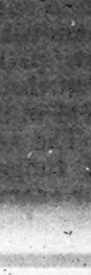


Fig. 10.



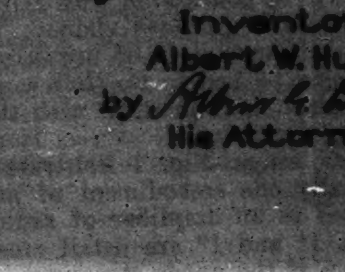


Fig. 4.

Inventor:
Albert W. Hull,
by Albert G. Davis
His Attorney.

1170

Patented Jan. 20, 1925. **1,523,776**

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRIC DISCHARGE DEVICE.

Application filed January [illegible], [illegible]. Serial No. [illegible].

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electric Discharge Devices, of which the following is a specification.

The present invention relates to an electric discharge device and the controlling and amplifying of electrical currents by means of vacuum tubes.

It has been proposed heretofore to control an electric discharge in a partially evacuated tube by means of a magnetic field. In this case the current depended upon gas ionization and the effect of an increasing magnetic field was to increase the current.

I have discovered that in a properly constructed and sufficiently evacuated device a properly applied magnetic field may be made to reduce the current carrying capacity of the space, and that by a suitable arrangement the current may be reduced from a large value to substantially zero by a slight increase of magnetic field.

My invention comprises a novel device consisting of an evacuated envelope containing an electron-emitting cathode and an anode, provided with means for generating a magnetic field for controlling the current between cathode and anode, and also a method of controlling an electron current by a magnetic field.

In a more specific aspect my device contains a cathode adapted to emit electrons independently of gas ionization and an anode contained in an evacuated envelope, and an electrical winding for producing and controlling a magnetic field whereby the electron current from the cathode to the anode may be varied or reduced to substantially zero. These and other aspects of my invention will be pointed out with more particularity in the appended claims. For a more detailed description of my invention, reference may be had to the following description taken in connection with the accompanying drawings.

In the drawings, Fig. 1 illustrates diagrammatically one embodiment of my invention used as an amplifier of radio signals; Figs. 1^a and 1^b are detail cross-sectional views of the anode structure; Figs. 2, 3 and 4 are diagrams showing electrical characteristics of my device; Fig. 5 illustrates diagrammatically an embodiment of my invention in a telephone repeater; Fig. 6 illustrates diagrammatically a series connection of amplifiers utilizing alternating current for heating the cathode; Fig. 7 illustrates a radio-telephone transmitting system for producing modulated high frequency oscillations; Fig. 8 is a radio-receiving system in which the new device is used as an amplifier and as a detector, and which illustrates other features of my invention; and Figs. 9 and 10 are diagrammatic views of modifications of tubes embodying my invention.

Fig. 1 illustrates one form of device embodying my invention comprising an elongated glass tube 1, containing a filamentary cathode 2 adapted to be heated to incandescence, and a surrounding concentric slotted cylinder 3 constituting the anode. The cathode is substantially equidistant from the anode at all points along its length and in general this structure is preferred in devices embodying my invention. The cathode 2 is adapted to emit electrons independently of the passage of the space current through the device. It consists of a suitable refractory material, preferably tungsten, and is connected by the conductors 4, 5, to a suitable source of electric current, such, for example, as a battery 6. A regulable series resistance 7 may be provided to control the heating current and thereby the temperature and electron emission of the cathode. The space within the envelope is evacuated and the parts within the envelope are deprived of gas to such extent that an electron discharge can occur therein substantially independent of gas ionization. A slight amount of gas ionization will do no harm and may improve the operation of the device by reducing space charge. If the gas pressure is too high, for example, so high as to enable a discharge to occur by ionization with a cold cathode, then the mean free paths of the electrons become so short that they are not controllable by a magnetic field in the manner described.

The anode conveniently may also consist of tungsten, but various other materials, for example molybdenum, copper or nickel, may also be used. The cylindrical anode is slotted, as shown in Figs. 1^a and 1^b, to prevent the anode from screening the space between anode and cathode from the variable field produced by coil 10. A metallic deposit on the glass wall of the envelope may be used as anode instead of a metallic cylinder.

The electrodes in the device shown in Fig. 1 are arranged in circular or rotational symmetry with respect to each other. Such an arrangement is a desirable although not a necessary attribute of a device embodying my invention. By circular or rotational symmetry I mean an arrangement such that the surfaces of the cathode and the anode are substantially surfaces of revolution about a common axis which is preferably the major axis of the container. For example, a cathode construction whereby substantially circular symmetry is obtained is shown in Figs. 5 and 7.

In the construction shown in Fig. 5 the cathode has the form of a helix, and in Fig. 7 it has the form of a double helix. When the anode is relatively large the cathode may have a shape widely departing from a surface of revolution without losing the attribute of circular symmetry. For example, as shown in Fig. 9, the cathode may consist of two wires 8 in the form of a V without losing the attribute of circular symmetry providing the wires are close enough together so that the electric field between the cathode and the anode is essentially radial. The anode likewise may assume various forms without losing the attribute of circular symmetry. For example, the anode may consist, as shown in Fig. 10, of a substantially circular loop of wire 9 surrounding the cathode.

Surrounding the envelope 1 is some suitable means for generating a variable magnetic field. In the embodiment of my invention shown in Fig. 1, the tube is surrounded by a solenoid 10. This solenoid is connected to the conductors 11, 12, which receive current from the secondary winding of a transformer 13. The primary winding of the transformer 13 is connected in series with a grounded aerial 14. Connected across the conductors 11, 12, is a variable condenser 15 whereby the resonance of the input circuit 11, 12 may be varied as desired.

Surrounding the envelope 1 is a second magnetic coil 16 which is supplied with direct current through the conductors 17, 18, by a battery 19. Desired adjustments of energizing current are made by an adjustable resistance 20. It is the function of the coil 16 to generate a polarizing field of desired value upon which is superimposed the fluctuating or variable magnetic field generated by the coil 10, thereby varying the electron current, as hereinafter explained. A choke coil 21 prevents the circulation of high frequency current induced in the coil 16. The output circuit 22 contains a source of direct current represented by a battery 23, a suitable detector as represented by a crystal 24, and a receiving instrument, as, for example, the telephone receiver 25.

When the cathode 2 is maintained at suitable incandescence by the heating current and a suitable voltage is impressed upon the electrodes, a current flows in the output circuit 22. With no modifying magnetic field, the value of this current is determined by various factors, among which are the impressed voltage, the cathode temperature, the size and geometrical relations of the electrodes, and the resistance of the output circuit. The electrons which carry or constitute this current travel outwardly in straight radial paths from the cathode to the surrounding anode. When a magnetic field is generated substantially parallel to the cathode and hence substantially at right angles to the electric field between the electrodes, then the electrons are deflected and caused to travel in a spiral path about the cathode on their way to the anode. As the field strength is increased the spiral path of the electrons becomes longer until finally at a critical magnetic field strength, characteristic of any particular device, some of the electrons fail to reach the anode by reason of this deflection, thereby resulting in a decrease of current. When the field strength is still further increased, above this critical value, the electron current rapidly falls and is finally reduced substantially to zero. In order to express the fact that the electrons are prevented from flowing through the space, as distinguished from deflection, to another electrode, I may say that the effective electron emission or generation is reduced or entirely suppressed.

This relation between magnetic field and current transmitted by the device is indicated for different cathode temperatures by the diagram constituting Fig. 2, the values of the magnetic field being plotted as abscissae and the corresponding current values as ordinates, the impressed voltage being constant. It will be observed that with any given filament temperature as the strength of the magnetic field is increased from zero, the current remains substantially constant until the magnetic field has reached a value represented as oa. A further increase of field strength produces a rapid reduction of current until by a relatively small increase of field strength of the current is reduced substantially to zero. The branches of the curves designated as t_1, t_2 and t_3 refer to different temperatures of the cathode. The maximum value of the current may be limited either by the electron emissivity of the cathode or by space charge without departing from the characteristic shown in Fig. 2. For example, the curves t_1 and t_2 may be assumed to refer to temperatures such that the maximum current is limited by the electron emissivity and the curve t_3 may be assumed to refer to a temperature so high that the maximum electron current is limited by space charge.

If the polarizing field generated by the coil 16 is fixed at some value between *oa* and *ob*, then even a small change of field strength caused by a variation of field generated by the coil 10 will cause a relatively great variation in the current transmitted by the device.

The volt-ampere characteristic of the device with a constant magnetic field is shown in Fig. 3. It will be observed that no current passes until the voltage has risen to a critical value, *op*, depending on the value of the applied magnetic field. An increase of voltage above *op* causes a very rapid increase in current up to a critical current value *oa*, characteristic of the device. A further increase of voltage causes the current to rise as a 3/2 power function of the voltage up to a saturation current not indicated in the figure.

Fig. 4 represents by three curves the relation between current and magnetic field at different constant electrode voltages designated by V_1, V_2 and V_3, the cathode temperature being assumed to be sufficiently high so that the current is limited by space charge. The dotted line drawn from zero through the knees of the curves V_1, V_2 and V_3 has substantially the form of a parabola. For the sake of convenience, I will refer to the device above described by the name of "magnetron" by which it has become known to engineers.

In the radio receiving system shown in Fig. 1, signals received by the aerial 14 produce a variation of the current in the plate circuit 22 in amplified measure providing the polarizing field has been properly adjusted. A suitable rectifying detector 24, shown symbolically as a crystal, renders the signals audible by a telephone receiver 25. As will hereinafter be described in connection with Fig. 8, the magnetron may itself be used as a detector of radio signals.

In Fig. 5 is illustrated a system for amplifying current of audio frequency in a wired telephone system. The terminal conductors 11, 12 of the coil 10 are connected to the secondary of a transformer 27, the primary of which is connected to a transmitter 28 in circuit with a battery 29. The output circuit 22 of the tube is connected to the primary of a transformer 30, and contains a battery 23 and an adjustable resistance 31. A condenser 32 is connected across the series combination of the battery and the resistance 31 to offer a low resistance path for the audio frequency current. The secondary of the transformer 30 is connected to a telephone receiver 33.

In the telephone amplifier system shown in Fig. 6 several additional features of my invention are embodied. In this system two magnetrons A and B are connected in series or cascade to amplify current undulations produced by the telephone transmitter 28. The cathode filaments of the magnetrons A and B are heated by alternating current supplied by transformers 34, 35, respectively, to the secondary windings of which the cathode conductors 4, 5 are directly connected.

In the magnetrons shown in this figure the functions of the polarizing and control field windings of devices A and B are combined in single windings 36 and 36′, respectively. The polarizing field of the tube A is produced by a battery 37, connected in series with a choke coil 38, and an adjustable resistance 39 across the conductors 40, 41. A transmitter 28 is connected in series with a battery 42 and a condenser 43 to the input circuit conductors 40, 41. Current of audio frequency will pass through the condenser 43 but is kept out of the polarizing circuit by the choke coil 38 while the polarizing unidirectional current is prevented from flowing in the transmitter circuit by a condenser 43. The direct current component of the transmitter current will flow in the circuit of the inductance coil 44.

The circuit 45, 46, joining the output circuit of the magnetron A to the input circuit of the magnetron B is connected to the middle point of the secondary winding of the transformer 34, so that the anode 3 will be at an average potential with respect to the cathode. The polarizing field of the amplifier B is produced by a battery 47 connected in series with a choke coil 48 and a resistance 49 across the conductors 45, 46. The output circuit 50, 51, connected between the anode of the magnetron B and the middle point of the secondary of the transformer 35 contains a battery 52 and a telephone receiver 53.

In Fig. 7, I have shown my new device in connection with a radio-telephone system. The magnetron is used in this system to generate high frequency oscillations modulated by an audio frequency current.

The magnetron shown in Fig. 7 is provided with two magnetic windings 55 and 56. The winding 55 for convenience is shown on the drawing apart from the tube but it is to be understood that the field of this winding is interlinked in any desired way with the field of the winding 56 as shown for example in Fig. 1. The winding 55 combines the functions of a polarizing winding and a control winding as already described in connection with the windings 36 and 36′ of Fig. 6. As the connections of the telephone transmitter 28 to the winding 55 is identical with the corresponding connection of Fig. 6 no further explanation is necessary.

The winding 56 is connected in series with the electrodes 2, 3, to a source of direct current (not shown) by the conductors 57, 58. Included in the conductor 57 is a choke coil 59 and the primary winding of a transformer 60. An adjustable condenser 61 is connected in shunt to the coil 56 and the transformer primary. The secondary winding of the transformer is connected in series with a choke coil 62 in a grounded antenna 63. With proper tuning high frequency oscillations are produced by the action of the coil 56 on the electron current, these oscillations being modulated by the coil 55. If unmodulated oscillations are desired the coil 55 and its circuit members are omitted.

The radio receiving system of Fig. 8 employs two magnetically controlled tubes, a magnetron C being used as an amplifier and the magnetron D being used as a detector.

The input circuit 65, 66 of the tube C is connected to the secondary winding of a transformer 67, having its primary winding connected in series with a grounded antenna 68. An adjustable condenser 69 is connected in shunt to the control winding 70. The polarizing winding 71 is supplied with rectified current derived from the transformer winding 72 through the conductors 73, 74 containing a rectifier 75, two series connected resistances 76, 77 and a ballast resistance 78 which steadies the current. Connected across the circuit, as indicated, are condensers 79, 80, 81 which with the resistances 76, 77, 78 constitute a capacity-resistance filter to smooth out the undulating rectified current. The core 83 of the transformer has a primary winding 84 supplied with current by an alternating current generator 85. A secondary winding 86 supplies the cathode 2 of the tube C with heating current and a winding 87 supplies the cathode of the hot cathode rectifier 75 with heating current.

The output circuit 89, 90 is connected to the winding 91 of the tube D, the conductor 90 being carried to the middle point of the winding 86 by the conductor 92 in series with the condenser 81. Resonance is secured by an adjustable condenser 93. The cathode of the tube D is heated by alternating current from a transformer 94. The output circuit 96, 97 is connected in series with a suitable direct current source (not shown) to an indicator 98, such, for example, as a telephone receiver.

The ampere turns of the winding 91 upon the magnetron D are so chosen that the magnetic field produced thereby is at the critical polarizing value described in connection with Fig. 1, at which an increase of field strength produces a decrease of current. Hence a signal received by the antenna and amplified by the tube C produces on increase of magnetic flux of the winding 91 and a decrease of current in the circuit 96, 97, which is audibly or otherwise indicated.

Devices embodying my invention are stable and reproducible, are operable over a wide range of impressed voltages and a small variation of magnetic field above the critical value produces a relatively large variation of space current in the device. These properties render the device particularly advantageous as an amplifier, and for other purposes. As distinguished from the three-electrode magnetically-controlled electron device of my prior Patent 1,387,985 issued August 16, 1921, my present device requires essentially but two main electrodes and the space between these electrodes is unobstructed. The variation and control of the current between the electrodes occurs solely by the action of the magnetic field as distinguished from the interception of electrons by an intermediate electrode.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. A vacuum tube of the pure electron discharge type having a cathode adapted to emit electrons in combination with means for impressing upon the space surrounding said cathode a magnetic field in such direction that when said field has a sufficient magnitude a reduction in the value of the effective electron emission of said cathode will occur and means for varying said field.

2. An electron discharge apparatus comprising a vacuum tube of the thermionic type, cooperating electrodes therein including a cathode adapted to emit electrons independently of gas ionization, means for impressing a magnetic field upon an electron current in said tube, said means being so positioned with respect to said electrodes that a small increase of field strength above a critical value at a given operating voltage will cause the effective emission of said cathode to be reduced and means for varying said magnetic field within an operating range above said critical value.

3. An electric device comprising a cathode adapted to emit electrons independently of positive ionization, an anode, an enclosing sealed envelope, the space and parts within said envelope being freed from gas to such extent that transfer of energy between said electrodes occurs substantially independently of positive ionization, means for subjecting the space between said electrodes to a magnetic field of sufficient strength to pro-

duce a decrease of current flow between said electrodes at a given voltage and means for superimposing a variable field upon said field.

4. A discharge device comprising a plurality of electrodes, one of which is adapted to emit electrons independently of gas ionization, an enclosing sealed envelope, means for impressing a magnetic field upon the space between said electrodes, said field being spacially so related to said electrodes and said device being sufficiently evacuated so that an increase of the effective strength of said field above a critical value materially decreases the current carrying capacity of said device.

5. An electric device comprising an electron-emitting cathode, a cooperating electrode, an enclosing sealed envelope, said device being freed from gas to such extent that passage of current across the space between said electrodes takes place substantially independent of gas ionization, electromagnetic control means for varying an electron current between said electrodes, the electrodes and magnetic means being spacially so related that an increase of magnetic field above a critical value produces a decrease of current.

6. An electric device comprising a cathode operable at incandescence, an anode arranged in unobstructed spacial relation to said cathode, an enclosing evacuated envelope, means for generating a magnetic field of predetermined value substantially parallel to said cathode, and of such strength that an increase of field strength produces a decrease of current at a given operating voltage, and means for varying said magnetic field.

7. An electric device comprising a cathode adapted to emit electrons independently of ionization effects, an anode located in unobstructed relation to said cathode, an enclosing evacuated envelope, means for generating a polarizing magnetic field for controlling the passage of electrons from said cathode to said anode, said electrodes being so positioned and the space within said envelope being sufficiently evacuated and the effective value of the magnetic field being so chosen with respect to a given electrode voltage that an increase of magnetic field above a critical value produces a decrease of current, and means for superimposing upon said field a variable magnetic field for varying the current transmitted by said device.

8. An electron discharge device comprising electrodes so positioned in rotational symmetry with respect to one another that the electron flow may assume straight unobstructed radial paths therebetween, magnetic means spacially so positioned with respect to said electrodes that a magnetic field may be generated thereby which will be substantially at right angles to an electron discharge occurring therebetween, and an envelope enclosing said electrodes, said envelope being evacuated to a residual gas pressure so low that the operation of said device will be substantially unaffected by ionization.

9. An electric discharge device comprising an electron emitting cathode and an anode, said cathode being substantially equidistant from the anode at all points, an enclosing sealed envelope, means for generating an electromagnetic field normal to the path of electrons passing from said cathode to said anode, the degree of evacuation of the tube being such that an increase of the magnetic field will cause a decrease in space current, a load circuit connected to said electrodes, and an input circuit connected to vary said electromagnetic field.

10. In combination, an electron discharge apparatus adapted to operate substantially independently of gas ionization, the electrodes of which are constituted exclusively by a cathode adapted when heated to emit electrons and an anode surrounding said cathode and arranged in substantially circular symmetry with respect to said cathode, the space between said electrodes being unobstructed, means for producing a magnetic field in a direction parallel to the axis of symmetry of said electrodes, and a load circuit connected to said anode.

11. An electron discharge device having electrodes constituted solely by a cathode capable of emitting electrons independently of gas ionization, an anode normally receiving substantially the entire discharge from said cathode, means for generating a magnetic field at right angles to the path of the electron discharge between said cathode and anode, and means for varying said field between a value at which an electron discharge flows between said electrodes and a higher value at which the current is reduced substantially to zero.

12. In combination, an electron discharge device comprising an evacuated envelope, electrodes therein constituted exclusively by an electron emitting cathode and a cylindrical anode arranged in circular symmetry about said cathode leaving the intervening space unobstructed for the passage of electrons, a load circuit connected to said anode and means for producing a magnetic field in a direction parallel to the axis of symmetry of said electrodes for controlling the flow of electrons from said cathode to said anode, the relation of the parts of said device to the gas residue being such that the device is capable of operation substantially unaffected by gas ionization.

13. An electron discharge device comprising electrodes one of which is arranged in rotational symmetry with respect to the

other and normally carrying substantially all of the current during operation, the intervening space being unobstructed, an enclosing envelope which is evacuated sufficiently to permit a discharge to pass between said electrodes without substantial gas ionization, means for generating a magnetic field at substantially right angles to the general direction of flow of electrons between said electrodes and means for varying said field between a lower value at which the electron current is substantially unaffected and a higher value at which the electron current is reduced to substantially zero.

14. An electric discharge device comprising main current-carrying electrodes arranged in circular symmetry in unobstructed relation about a main axis, a container therefor evacuated sufficiently to prevent gas ionization discharges therein, means for producing an electromagnetic field normal to the discharge path between said electrodes whereby an increase of field strength from zero to a critical value produces no substantial change of electron current obtainable with a given voltage applied to said electrodes and at field values above said critical value produces a rapid decrease of electron current with a progressive increase of said field.

15. An amplifier comprising the combination of a discharge device comprising an electron-emitting cathode, an anode arranged in circular symmetry about said cathode and means for impressing a magnetic field upon the space between said electrodes, the degree of evacuation of said device being such that an increase of effective field strength above a critical value causes a decrease of current, means for varying the strength of said magnetic field within the range over which changes of effective field strength are accompanied by changes in current carrying capacity of said device, an input circuit connected to said magnetic means, an output circuit connected to said cathode and anode, a source of current in said output circuit and a translating device in said output circuit.

16. An electric discharge device having two electrodes only, one of which is a cathode adapted to emit electrons independently of gas ionization, the space between said electrodes being unobstructed, an enclosing evacuated envelope and means for generating a magnetic field normal to the discharge path between said electrodes.

17. An electric discharge device containing two electrodes only, one of which is a cathode adapted to emit electrons independently of positive ionization, the space between said electrodes being clear to permit unobstructed passage of electrons, an enclosing evacuated envelope, means for impressing a magnetic field upon the space between said electrodes, the magnitude of said field and the degree of evacuation of said device being such that an increase of effective strength of said field above a critical value produces a decrease of current, and means for varying the effective strength of said magnetic field.

18. An amplifier comprising the combination of a discharge device comprising an electron-emitting cathode, an anode, and means for impressing a magnetic field upon the space between said electrodes, the degree of evacuation of said device being such that an increase of effective field strength above a critical value causes a decrease of current, an input circuit connected to said magnetic means, an output circuit connected to the electrodes of said device, a source of current in said output circuit, and a translating device in said output circuit.

19. The method of operating an electron discharge apparatus comprising an electron-emitting cathode and an anode arranged in circular symmetry directly about said cathode which consists in setting up a magnetic field parallel to said cathode, and increasing the strength of said field beyond a critical value characteristic of the device whenever a reduction in current-carrying capacity of said apparatus is desired.

20. The method of controlling the passage of current in a device having an evacuated receptacle containing an anode and a cathode capable of emitting electrons independently of an impressed voltage which consists in applying a voltage between cathode and anode, impressing a magnetic field substantially parallel to said cathode and producing variations in the strength of said field between a critical value at which an increase of field strength decreases the current and a saturation value of magnetic field strength at which substantially no electron current flows.

21. The method of controlling the passage of current in a device having an electron-emitting cathode and an anode which consists in impressing a voltage between said electrodes to produce current flow between the same, impressing substantially parallel to said cathode a varying magnetic field and maintaining the gaseous pressure about said electrodes so low that a variation of magnetic field produces a variation of current between said electrodes in an inverse sense.

22. The method of controlling current in a circuit which consists in causing the emission of electrons from a cathode in said circuit independently of gaseous ionization, producing a flow of electrons from said cathode to an anode in substantially straight radial paths in an evacuated space, and generating a magnetic field at right angles to the general course of said discharge, said

field value being made of sufficient magnitude to materially reduce the effective electron emission from said cathode when a reduction of current is desired.

23. An apparatus for modifying electric currents comprising the combination of a device having electrodes adapted to produce an electron discharge, means for magnetically controlling said discharge, an output circuit connected to said electrodes, a second device having electrodes adapted to produce an electron discharge, a second output circuit connected thereto, means for magnetically controlling said second discharge, connections between said first output circuit and the control means for said second discharge, and a translating device in said second output circuit.

24. An apparatus for modifying or controlling electric currents comprising the combination of a set of electrodes arranged in substantially circular symmetry with respect to each other, an enclosing evacuated container, magnetic control means, an input circuit connected to said control means, a second set of electrodes arranged in substantial circular symmetry, magnetic control means therefor, a circuit connecting said first set of electrodes with said second control means, a source of electric energy in said circuit, an output circuit connected to said second set of electrodes, and a source of energy in said output circuit.

25. An apparatus for amplifying variable electric currents comprising the combination of a set of electrodes arranged in substantial circular symmetry with respect to one another, the cathode being adapted to be independently heated to incandescence, an evacuated container therefor, means for generating a magnetic field substantially parallel to said cathode, an input circuit connected to said means, a second set of electrodes comprising an incandescible cathode, an evacuated container therefor, means for generating a magnetic field substantially parallel to said second cathode, a circuit connecting said first set of electrodes with said second magnetic means, a source of direct current in said connecting circuit, choke coils connected in shunt to said respective magnetic control means, a load circuit connected to said second set of electrodes, and a source of energy in said load circuit.

26. An apparatus for amplifying currents of audio frequency comprising the combination of a magnetron, a telephone transmitter connected to the input circuit of said magnetron, a source of direct current in said circuit, a condenser connected in series with said transmitter and source, a second source of energy connected to said input circuit in shunt to said transmitter current source and condenser, a choke coil connected in series with said second source, and a telephonic receiving apparatus connected to the output circuit of said magnetron.

27. A telephone amplifier comprising the combination of a magnetron, a source of current for generating a polarizing field connected to the magnetic control winding of said magnetron, a telephone transmitter also connected to said winding, a condenser connected between said telephone transmitter also connected to said winding, a condenser connected between said telephone transmitter and said source, a transformer connected to heat the cathode of said magnetron, a second magnetron, an electrical circuit connecting the magnetic winding of said second magnetron to the middle point of said transformer, and to the anode of the first magnetron, a source of current in said circuit, a polarizing source of current connected to the magnetic winding of said second magnetron, a choke coil connected in series with said polarizing source, and a telephone receiving circuit connected to the electrodes of said second amplifier.

28. An electric discharge device having two load-carrying electrodes only constituted by a substantially linear cathode and a cylindrical anode located symmetrically about said cathode, an evacuated container therefor, and means for producing a magnetic field substantially parallel to the axis of said anode.

29. An electric discharge device containing two electrodes exclusively, one of which is adapted to emit electrons independently of voltage applied thereto, said electrodes being constituted by a generally rectilinear electrode and a second electrode having the general shape of a surface of revolution about said rectilinear electrode, a container for said electrodes evacuated sufficiently to prevent substantial positive ionization, and means for producing a magnetic field at an angle to the discharge path between said electrodes.

30. An electric discharge device having two electrodes only constituted respectively by a substantial linear filamentary cathode which is adapted to emit electrons when heated, a substantially cylindrical anode located symmetrically about said cathode and means for producing a magnetic field substantially at right angles to an electrostatic field between said electrodes.

31. An electron discharge device comprising an evacuated envelope, electrodes therein constituted exclusively by an electron-emitting cathode, and an anode enclosing said cathode and means for producing a magnetic field in such direction with respect to the general course of electron current between said electrodes that when a constant voltage is applied to said electrodes and the magnetic field strength is progressively increased, the effective electron emis-

sion from said cathode is substantially unchanged up to a definite value of field strength, while with a small increase above said value the effective emission is reduced substantially to zero.

32. An electron discharge device comprising an envelope having the space therein evacuated to a pressure so low that an electron discharge therein may occur without material ionization, a cathode adapted to emit electrons independently of the impressed voltage, a cylindrical electrode located substantially symmetrically about said cathode, means for producing a flow of load current between said electrodes, and means for producing a magnetic field substantially at right angles to the load current between said electrodes, said device having no electrode which may exert an electric field tending to deflect said electrons into a direction parallel to said magnetic field.

33. The method of controlling the current in an electric circuit which consists in producing a substantially pure electron discharge in said circuit, impressing a magnetic field substantially at right angles to said discharge, and varying the strength of said field in response to the current to be controlled between a critical value sufficiently high to cause a decrease of current and a greater value at which substantially no current will pass.

In witness whereof, I have hereunto set my hand this 27th day of January, 1920.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 292.

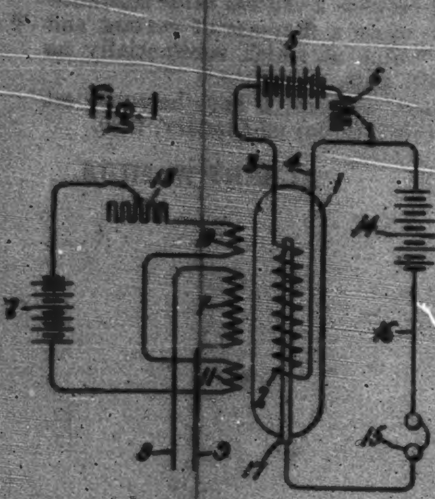
April 21, 1925. 1,535,087

E. F. W. ALEXANDERSON

ELECTRON DISCHARGE DEVICE

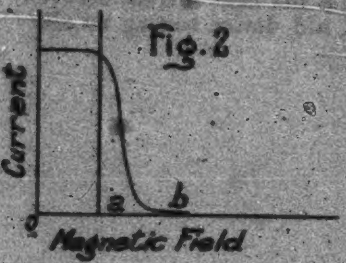
Original Filed Sept. 28, 1920

Fig. 1

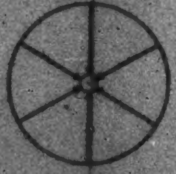


5
6
3
4
1
10
14
7
16
11
2
8
9
15
17

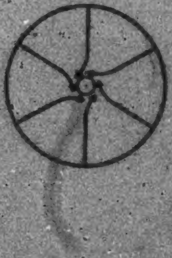
Fig. 2



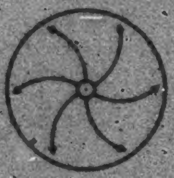
3a



3b



3c



Inventor:
Ernst F. W. Alexanderson,
by Albert G. Davis
His Attorney.

Patented Apr. 21, 1925. **1,535,082**

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, OF NEW YORK, N. Y.

ELECTRON-DISCHARGE DEVICE.

Application filed September 22, 1920, Serial No. 412,397. Renewed March 12, 1923.

To all whom it may concern:

Be it known that I, Ernst F. W. Alexanderson, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electron-Discharge Devices, of which the following is a specification.

The present invention comprises a novel electron discharge device which is particularly adapted to the controlling and amplifying of electrical currents.

Heretofore electron discharge devices have been constructed in which the transmitted current was subject to the control of a variable magnetic field. In these devices the cathode was axially arranged within the anode, preferably being substantially equidistant from the anode at all points along its length.

I have discovered that an even more sensitive device can be constructed by locating the anode centrally with respect to the cathode, and preferably spacing the electrodes symmetrically.

I have illustrated diagrammatically in Fig. 1 a form of apparatus embodying my invention; Fig. 2 is a diagram illustrating an electrical characteristic of my device, and Figs. 3^a, 3^b and 3^c illustrate visually electron flow under various conditions as an aid to explain my invention.

The device shown in Fig. 1 is adapted for use as an amplifier for weak electrical currents, for example, radio signals. It comprises an elongated glass envelope 1 containing a centrally located elongated or rod-like anode 17 and a helical cathode 2 symmetrically surrounding the anode. The cathode 2 is preferably although not necessarily equidistant from the anode 17 at all points along its length and in general I prefer to arrange the electrodes in devices embodying my invention in circular symmetry with respect to each other.

The cathode 2 is adapted to emit electrons independently of the passage of current across the space between the electrodes; for example, in the case illustrated in the figure the cathode consists of refractory material, preferably tungsten, connected by conductors 3, 4, to a suitable source of electric energy represented by an electric battery 5. A regulable resistance 6 is provided to control the heating current. The anode 17 may also consist of tungsten and various other metals may also be used. The space within the envelope is evacuated and the parts of the device are deprived of gas to such an extent that the electron discharge can occur therein without material gas ionization. A slight amount of gas ionization will do no harm, but it should not be so high as to make the electrons uncontrollable by a magnetic field. Some suitable means for generating a variable magnetic field is provided, as, for example, a coil 7 which has been diagrammatically shown adjacent to the discharge tube, but which, as in devices of this type, will ordinarily surround the tube. This coil 7 is connected to the source of weak variable current which is to be amplified, as represented in this case by the conductors 8, 9.

There is also provided some means for generating a polarizing electric field, as represented by coils 10 and 11, connected in series to a source of direct current such as a battery 12 in circuit with a variable resistance 13. In circuit with the electrodes 2 and 17 are included a suitable source of direct current as represented by the battery 14 and a suitable indicating device such as a telephone receiver 15.

When no exterior magnetic field is applied to an electron discharge device having an anode centrally located with respect to the cathode the electrons in general tend to move in direct paths from the cathode to the anode, as shown in Fig. 3^a. When a magnetic field is generated substantially parallel to the cathode, the electrons are deflected out of a direct path. With a central location of the cathode in prior devices the path of the electrons tend to become curved as shown in Fig. 3^b. When the magnetic field is increased sufficiently the electrons eventually travel in a long spiral path about the cathode on their way to the anode and finally when the field strength is increased sufficiently electrons will fail to reach the anode by reason of this deflection.

In a device having a centrally located anode the electrons flowing inwardly from the surrounding cathode to the anode when deflected by a magnetic field as shown in Fig. 3^c, are caused to travel in a general direction tangentially to the anode and tend to form orbits about the anode. As the centrifugal force of the mass of electrons works in the same direction as the magnetic field in a device having a centrally located anode, such a device is much more sensitive to variations of the magnetic field than a device having the cathode located within the anode. In the latter case the magnetic field must be strong enough to overcome the centrifugal force of the electrons in their circular path. The relation between the magnetic field tending to deflect the electrons and the current transmitted by the device is indicated by the diagram constituting Fig. 2, the values of the magnetic field being plotted as abscissæ and the corresponding field values as ordinates for a given cathode temperature. As the strength of the magnetic field is increased from zero the current remains substantially constant until the magnetic field reaches a value represented as *oa* on the abscissæ. A further increase of field strength causes a rapid reduction of current until at a field strength of *ob* current has fallen substantially to zero.

The magnetic field necessary to produce a decrease in current, in other words, the value *oa* will be less in a device embodying my invention than in devices heretofore constructed having a centrally located cathode. In practice the strength of the polarizing magnetic field is adjusted at some value between *oa* and *ob*. Consequently when the variable magnetic field of the coil 7 is superimposed upon the polarizing field an increase or decrease of conductivity of the device occurs. For example when the variable magnetic field produced by the coil 7 tends to assist the polarizing field generated by the coils 10 and 11, the current in the circuit 16 tends to decrease, and conversely, when the magnetic field of the coil opposes the polarizing field the current in the circuit 16 increases. Therefore, a variable current in the circuit 8, 9 produces a corresponding amplified variable current in the circuit 16 which can be used in any desired manner, as in a telephone receiver 15.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. In combination, an electron discharge device adapted to operate independently of gas ionization comprising the combination of an anode, an electron-emitting cathode arranged about said anode and magnetic means arranged to oppose the passage of electrons from said cathode to said anode.

2. In combination, an electron discharge device comprising an evacuated envelope, an electron-emitting cathode and an anode inclosed by said cathode and having a major axis extending in the direction of the major axis of said cathode and means for producing a magnetic field parallel to the axis of symmetry of said electrodes for controlling the flow of electrons from said cathode to said anode.

3. An electron discharge device comprising the combination of electrodes contained in an evacuated space, the cathode comprising a coiled conductor, the anode being located substantially centrally within said coiled conductor, and means for generating a magnetic field substantially parallel to the axis of said cathode.

4. An electron discharge device comprising the combination of an elongated anode, a helical cathode symmetrically spaced about said anode, means for heating said cathode, an enclosing evacuated envelope and magnetic means for controlling an electrical discharge between said electrodes.

5. An electron discharge apparatus comprising the combination of an elongated electrode, a helical electrode spaced about the same, means for conducting an electric current through said helix, a sealed evacuated envelope enclosing said electrodes, a load circuit connected to said electrodes, and a magnetic winding located to generate a magnetic field substantially parallel to the axis of said helix.

6. An electron discharge device comprising in combination an evacuated envelope, an elongated anode, a filamentary cathode symmetrically spaced about said anode, and means for generating a magnetic field substantially parallel to the axis of said cathode.

7. An electron discharge device comprising in combination an evacuated envelope, an elongated anode, a helically coiled cathode symmetrically arranged about said anode, means for heating said cathode to a temperature sufficiently high to emit electrons, magnetic means for producing a field which will deflect electrons out of a direct path between said electrodes, means for varying said field, and a load circuit connected to said electrodes.

8. An electron discharge apparatus comprising the combination of an anode, an electron-emitting cathode arranged about said anode, an enclosing evacuated envelope, an output circuit connected thereto, magnetic means for generating a field opposing the passage of electrons from said cathode to said anode and input means for varying said field.

In witness whereof, I have hereunto set my hand this 27th day of September, 1920.

ERNST F. W. ALEXANDERSON.

DEFENDANT'S EXHIBIT No. 293.

Aug. 18, 1925. 1,549,737

E. F. W. ALEXANDERSON

SIGNALING SYSTEM

Filed Sept. 15, 1919 2 Sheets-Sheet 1

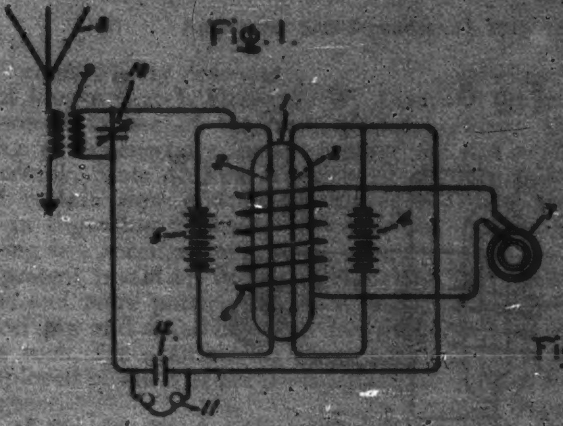
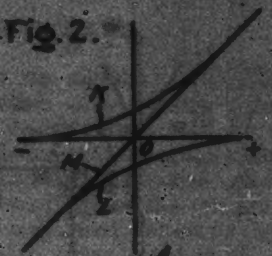
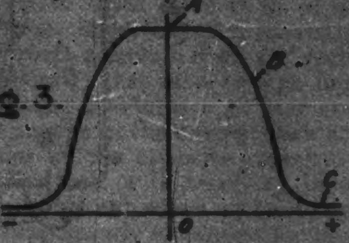
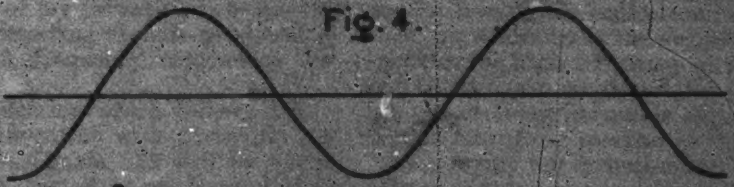
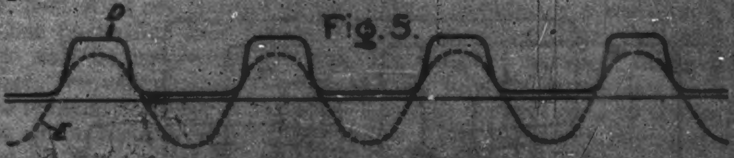


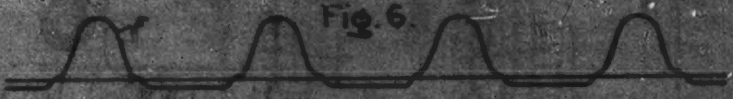
Fig. 1.
8
9
10
1
2
3
5
6
7
4
11

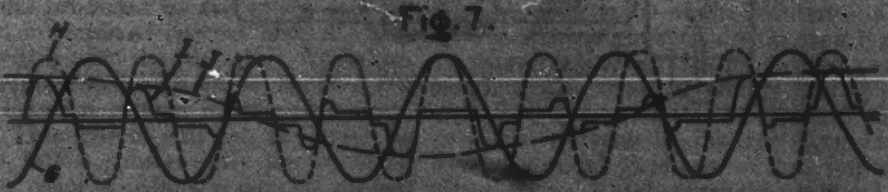












Inventor:
Ernst F.W. Alexanderson,
by
His Attorney.

1182

Aug. 18, 1925. 1,549,737

E. F. W. ALEXANDERSON

SIGNALING SYSTEM

Filed Sept. 15, 1919 7 Sheets-Sheet 2

Fig. 8.

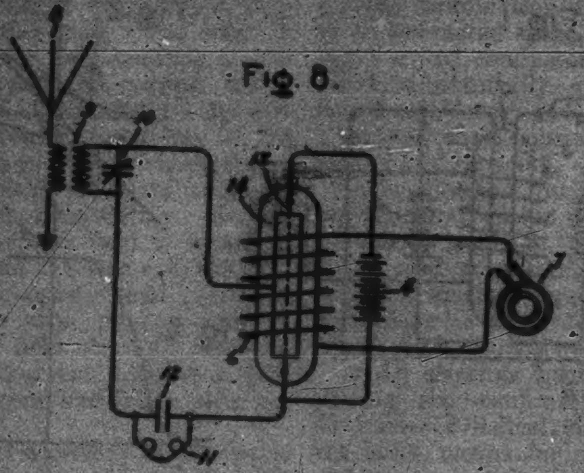
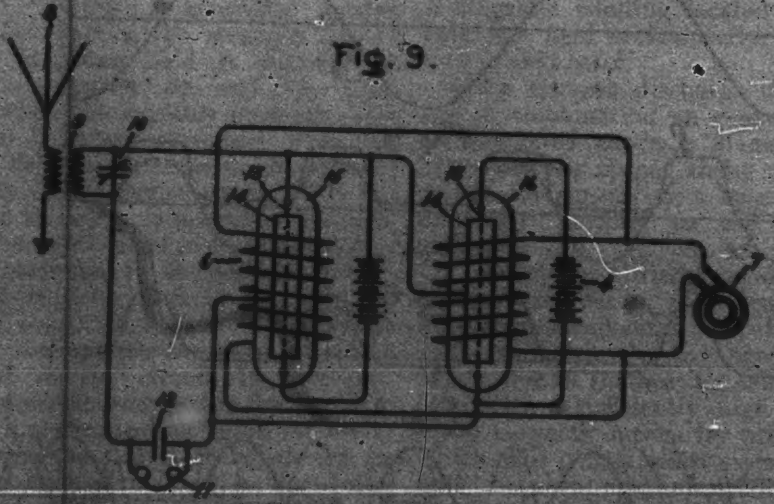


Fig. 9.



Inventor:
Ernst F.W. Alexanderson,
by Albert G. Davis
His Attorney.

Patented Aug. 18, 1925. 1,549,737

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

SIGNALING SYSTEM.

Application filed September 15, 1919. Serial No. 323,745.

To all whom it may concern:

Be it known that I, ERNST F. W. ALEXANDERSON, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Signaling Systems, of which the following is a specification.

My present invention relates to signaling systems and more particularly to a system for receiving and detecting high frequency signals such, for example, as those which are employed in the wireless transmission of intelligence.

One of the objects of my invention is to provide a simple and efficient means for detecting high frequency signals. A more specific object of my invention is to provide a means for detecting signals produced by means of high frequency continuous currents.

In the specification which follows I have described my invention with particular reference to radio signals. It will be understood, however, that it is not limited in its usefulness to that particular field but that it may equally well be employed for the detection of high frequency signaling currents which are transmitted over wire lines.

All detectors which have been used heretofore, whether of the crystal or vacuum tube type, have fundamentally the same characteristics. They may all be considered as relays which are actuated by the voltage applied from the receiving antenna and results produced by the relays may be measured in terms of current output. The characteristics of the detector therefore may be represented by a curve showing the relation between voltage input and current output. This curve will in all cases be found to follow substantially the equation $i=e^2$. In other words, the current output of the detector does not follow Ohm's law but instead of being proportional to the signaling voltage impressed on the detector is proportional to the square of the voltage. This characteristic is particularly disadvantageous in radio receiving for receiving weak signals when strays are present which are of greater magnitude than the signals. If, for example, the strays are four times as strong as the signaling waves the response produced in the detector by the strays will be sixteen times as strong as that produced by the signals. A further object of my invention is to provide a detector in which this disadvantage will be overcome and in which the current output will be substantially proportional to the voltage input instead of the square of the voltage input.

All previously used detectors depend for their operation upon some form of asymmetry in their operating characteristics by reason of which a certain degree of rectification is obtained; that is, a voltage impulse of one polarity produces a greater current output or change in the current than a voltage impulse of the opposite polarity. An effect of this nature is necessary in order to produce a current which will actuate one of the devices usually employed for producing an intelligible indication of the signal, such, for example, as the ordinary telephone receiver, the high frequency alternating currents which are employed for transmitting the signal being incapable of actuating the diaphragm of the receiver.

In carrying my invention into effect I provide as a detector a resistance device which may be included in the receiving circuit. The current through this device substantially follows Ohm's law and is therefore directly proportional to the impressed voltage. The necessary asymmetry of the device for securing the required rectifying effect is secured by periodically varying the value of this resistance by means of a suitable modifying force which is controllable at the will of the operator at the receiving station. The value of the resistance is controlled or varied in such a way that it is made comparatively small during desired periods and is made exceedingly large during other periods. This permits the flow of an appreciable current in the receiving circuit during desired portions of the impressed signaling wave and causes the practical suppression of the current in the receiving circuit during other portions of the signaling wave.

My improved detector may be operated in various ways. If the means for varying its resistance is so arranged that the resistance is varied between its maximum and minimum values at a frequency corresponding to the frequency of the signaling current and the relations between the signaling current and the modifying force are so fixed that the periods of maximum conductivity correspond with the periods of voltage impulses of one polarity all current impulses of one polarity will be allowed to flow through the device and all current impulses of the opposite polarity will be substantially suppressed. In this way a practically complete rectification may be obtained and the resulting current will be a pulsating direct current. In the case of telegraphic signals the pulsations of this current will all be of high frequency and no audible indication will be produced by the current in a telephone receiver. Such a current, however, may be employed to produce an indication in a photographic recorder or other indicating device which is operable by a steady direct current.

Because of the difficulty of keeping the modifying force operating in synchronism with the signaling wave as well as the fact that the current produced in this way does not give an audible indication in a telephone receiver it will usually be found desirable to supply the modifying force in such a way that the resistance is caused to vary between its maximum and minimum values at a frequency slightly different from that of the signaling wave. The current which will flow in the detector circuit will then be in effect a pulsating or alternating current of a frequency corresponding to the difference of frequency between the signaling current and the frequency of the changes in resistance. If this difference in frequency is such as to come within the range of audible frequencies the resulting current will be capable of producing an indication in the ordinary telephone receiver.

The resistance device used in carrying my invention into effect may assume a variety of forms. In the preferred form of my invention it consists of an evacuated receptacle containing an electron emitting cathode and an anode the current through the device being carried by a stream of negative electrons flowing across the evacuated space from cathode to anode. This stream of negative electrons is controlled by means of a magnetic field produced by a coil which surrounds the evacuated receptacle. If this field is made strong enough substantially all of the electrons emitted from the cathode will be prevented from reaching the anode and the resistance of the device to the flow of current will be exceedingly large. Where no magnetic field is present or where the magnetic field is weak the resistance of the device will be small in comparison to its resistance with a strong magnetic field, and appreciable currents will be allowed to flow.

The magnetic field for controlling the stream of electrons and the resistance of the device may be produced by an alternating current of suitable value. When this current is passing through its zero values the resistance of the device will be a minimum and when it reaches its maximum positive and negative values the resistance of the device will be a maximum. Hence there will be two points of maximum value and two points of minimum value of the resistance for every complete cycle of the alternating current. In order to produce a complete rectification of the signaling current therefore the alternating current which produces the magnetic field should have a frequency equal to half the frequency of the signaling current. When it is desired to produce an audible pulsating or alternating current in the detector circuit the alternating current which produces the magnetic field should differ in frequency from half the frequency of the signaling current by an amount equal to half the frequency of the audible current desired.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation together with further objects and advantages thereof will best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 illustrates diagrammatically a circuit connection which may be used in carrying my invention into effect; Fig. 2, shows the relation between the characteristic curves of other forms of detector and that of my improved devices; Figs. 3 to 7 are diagrams illustrating the operation of my system, and Figs. 8 and 9 are modified circuit connections which may be used.

In Fig. 1, I have indicated as one form in which my detector may be embodied an evacuated receptacle 1 containing two filamentary electrodes 2 and 3 which are supplied with heating current by means of the batteries 4 and 5. A magnetic field, in a direction parallel to that of the electrodes 2 and 3, for controlling the flow of current between these electrodes may be produced by means of the coil 6 surrounding the receptacle; this coil being supplied with magnetizing current by a local source 7. Received high frequency signaling waves which it is desired to detect may be impressed from the antenna 8 upon the usual resonant receiving circuit which comprises the coupling inductance 9 and condenser 10 and which is connected to the electrodes 2 and 3 of the detector. The receiving circuit also includes an indicating instrument which, in case an audible frequency current is to be produced, may be the usual telephone receiver 11 shunted by a condenser 12. In case a constant direct current is to be produced or a current which is incapable of actuating a telephone receiver a photographic recorder or other instrument which will be actuated by such currents may be substituted for the telephone receiver.

When there is no magnetic field set up in the coil 6, the detector may be considered as a constant resistance in the receiving circuit through which current may flow in either direction by reason of the fact that both electrodes are heated. The electrons will then tend to move in straight lines between the electrodes and the resistance will be a minimum. If, however, a magnetic field is set up in coil 6 the electrons will be caused to move in spiral lines around the electrodes, the distance between turns of the spiral decreasing as the magnetic field is increased. As the field is increased the number of electrons passing between the electrodes will decrease and hence the resistance of the device will increase. If the field is made strong enough practically all of the electrons will be prevented from flowing between the electrodes, and the resistance of the device will become a maximum, this maximum value being many times greater than the minimum value. In Fig. 3, I have indicated the variation in conductivity of the device with varying magnetic field, conductivity being plotted as ordinates and strength of magnetic field as abscissæ. When there is no magnetic field, the conductivity of the device is represented by point "A". When the magnetic field in one direction increases the conductivity decreases as represented by the portion "B" of the curve until a point "C" is reached at which the conductivity becomes a minimum. Further increase in the strength of the magnetic field beyond this point will produce substantially no change in conductivity. In so far as its effect on the conductivity of the device is concerned the direction of the magnetic field is immaterial. The curve of Fig. 3, shows the variations in conductivity of the device with changes in the magnetic field from a maximum in one direction, marked negative for convenience, to zero and to a maximum in the opposite direction.

The curve of Fig. 4 represents the variations in the force which modifies the resistance of the detector. In the case illustrated the modifying force is produced by a current of half the frequency of the signaling waves and the curve of Fig. 4, may be considered as representing changes in the magnetic field.

The curve "D" of Fig. 5, represents the changes in conductivity of the detector produced by the modifying force illustrated in Fig. 4. At points where the modifying force is zero, the conductivity is maximum, and at points where the modifying force exceeds a critical value the conductivity is a minimum, thus for every cycle of the local source of current there will be two points of maximum conductivity and two points of minimum conductivity.

If the curve "E" of Fig. 5 represents the signaling potential impressed upon the detector the current through the detector will be represented by the curve "F" of Fig. 6. The periods of positive signaling impulses correspond to the periods of maximum conductivity and the periods of negative signaling impulses correspond to periods of minimum conductivity. Hence the current through the detector will be substantially all in one direction and will in effect be a direct current having high frequency pulsations. These pulsations will be smoothed out by the condenser 12 and the effect of the current upon the indicating instrument will be substantially the same as that of a steady direct current. This current, of course, will not produce an audible tone in a telephone receiver but may be used to actuate a photographic recorder or any other form of indicating device which is responsive to a steady direct current.

It is, of course, difficult to maintain a local source of current at a frequency equal to just half the frequency of the received signaling currents and to keep the phase relation between the local current and the signaling current just right to produce the effect above described. For this reason and because of the advantages of audible reception it will be preferable to operate the local source of current at a frequency somewhat different from half the frequency of the signaling current. The curves of Fig. 7 illustrate the effects of this method of operation. In this case the modifying force as represented by the curve G has a frequency slightly greater than half the frequency of the signaling potential, which is represented by the curve H. The resultant current through the detector is represented by the curve I. This current has high frequency pulsations like that of curve F of Fig. 6 but is made up of impulses of both polarities. When the high frequency impulses are smoothed out the effective current will be substantially as represented by the curve J; that is, the resultant current will be a low frequency alternating current which, if the frequency of the local source is properly adjusted, will produce an audible note in the telephone receiver 11. The frequency of this current will be equal to twice the amount by which the local source differs from half the frequency of the signaling waves.

The curve K of Fig. 2 represents the current characteristic of the usual detector, the ordinates representing current and the abscissæ applied voltages. This characteristic in all previous detectors is a curve and not a straight line, that is, the current instead of varying directly as the voltage varies as some power of the impressed voltage. In vacuum valve or electron discharge detectors having rectifying properties the current does not become zero, when the applied voltage becomes zero but by reason of the initial velocity of the electrons current will flow when no voltage is impressed upon the electrodes and a negative potential upon the anodes is required to completely stop the current flow, the negative potential required being ordinarily large in comparison with the signaling potentials applied by the reception of weak signals. Such devices therefore are very inefficient rectifiers, the rectifying effect being due entirely to the fact that a positive potential on the anode produces a greater current than a negative potential. By reason also of the fact that the current is not directly proportional to the voltage, as has been pointed out previously, the ratio between strays and signaling currents is increased by the detector.

If the current K of Fig. 2 represents the current of negative electrons which tends to flow from electrode 2 to electrode 3 the curve L will represent the current of negative electrons which tends to flow from electrode 3 to electrode 2, the combination of these two curves and the resultant current through the device may be represented by the straight line M. Thus it will be seen that the effect of the initial velocity of the electrons is eliminated and the current becomes zero when the impressed voltage is zero. The current also is directly proportional to the impressed voltage and the disadvantage of previous detectors with respect to strays is overcome. It is of course apparent from an inspection of the characteristic M that the device of itself has no asymmetric property and hence no rectifying effect will occur without the influence of the magnetic field. This is immaterial however since by means of the magnetic field the resistance of the device may be varied to such an extent as to practically suppress the current during any desired portion of the signaling wave and thus produce substantially perfect rectification. The effect in the indicating device therefore will be due to current changes produced by impulses of one polarity only rather than the difference in current changes produced by two impulses of opposite polarity as in previous detectors.

In its broader aspect my improved detector may be considered as an ordinary resistance having the usual resistance characteristic that the current flowing therethrough is directly proportional to the impressed voltage. The rectifying or detecting effect is produced, not by means of any inherent asymmetry in the current characteristics of the device but purely by variations in the value of the resistance without altering its pure resistance characteristic.

The receiving system which I have described differs in several important particulars from the well-known heterodyne receiving system which has heretofore been used extensively for the reception of continuous wave signals. The heterodyne receiving system as customarily used involves the use of local oscillations which are radiated through the receiving antenna and thus produce interference with other signals which it may be desired to receive in the neighborhood of the receiving station. In my system, the local source of oscillations is entirely independent of the radiating system and therefore under no circumstances will it produce such interference. The heterodyne receiving system involves the use of a rectifying detector which rectifies all impulses impressed upon the system along with the signals which it is desired to receive. It is therefore subject to interference from any radio telephone messages which may be impressed upon the receiving system as well as from any spark signals which may be impressed thereon. On the other hand, my receiving system does not produce an audible indication except in response to waves of a frequency differing from that of the signals to be received by an amount in the audible range. The heterodyne receiving system also involves a combination of the locally produced current and the received impulses whereby a beat effect is produced. In my system, there is no combination of the local current with the received impulses and no beat effect is produced. The only energy which serves to actuate the receiver is the energy of the received impulses, whereas in the heterodyne system the receiver is actuated by the combined energy of the received impulses and the energy of the locally produced current.

The principal advantages of my invention may be also obtained by means of a modified form of detector as indicated in the diagram of Fig. 8. In this case the detector comprises a linear filamentary cathode 13 surrounded by a cylindrical anode 14. In the absence of any magnetic field the detector in this case would have a characteristic similar to the curve K of Fig. 2. Since however by the aid of the magnetic field the current may be reduced to substantially zero when the signaling voltage falls to zero the real characteristic of the device will approximate the straight line M of Fig. 2 and the current will be directly proportional to the voltage. If the receptacle is so highly evacuated that no gas effects are present current will of course flow in only one direction through the device. It is immaterial however in so far as the operation of the telephone receiver is concerned whether the resultant current through the detector is an alternating current as indicated by curve J of Fig. 7 or a pulsating unidirectional current.

In Fig. 9 I have indicated an arrangement whereby exactly the same effect may be secured as by the arrangement of Fig. 1. In this case the detector of Fig. 1 is replaced by the devices 15 and 16 like the device of Fig. 8 and so connected to the receiving circuit that current may flow in either direction through the receiving circuit. The local source 7 supplies magnetizing current for the fields of both devices.

I am aware that it has been proposed to obtain results similar in nature to those which I have described by means of a rotating commutating device, known in the art as the "tone wheel". This device however involves the difficulties inherent in all devices having moving parts and which depend for their operation upon the making and breaking of contacts. In contradistinction to these devices my improved detector does not require any moving parts for its operation and produces the desired result without any making or breaking of contacts in the receiving circuit and for these reasons is much simpler and more efficient in its operation.

While I have described the preferred form of variable resistance device my invention is by no means limited to this particular form as it is apparent that other forms of variable resistance may be used in carrying my invention into effect. I have also indicated the receiving circuit as being directly associated with the receiving antenna. It is obvious that this is not at all essential to my invention but that any desired degree of amplification may be made before the signaling waves are impressed upon the detector and furthermore that, if desired, the current in the detector may be amplified before it is impressed upon the indicating device.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. A detector for high frequency signaling currents comprising a pair of electron discharge devices oppositely connected in a circuit upon which received signaling currents may be impressed, and means for producing a magnetic field for periodically varying the current flow through said devices.

2. A detector for high frequency signaling currents comprising a pair of electron discharge devices oppositely connected in a circuit upon which received signaling currents may be impressed, and means for producing a magnetic field for periodically varying the current flow through said devices at a frequency slightly different from the frequency of the signaling currents to be detected.

3. A detector for high frequency signaling currents comprising a pair of electron discharge devices oppositely connected in a circuit upon which received signaling currents may be impressed, and means for producing a magnetic field for periodically varying the resistances of said devices independently of the current flow therethrough.

4. Means for detecting high frequency signals comprising a circuit upon which signaling currents received from a distant station may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, and means controlled independently of current flowing between said cathode and anode for periodically varying the value of said resistance.

5. Means for detecting high frequency signals comprising a circuit upon which signaling currents received from a distant station may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, and a local source of current for periodically varying the value of said resistance independently of the current flowing between said cathode and anode.

6. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, indicating means in said circuit, and a local source of current for periodically varying the value of said resistance independently of the current in said circuit.

7. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, means for producing a magnetic field for periodically varying the value of said resistance, and means associated with said circuit for producing an indication of the signals impressed upon the circuit.

8. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, a local source of current for producing a magnetic field for periodically varying the value of said resistance, and means associated with said circuit for producing an indication of the signals impressed upon the circuit.

9. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, indicating means

in said circuit, and a local source of current for producing a magnetic field for periodically varying the value of said resistance.

10. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance device in said circuit through which the current is carried by a stream of negative electrons, means independent of the current in said circuit for controlling the electron stream and thereby periodically varying the conductivity of said resistance device, and means associated with said circuit for producing an indication of the signals impressed upon the circuit.

11. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance device in said circuit through which the current is carried by a stream of negative electrons, means independent of the current in said circuit for producing a magnetic field for controlling the electron stream and thereby varying the conductivity of said resistance device, and means associated with said circuit for producing an indication of the signals impressed upon the circuit.

12. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance device in said circuit through which the current is carried by a stream of negative electrons, a local source of high frequency current for producing a magnetic field for controlling the electron stream and thereby varying the conductivity of said resistance device, and means associated with said device for producing an indication of received signals.

13. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit, and a source of high frequency current of a frequency slightly different from half the frequency of the signaling currents for periodically varying the value of said resistance.

14. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, and a source of high frequency current of a frequency slightly different from half the frequency of the signaling currents for periodically varying the value of said resistance.

15. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit, and a source of high frequency current of a frequency slightly different from half the frequency of the signaling current for producing a magnetic field for periodically varying the value of said resistance.

16. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, and a source of high frequency current of a frequency slightly different from half the frequency of the signaling currents for producing a magnetic field for periodically varying the value of said resistance.

17. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance device in said circuit through which the current is carried by a stream of negative electrons, and a local source of high frequency current of a frequency slightly different from half the frequency of the signaling currents for controlling the electron stream and thereby periodically varying the conductivity of said resistance device.

18. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance device in said circuit through which the current is carried by a stream of negative electrons, and a local source of high frequency current of a frequency slightly different from half the frequency of the signaling currents for producing a magnetic field for controlling the electron stream and thereby periodically varying the conductivity of said resistance device.

19. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit, and means for producing a magnetic field for varying the value of said resistance which periodically varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling current.

20. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit, and a local source of high frequency current for producing a magnetic field for varying the value of said resistance which periodically varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling current.

21. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, and means for producing a magnetic field for varying the value of said resistance which periodically varies between maximum and minimum

values at a frequency slightly different from the frequency of the signaling current.

22. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit comprising an electron discharge device having an electron emitting cathode and an anode, and a local source of high frequency current for producing a magnetic field for varying the value of said resistance which periodically varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling current.

23. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit through which the current is carried by a stream of negative electrons, and means for producing a magnetic field for controlling the electron stream which periodically varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling current.

24. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a resistance in said circuit through which the current is carried by a stream of negative electrons, and a local source of high frequency current for producing a magnetic field for controlling the electron stream which periodically varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling current.

25. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a pair of resistances connected in said circuit through each of which current is carried by a stream of negative electrons, said resistances being connected to carry current in opposite directions, and means for producing magnetic fields for controlling the electron streams which vary periodically between maximum and minimum values.

26. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a pair of resistances connected in said circuit through each of which current is carried by a stream of negative electrons, said resistances being connected to carry current in opposite directions, and means for producing magnetic fields controlling the electron streams which vary periodically between maximum and minimum values at a frequency slightly different from the frequency of the signaling current.

27. Means for detecting high frequency signals comprising a circuit upon which signaling currents may be impressed, a pair of resistances connected in said circuit through each of which current is carried by a stream of negative electrons, said resistances being connected to carry current in opposite directions and a local source of high frequency current for producing magnetic fields for controlling the electron streams which vary periodically between maximum and minimum values.

28. A detector for high frequency signaling currents comprising a resistance device, and means for producing a magnetic field for periodically varying the conductivity of said device between fixed maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

29. A detector for high frequency signaling currents comprising a resistance device through which the current is carried by a stream of negative electrons, and means for producing a magnetic field for controlling the electron stream and thereby varying the conductivity of said device between fixed maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

30. A detector for high frequency signaling currents comprising a resistance device having an electron emitting cathode and an anode, and means for producing a magnetic field for periodically varying the conductivity of said device between fixed maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

31. A detector for high frequency signaling currents comprising a pair of resistance devices oppositely connected in an electric circuit, and a source of current associated therewith for periodically varying the conductivity of said devices between fixed maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

32. A detector for high frequency signaling currents comprising a pair of resistance devices oppositely connected in an electric circuit and through which the current is carried by a stream of electrons, and a source of current associated therewith for controlling the electron streams and thereby periodically varying the conductivity of said devices between fixed maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

33. A detector for high frequency signaling currents comprising a linear filamentary cathode adapted to be heated to incandescence to emit electrons and a cooperating anode enclosed in an evacuated receptacle, means for producing by the signaling currents to be detected a flow of electrons from said cathode to said anode, and means for

producing a variable magnetic field in a direction parallel to said cathode and thereby varying the number of electrons which will reach said anode from said cathode.

34. A detector for high frequency signaling currents comprising a linear filamentary cathode adapted to be heated to incandescence to emit electrons and an electrode surrounding said cathode and coaxial therewith, enclosed in an evacuated receptacle, means for producing by the signaling currents to be detected a flow of electrons from said cathode to said anode, and means for producing a variable magnetic field in a direction parallel to said cathode and thereby varying the number of electrons which will reach said anode from said cathode.

35. A detector for high frequency signaling currents comprising a linear filamentary cathode adapted to be heated to incandescence to emit electrons and a cooperating anode enclosed in an evacuated receptacle, means for producing by the signaling currents to be detected a flow of electrons from said cathode to said anode, and means for producing a variable magnetic field in a direction parallel to said cathode and thereby varying the current flow between cathode and anode.

36. A detector for high frequency signaling currents comprising a linear filamentary cathode adapted to be heated to incandescence to emit electrons and a cooperating anode enclosed in an evacuated receptacle, means for producing by the signaling currents to be detected a flow of electrons from said cathode to said anode, and a local source of alternating current of materially lower frequency than the frequency of the signaling currents to be detected and for producing a variable magnetic field in a direction parallel to said cathode thereby varying the number of electrons which will reach said anode from said cathode.

37. A detector for high frequency signaling currents comprising a linear filamentary cathode adapted to be heated to incandescence to emit electrons and a cooperating anode enclosed in an evacuated receptacle, means for producing by the signaling currents to be detected a flow of electrons from said cathode to said anode, a local source of current of a frequency slightly different from half the frequency of the signaling currents to be detected for producing a magnetic field in a direction parallel to said cathode and thereby varying the number of electrons which will reach said anode from said cathode.

38. A detector for high frequency signaling currents comprising an electron discharge apparatus having the characteristic that the current flowing therethrough is directly proportional to the impressed voltage, and means for periodically varying the value of the resistance of said apparatus.

39. A detector for high frequency signaling currents comprising an electron discharge apparatus having the characteristic that the current flowing therethrough is directly proportional to the impressed voltage, and means for periodically varying the value of the resistance of said apparatus between fixed maximum and minimum values.

40. A detector for high frequency signaling currents comprising an electron discharge apparatus having the characteristic that the current flowing therethrough is directly proportional to the impressed voltage, and means for producing a varying magnetic field for periodically varying the value of the resistance of said apparatus.

41. A detector for high frequency signaling currents comprising an electron discharge apparatus having the characteristic that the current flowing therethrough is directly proportional to the impressed voltage, and a local source of alternating current for producing a varying magnetic field for periodically varying the value of the resistance of said apparatus.

42. A detector for high frequency signaling currents comprising a resistance device having the characteristic that the current flowing therethrough is directly proportional to the impressed voltage, and a local source of current of a frequency slightly different from half the frequency of the signaling currents to be detected for periodically varying the value of said resistance.

43. A detector for high frequency signaling currents comprising a resistance device having the characteristic that the current flowing therethrough is directly proportional to the impressed voltage, and a local source of current of a frequency slightly different from half the frequency of the signaling currents to be detected for periodically varying the value of said resistance between fixed maximum and minimum values.

44. A detector for high frequency signaling currents comprising an evacuated envelope containing a linear filamentary cathode adapted to be heated to incandescence to emit electrons and an anode extending in a direction parallel to that of the cathode, and means for producing a variable magnetic field in a direction parallel to that of the cathode and thereby varying the flow of current from said cathode to said anode.

45. A detector for high frequency signaling currents comprising an evacuated envelope containing a linear filamentary cathode adapted to be heated to incandescence to emit electrons and an anode extending in a direction parallel to that of the cathode, means for producing by the signaling im-

pulses to be detected a flow of current from said cathode to said anode, and means for producing a variable magnetic field in a direction parallel to that of the cathode and thereby varying the flow of current from said cathode to said anode.

46. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing a filamentary cathode adapted to be heated to incandescence and a cooperating anode, both of which extend in a direction parallel to the axis of said receptacle, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, and means for producing a variable magnetic field in a direction parallel to the axis of said receptacle and thereby varying the flow of current from said cathode to said anode.

47. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing a filamentary cathode adapted to be heated to incandescence, and a cooperating anode, both of which extend in a direction parallel to the axis of said receptacle, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, and means for producing a variable magnetic field in a direction parallel to the axis of said receptacle and thereby varying the flow of current from said cathode to said anode.

48. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing a filamentary cathode adapted to be heated to incandescence and a cooperating anode, both of which extend in a direction parallel to the axis of said receptacle, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, a coil surrounding said receptacle, and means for supplying a variable current to said coil.

49. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing a filamentary cathode adapted to be heated to incandescence and a cooperating anode, both of which extend in a direction parallel to the axis of said receptacle, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, a coil surrounding said receptacle, and means supplying to said coil an alternating current of a frequency slightly different from half the frequency of the signaling currents to be detected.

50. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing an electron emitting cathode and an anode, a coil surrounding said receptacle, and means for supplying to said coil an alternating current of a frequency slightly different from half the frequency of the signaling currents to be detected.

51. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing an electron emitting cathode and an anode, and means for producing a magnetic field in a direction parallel to the axis of said receptacle, which varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected and whose maximum value is great enough to interrupt the current between cathode and anode.

52. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing an electron emitting cathode and an anode, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, and means for producing a periodically varying magnetic field in a direction parallel to the axis of said receptacle and thereby varying the flow of current from said cathode to said anode.

53. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing an electron emitting cathode and an anode, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, a coil surrounding said receptacle, and means for supplying a variable current to said coil.

54. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing an electron emitting cathode and an anode, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, a coil surrounding said receptacle, and means for supplying to said coil an alternating current of a frequency slightly different from half the frequency of the signaling currents to be detected.

55. A detector for high frequency signaling currents comprising a tubular evacuated receptacle containing an electron emitting cathode and an anode, means for producing by the signaling impulses to be detected a flow of current from said cathode to said anode, and means for producing a magnetic field in a direction parallel to the axis of said receptacle which varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

56. A detector for high frequency signaling currents comprising a pair of tubular evacuated receptacles each containing an electron emitting cathode and an anode, means for producing by means of signaling impulses an alternate flow of current through the two devices and means for producing simultaneously magnetic fields in directions

parallel to the axes of the two receptacles which vary between maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

57. A detector for high frequency signaling currents comprising a pair of tubular evacuated receptacles each containing an electron emitting cathode and an anode, means for producing by means of signaling impulses an alternate flow of current through the two devices, a coil surrounding each of said receptacles, and means for supplying current to said coils, for producing simultaneously magnetic fields in directions parallel to the axes of the two receptacles which vary between maximum and minimum values at a frequency slightly different from the frequency of the signaling currents to be detected.

58. A detector for high frequency signaling currents comprising a pair of tubular evacuated receptacles each containing an electron emitting cathode, and an anode, means for producing by signaling impulses to be detected an alternate flow of current through the two devices, coils surrounding both receptacles and means for simultaneously supplying a variable current to both coils.

59. A detector for high frequency signaling currents comprising a pair of tubular evacuated receptacles each containing an electron emitting cathode and an anode, means for producing by signaling impulses to be detected an alternate flow of current through the two devices, coils surrounding both receptacles and means for simultaneously supplying to both coils an alternating current of a frequency slightly different from half of the frequency of the signaling currents to be detected.

60. The method of detecting high frequency signaling currents which comprises impressing the currents to be detected upon a circuit containing a resistance and causing a locally produced current having a frequency slightly different from half the frequency of the signaling currents to periodically vary the value of the resistance.

61. The method of detecting a high frequency signaling current, which comprises impressing the current to be detected upon a circuit containing a resistance, producing a variable magnetic field and subjecting said resistance to the action of said magnetic field in such a way as to vary the value of the resistance in accordance with variations in the magnetic field.

62. The method of detecting a high frequency signaling current, which comprises impressing the current to be detected upon a circuit containing a resistance, utilizing a local source of high frequency current to produce a variable magnetic field and subjecting said resistance to the action of said magnetic field in such a way as to vary the value of the resistance in accordance with variations in the magnetic field.

63. The method of detecting a high frequency signaling current, which comprises impressing the current to be detected upon a circuit containing a resistance, utilizing a local source of high frequency current to produce a magnetic field which varies between maximum and minimum values at a frequency slightly different from the frequency of the signaling current, and subjecting said resistance to the action of said magnetic field in such a way as to vary the value of the resistance in accordance with variations in the magnetic field.

64. The method of receiving and translating into a signal radio frequency signal-representing energy, which comprises receiving the signal-representing energy, and rectifying the current thereof in a circuit whose impedance is always finite, independently generating an electromotive force varying in amplitude at predetermined frequency, producing variations of impedance of said circuit by said electromotive force, and translating into a signal the rectified current as modified by said impedance variation.

65. Receiving apparatus for translating radio frequency current comprising a circuit, a thermionic device comprising an anode and cathode in said circuit, said circuit being normally without current, means for impressing the received current upon said anode-cathode circuit, a translating instrument subjected to the modified received current in said circuit, and means for independently varying the impedance of said circuit for varying the amplitude of said current.

66. Receiving apparatus for translating radio frequency current comprising a circuit, a thermionic device, comprising an anode, cathode and field-producing means for varying the discharge between said anode and cathode, said anode and cathode being disposed in said circuit and said field-producing means being external to said circuit, means for independently varying said field for varying the amplitude of the modified current in said circuit, and a translating instrument subjected to said modified current of varying amplitude.

67. The method of receiving and translating into a signal radio frequency signal representing energy, which comprises receiving the signal representing energy, rectifying the current thereof in a circuit whose impedance is always finite, independently generating an electromotive force varying in amplitude at a predetermined frequency, utilizing the electromotive force thus generated to produce a field which is entirely independent of any field produced by signal representing

energy, producing by means of this field variations in the impedance of said circuit and translating into a signal the rectified current as modified by said impedance variation.

68. Receiving apparatus for translating radio frequency current comprising a circuit, means for impressing signal representing radio frequency currents upon said circuit, a thermionic device comprising an anode and a cathode included in said circuit, field producing means which are external to said circuit, means for varying said field exclusively by a local source of currents, and independently of any signal representing currents, and thereby varying the amplitude of the current in said circuit, and a translating instrument subjected to said current of varying amplitude.

In witness whereof, I have hereunto set my hand this 12th day of September, 1919.

ERNST F. W. ALEXANDERSON.

DEFENDANT'S EXHIBIT No. 294.

Oct. 20, 1925 1,558,437

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. 29, 1913 2 Sheets-Sheet 1

Fig 1

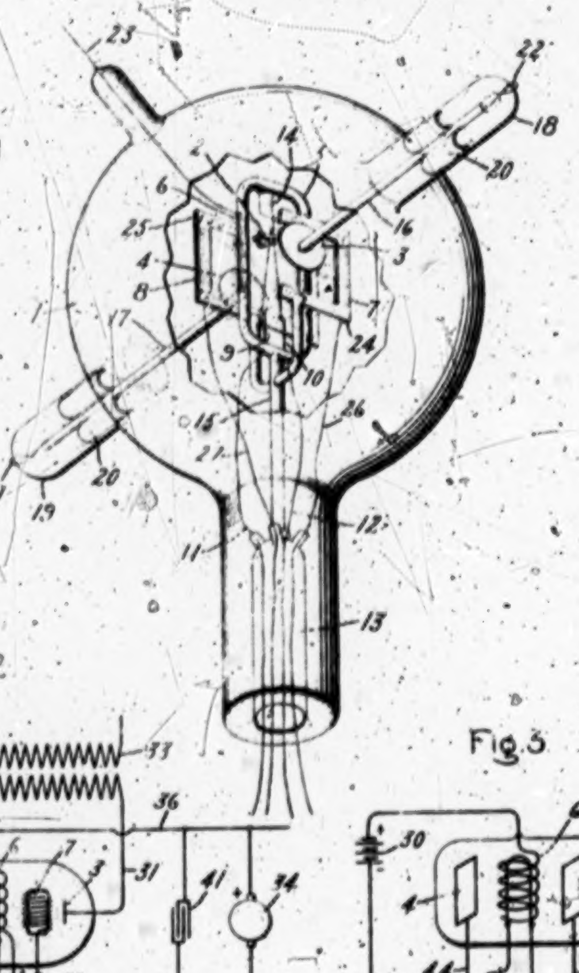

23
22
18
14
2
6
25
4
8
3
16
20
7
24
17
1
9
10
15
26
21
20
21
19
11
12
13

Fig. 2

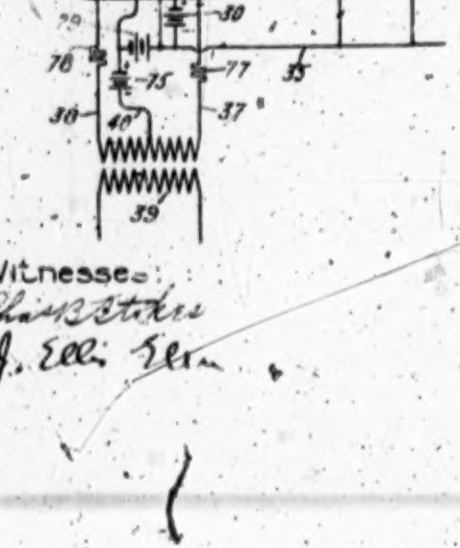
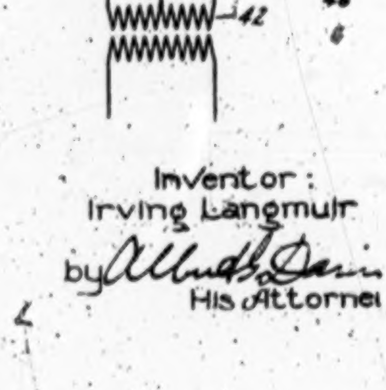

33
36
32
8
2
6
7
3
31
41
34
29
30
76
75
77
35
38
40
37
39

Fig. 3


30
6
4
3
44
43
45
29
46
42

Witnesses:
Chas B. Stokes
J. Ellis Glen

Inventor:
Irving Langmuir
by Albert G. Davis
His Attorney

Oct. 20 1925 1,558,437

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. 29, 1913 2 Sheets-Sheet 2

Fig. 4.

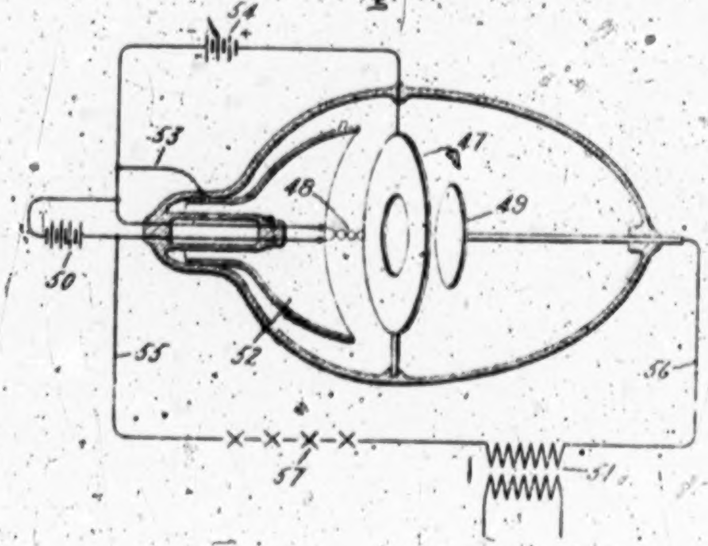
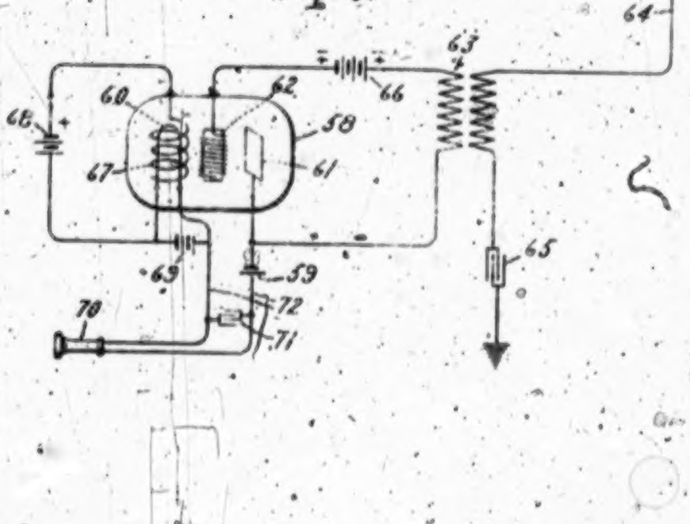

54
53
47
48
49
50
55
52
56
57
51

Fig. 5.


64
63
66
62
60
68
58
67
61
69
59
65
72
70
71

Witnesses:
George H. Tilden
J. Ellis Elen

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney

Patented Oct. 20, 1925. 1,558,437

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRICAL DISCHARGE APPARATUS.

Application filed October 29, 1913, Serial No. 797,986. Renewed February 29, 1924.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical Discharge Apparatus, of which the following is a specification.

The present invention relates to electrical discharge apparatus operating with an electron discharge and it concerns particularly the type of device operating without gas ionization and conduction.

Such a device consists essentially of an electron-emitting cathode, and one or more anodes thoroughly freed from gas, located in an envelope evacuated to such a high degree that an electron discharge can take place from the cathode to the anode or anodes without causing appreciable gas ionization by collision with residual gas molecules.

A pure electron discharge consists of negative charges of electricity, ordinarily called "electrons", moving from a cathode to an anode in a highly evacuated space. These electrons may be emitted by a highly incandescent solid or by certain metals illuminated by ultraviolet light, particularly the alkali metals. As each of these electrons is surrounded by a negative electrostatic field and, also when in motion, by a magnetic field, the motion of the electrons is subject to the influence of both electrostatic and electromagnetic forces. For this reason each of the electrons in a given space is influenced by the field of the other electrons in this space, an effect which will hereinafter be referred to as the "space charge". I have found that the effect of the "space charge" is to limit the current flowing with a given voltage to a value which is independent of the temperature of the cathode above a certain value. This limiting current is dependent upon the geometrical shape of the electrodes, the distance between the electrodes, and other factors. A negatively charged body located in the vicinity of the cathode will reduce the electron discharge current with a given impressed voltage and may also deflect the electrons dependent upon its position and configuration.

Some of the objects of the present invention are: to reduce the effect of the space charge in an electron discharge device; to modify or eliminate the effect of negatively charged bodies in the proximity of the cathode; to increase the discharge current with a given voltage; to furnish electrons having a relatively uniform velocity and to protect the cathode itself from mechanical injury or distortion by electrostatic forces.

With these objects in view the electron discharge apparatus is provided with a conductor located in the vicinity of the cathode and maintained at a predetermined positive potential. This conductor ordinarily assumes the form of a wire grid or grating surrounding the cathode and it is connected to a continuously maintained source of potential, preferably of low voltage.

My invention will be more fully explained in the following description taken in connection with the accompanying drawings in which Fig. 1 shows in perspective a discharge apparatus embodying my invention and suitable for converting direct current into alternating current; Figs. 2, 3 and 5 are diagrams illustrating various electrical systems of connection utilizing an electron discharge device made in accordance with my invention, and Fig. 4 illustrates a modified form of apparatus in which a positively charged plate is used instead of a grid.

In the electron discharge device shown in Fig. 1, the enclosing globe 1 has been shown as partly broken away to disclose the interior arrangement of the electrodes comprising a V-shaped filamentary cathode 2 and plate-shaped anodes 3 and 4. Surrounding the cathode is a frame 5, consisting conveniently of glass, upon which is wound fine wire constituting a grid 6 with closely adjacent turns surrounding the cathode 2. Located respectively between this grid and each of the anodes are grids 7 and 8, the function of which will be hereinafter explained.

The cathode conductor is attached to terminal supports 9 and 10 which are in turn connected to leading-in wires 11 and 12, sealed into the stem 13 of the enclosing globe in the usual manner. The cathode filament is maintained taut by being anchored by its bight by means of the spring 14 attached to the frame 5. The electrodes and grid wires consists preferably of ductile tungsten. The cathode and grids are all carried by glass stems attached to a pedestal 15. The anode stems 16 and 17 consist of tungsten or molybdenum and are held in position in the extensions 18 and 19 of the bulb by springs 20, which grip the walls of the bulb. Connection is made to the anodes in the usual manner by the leading-in wires 21 and 22. Connection to the grid surrounding the cathode is made by a leading-in wire 23. The grids 7 and 8 are preferably wound upon metallic frames 24 and 25 consisting, for example, of ferro-chrome which thus short-circuit the turns of the gird. Electrical connection is made thereto by conductors 26 and 27. The relative position of the anodes the cathode and the grids is more clearly indicated in a diagrammatic manner in Fig. 3; Fig. 1 illustrates particularly the structural features.

As shown in Figs. 2 and 3, the cathode 2 is maintained at incandescence by means of a battery 29, or other suitable externally located source of energy. The surrounding grid 6 is attached to the positive terminal of a source of potential, for example a battery 30, the negative terminal of which is connected to the cathode.

The discharge device is evacuated to the highest obtainable vacuum, the electrodes being freed from gas by operating the device while on the pump at a voltage below the value at which harmful gas ionization, as indicated by blue glow, takes place. As gas is driven out of the anode by electron bombardment, the impressed voltage is progressively increased, the removal of gas by the pump being continued. The impressed voltage thus attained before sealing-off should ordinarily be higher than the voltage at which the device is intended to operate. The degree of vacuum in the completed device while depending somewhat upon the character of the device should ordinarily be as low as a few hundred thousandths of a millimeter of mercury, preferably even lower.

The system shown in Fig. 2 is adapted particularly for the conversion of direct current into alternating current and for this purpose the anodes 3 and 4 are connected by means of conductors 31, 32 to the primary winding of a transformer 33. Energy is supplied by a direct current source of energy 34, for example, a dynamo, or a battery connected at its negative terminal by means of conductor 35 to the cathode and at its positive terminal by means of conductor 36 to an intermediate point upon the primary of the transformer 33. The grids 7 and 8 are connected by means of the conductors 37 and 38, to a source of alternating current 39 having the frequency desired for the alternating current to be produced by the device. This source has been diagrammatically indicated as a transformer altho of course any suitable alternating current source may be used. The cathode 2 is connected by means of a conductor 40 to an intermediate point on the secondary of the transformer 39.

The operation of the system above described is as follows:—When the cathode 2 is brought to incandescence it emits electrons, which travel under the influence of the impressed electromotive force to a positive electrode. When, however, a conductor, located between the cathode and an anode between which electrons are passing, is negatively electrified, the electrons are repelled in accordance with the degree of negative charge, thereby decreasing or interrupting entirely the discharge current. On the other hand, when a conductor, located between an electron-emitting cathode and an anode, is positively electrified the discharge is assisted and the current increased. Some of the electrons go to the positively charged conductor, but when this conductor has a relatively small obstructing surface, as in the case when a fine filament serves as the grid or other conducting body, very little energy will be absorbed thereby. For example, a tungsten wire having a diameter of about .0004 to .0010 of one inch wound with about 100 turns to the inch may be used but the turns per inch vary widely. When the impressed electromotive force between cathode and anode is high the amount of energy lost by the absorption of electrons by a grid having a relatively low positive charge is negligible.

As the grids 7 and 8 are made alternately negative and positive by the alternating source 39, the discharge current, or stream of negative charges, passes in turn to anodes 3 and 4, thereby setting up an alternating current in the primary of the transformer 33, and in that manner repeating in the divided output circuit, acting as the primary of the transformer, with amplified energy the electric waves in the divided input circuit, acting as the secondary of the transformer 39. If desired, a condenser 41 may be provided in order to absorb current variations and to neutralize the inductive effect of the transformer and provide a more rapid rise and fall of current. At any given instant either of input electrodes 7 or 8 will be negatively charged, and being in close proximity to the cathode, will tend to reduce the electron current flowing. However, when a positive field is established in the vicinity of the filament by the grid 6, this grid screens the cathode from the negative field, and assists the flow of electron current, thus making possible the combination of two repeating elements in a single electron discharge apparatus. The electrons are emitted by the cathode at variable speed but all being subject to the same static field which greatly increases the speed of all an equal amount, the differences of speed represent a relatively small fraction of the impressed resultant speed. As the positive field near the cathode opposes the current-reducing effect of the space charge, the distance between the cathode and the anodes may be increased without sacrifice of efficiency.

Some energy is lost by the absorption of the electrons by the positively charged grid 6 but as its surface is small and the positive potential may be made relatively small as compared with the voltage impressed between the cathode and the anodes, this loss will form but a relatively small proportion of the total amount of energy in the output circuit.

It is desirable that the rise of static potential of the grid becoming negative should be rapid so as to shut off the flow of electron current completely to its corresponding anode. This result can be effected by making the alternating source 39 of high potential, but this also increases the positive charge on the companion grid. A high positive grid potential increases the absorption of energy by the grid. By including a battery 75 or other source of potential in the conductor 40 connected to the cathode and an intermediate point of the secondary of the transformer 39, with its negative terminal connected to the transformer, the potential on the grid negatively charged is increased, and the potential on the grid positively charged is diminished, providing, of course, that the potential of the source 75 does not exceed the potential of the source 39. If desired resistances 77, 78, may be included in the grid circuits 37, 38, or these resistances may be replaced by a single resistance in conductor 40 to reduce current flow therein without reducing the potential. In some cases such resistances may make a separate superimposed negative potential unnecessary.

In the system illustrated by Fig. 3, an electron discharge tube is employed to rectify alternating current furnished by the primary of a transformer 42, the terminals of which are connected to the anodes 3 and 4, respectively, by conductors 43, and 44. The conductor 45 of the direct current consumption circuit is connected to the cathode 2 and the conductor 46 of the direct current circuit is connected to a point of intermediate potential upon the secondary of the transformer 42. It will be observed that the electrodes 3 and 4 will be in turn made positive and negative, current passing from the cathode to the positive electrode. Here likewise the electrode which is connected to the opposite terminal of the source, and hence is negative, would act to cut down the current passing from the cathode to the positive electrode. This effect, however, is prevented by the positively charged grid 6. In the case of a rectifier having a plurality of electrodes functionating as anodes, the current-reducing effect of the electrodes when negatively charged is especially marked as the drop of potential in the direct current load will reduce the potential of the positive electrode which is taking current. As no current is flowing to a negative electrode, it will have the full potential of the source. For this reason also the mechanical distortion of the cathode located in the unsymmetrical field would be serious were the positive grid 6 not present, whereby the cathode is screened and protected.

The positively charged body need not necessarily be grid-shaped. Fig. 4 illustrates somewhat diagrammatically a rectifying device in which a plate 47 is located between an electron-emitting cathode 48 and an anode 49. Heating current is supplied the cathode conductor by a battery 50, and a source of energy for example, a transformer 51 is connected between the cathode and the anode. Surrounding the cathode is a concave dished plate 52, which is maintained negatively charged, conveniently by connecting it to the cathode by means of a conductor 53. This ring serves to modify the static field so as to focus the electrons into a fairly well-defined stream which passes through an aperture in the plate 47 to the anode.

By maintaining the plate 47 positively charged, for example, by means of a battery 54, the passage of the electrons from the cathode to the anode is assisted. The potential of the battery 54 and hence the charge on the plate 47, may be only a fraction of the potential between supply conductors 55, 56. The electrons will be attracted to the plate 47 but will largely pass through the aperture in the same as this represents the center of static attraction. By making the potential of the plate 47 relatively low the loss of energy by the absorption of electrons on the part of the plate 47 will be relatively small, and will be more than compensated by the increase in discharge current. The rectified current may be utilized by load devices 57. If it is desired to utilize both half waves of the alternating current, two sets of the devices illustrated are used in any well-known manner, such, for example, as that disclosed in Arsem Patent #929,371, or Alexanderson Patent #996,445.

As indicated in Fig. 5 the positively charged conductor may be used to advantage in a device for amplifying or repeating weak variable currents, such as signals in radio-telegraphy, or telephony. The repeater or electron discharge tube 58 is provided with a local source of energy, for example a battery 59, which may be of very low voltage, and is connected between the cathode 60 and the anode 61. The grid 62 and the cathode 60 are connected to the secondary of a transformer 63, the primary of which is included in the antenna circuit. The latter has as usual an aerial antenna 64, and a grounded condenser 65. The grid 62 may be maintained at a definite potential by a battery 66. The cathode is surrounded by a grid 67, maintained at a perdetermined positive potential with respect to the cathode by a battery 68. When the cathode is heated by a local source of energy 69, a current will tend to flow from the cathode to the anode but this current is either prevented from flowing or is greatly reduced when the field of the grid 62 is negative. As the electrons are drawn away from the cathode 60 by the positive field furnished by the grid 67, a very low voltage may be used in the plate circuit, in fact, I prefer in some cases to use but a single cell for the battery 59, as indicated. A negative potential on the grid 62 on the other hand may be made relatively high. The current variations in the electrode circuit 72 due to the signal impulses impressed upon the grid circuit, are correspondingly great. The signals may be received by a telephone 70, or other suitable receiver, connected in shunt with a condenser 71.

The sensitiveness of this arrangement is especially marked as the electrons leave the grid 67 at substantially uniform velocity and hence are all affected to an equal extent by the variations in the negative charge of the grid 62.

What I claim as new and desire to secure by Letters Patent of the United States is:—

1. A discharge apparatus operating with an electron discharge comprising a highly evacuated envelope, an electron-emitting cathode, an anode, a conductor therein located near the cathode, means for maintaining said conductor at a substantially uniform positive potential with respect to said cathode, and separate means within said envelope for varying the electron discharge between said cathode and anode.

2. An electrical discharge apparatus, comprising an electron-emitting cathode, an anode, an envelope therefor, said electrodes and the space in said envelope being freed from gas to a degree permitting a substantially pure electron-discharge to take place therein without gas ionization, a conducting body in said envelope located near the cathode, and a source of potential having its positive terminal connected to said body and its negative terminal directly to the cathode.

3. An electron discharge device comprising a highly evacuated container, a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a conductor located in part at least between said cathode and anode, means for maintaining said conductor at a uniform positive potential with respect to the cathode, and independent means for establishing an electrostatic field to control an electron discharge between cathode and anode.

4. An electrical discharge apparatus comprising an evacuated container, an electron-emitting cathode, a cooperating anode and a conductor in part surrounding the cathode, means for maintaining said conductor at a uniform positive polarity with respect to the cathode, and means for producing a negative charge in the vicinity of said cathode.

5. The combination of an electron discharge device comprising an evacuated container, an electron-emitting cathode, an anode, a conductor coiled about said cathode but spaced apart therefrom, and a source of potential having its positive terminal connected to the said conductor and its negative terminal connected directly to the cathode.

6. The combination of an electron-discharge apparatus comprising a cathode, means for heating said cathode, cooperating anodes located on opposite sides of said cathode, a grid surrounding the cathode but spaced apart therefrom, a source of potential having its positive terminal connected to said grid, grids located respectively between said surrounding grid and the anodes, and a source of alternating potential connected to said intermediate grids.

7. The combination of a discharge device, comprising an envelope, an electron-emitting cathode and an anode, a conductor located near said cathode, means for maintaining said conductor at a positive potential with respect to said cathode, a second conductor located near said cathode, and means for maintaining said second conductor at a negative potential with respect to said cathode.

8. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor surrounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said transformer primary, charge-controlling conductors located between said cathode and said anode, and means for charging said conductors alternately negative and positive.

9. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor

surrounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said tranformer primary, charge-controlling conductors located between said cathode and said anodes, a source of alternating current connected to said charge-controlling conductors and a source of direct current connected at the positive terminal to said cathode and at the negative terminal to a point of intermediate potential on said alternating current source.

10. The combination with an electron discharge device comprising a cathode and a pair of input electrodes enclosed in an evacuated envelope, a transformer secondary having its terminals connected to said input electrodes, a source of direct current having its positive terminal connected to said cathode and its negative terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

11. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence and a pair of input electrodes enclosed in an evacuated envelope of a transformer secondary having its terminals connected to said input electrodes, a source of direct current having one terminal connected to said cathode and its other terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

12. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence, a pair of anodes and a pair of input electrodes enclosed in an evacuated receptacle, said input electrodes being located between said cathode and said anodes, means for maintaining both of said input electrodes normally at a definite potential with respect to said cathode which is different than that of the cathode, and means for charging said input electrodes alternately negative and positive.

13. An electron-discharge device comprising an evacuated vessel containing a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a discharge controlling electrode and a fourth electrode near said cathode, means for producing a current between said cathode and said anode, and means for maintaining said fourth electrode at a definite potential with respect to said cathode.

14. A device of the audion type comprising a thermionic cathode, an anode and an auxiliary electrode, means for supporting said auxiliary electrode, said cathode being filamentary in form, and a planary supporting frame therefor parallel to one of said electrodes and comprising spaced parallel members.

15. Parallel supporting members, and a filamentary thermionic cathode insulatingly supported at a plurality of points thereby, a grid frame at each side of said cathode, and an arbor for supporting said members and said frames.

16. A device of the audion type comprising parallel grids, a support therebetween comprising spaced parallel members, and a cathode extending between said members and supported thereby.

17. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

18. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a positive potential with respect to the cathode, means for maintaining the grid nearest the anode at a negative potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

19. The combination of an electron discharge device comprising an electron emitting cathode, an anode, and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, means for varying the potential of the grid nearest the anode with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that impressed upon the grid nearest the cathode.

20. The combination of an electron discharge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, and means for varying the potential of the other grid with respect to the cathode.

21. The combination of an electron dis-

charge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, means for varying the potential of the other grid with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that at which the first of said grids is maintained.

22. An evacuated vessel containing a filament electrode and a cold electrode, a second cold electrode located between the filament and the first cold electrode, and a third cold electrode located between the filament and second cold electrode.

23. An evacuated vessel containing a filament electrode and a plate electrode, a grid electrode interposed between the filament and the plate electrode, and a second grid electrode interposed between the first grid electrode and the filament.

24. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode surrounding said cathode and a second grid electrode outside of said first grid electrode, a stem through which leading-in conductors for at least two of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

25. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

26. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, and a support of insulating material within said vessel for supporting all of said electrodes.

27. An electron discharge device comprising an electron emitting cathode, an anode, a pair of grid electrodes located in different planes between said cathode and said anode, an evacuated vessel, and a support of insulating material for supporting the cathode and grid electrodes in desired spaced relation within said vessel.

28. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids located in different planes and successively passed by the electron stream.

29. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids which are successively passed by the electron stream.

30. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container, and supporting means for supporting all of said electrodes from a single point in said container.

31. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container and supporting means for supporting all of said electrodes from a single point in said container, said supporting means being arranged to insulate all of said electrodes from one another.

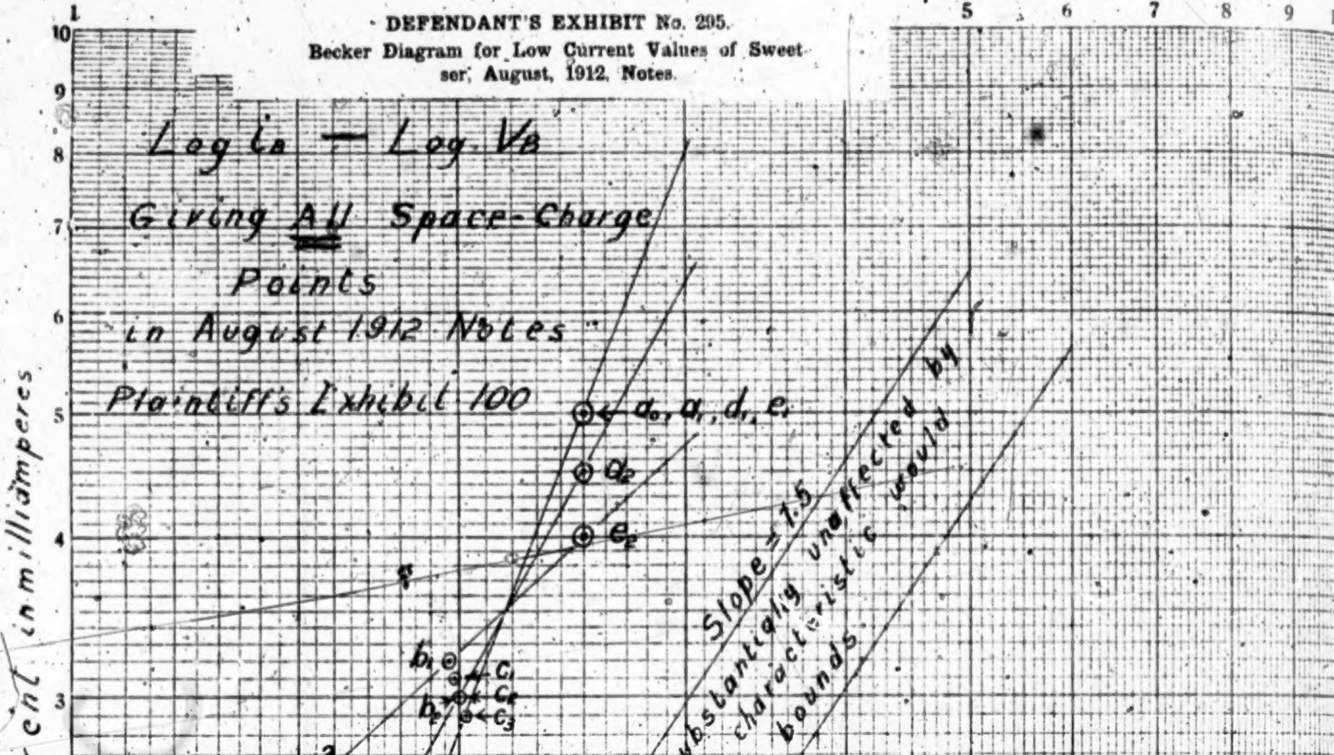
32. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting a plurality of said electrodes from said stem.

33. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting all of said electrodes from said stem.

In witness whereof, I have hereunto set my hand this 27th day of October 1913.

IRVING LANGMUIR.

DEFENDANT'S EXHIBIT No. 295.
Becker Diagram for Low Current Values of Sweetser, August, 1912, Notes.



Point	Page	Pressure	
a_0	1177	.52	Microns
a_1	"	.366	"
d_2	1178	.336	"
b_1	"	.536	"
b_2	"	.430	"
c_1	1179	.71 - .51	"
c_2	"	.454	"
c_3	"	.430	"
d_1	1186	.397	"
e_1	1187	.522	"
e_2	"	.298	"

DEFENDANT'S EXHIBIT No. 296.

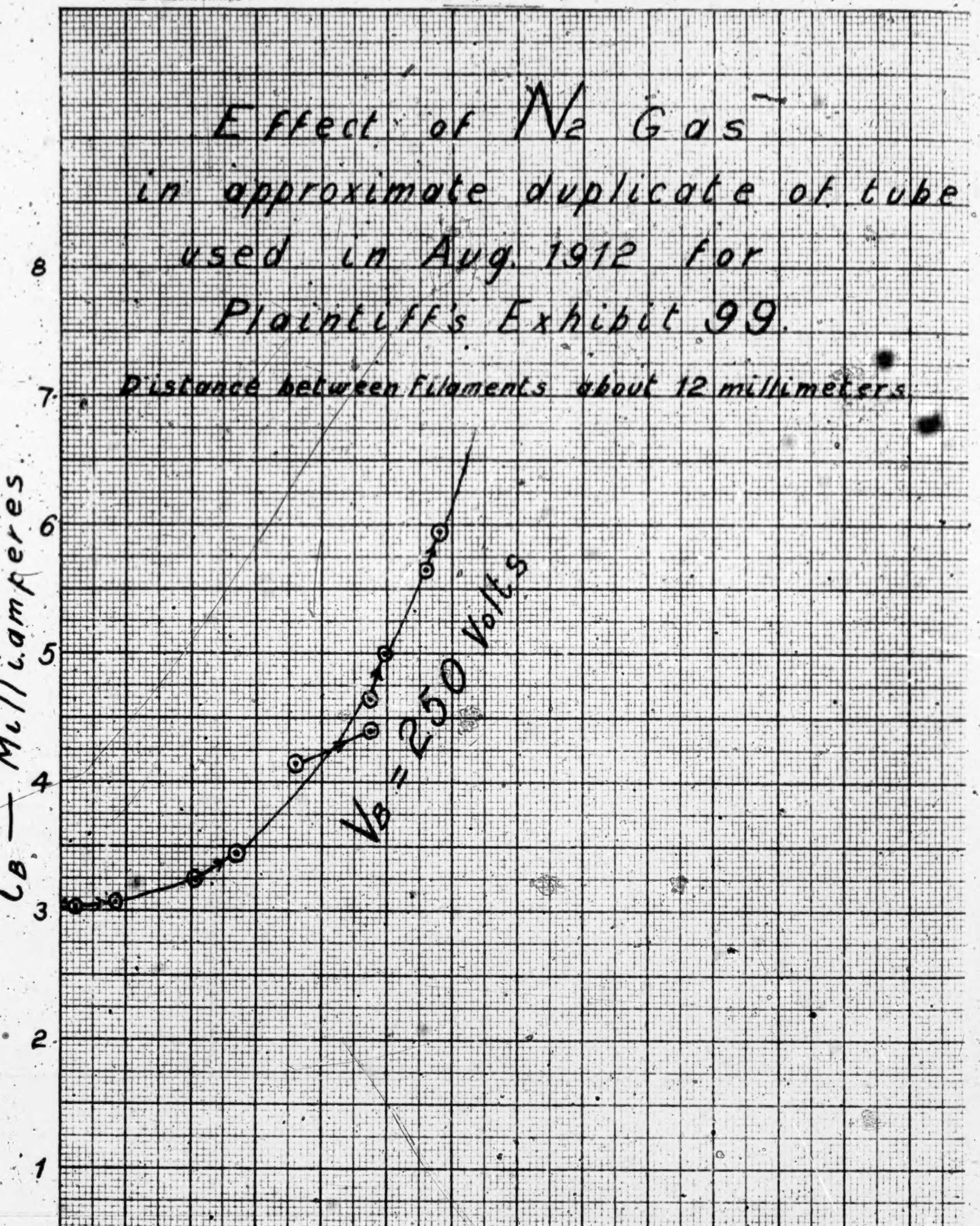
Becker Approximate Duplicate of Sweetser Tube,
August, 1912.

DEFENDANT'S EXHIBIT No. 297.

Becker Diagram for Current-Pressure-Relation in Tube Defendant's Exhibit No. 296.

BELL TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES



Effect of N_2 Gas in approximate duplicate of tube used in Aug. 1912 for Plaintiff's Exhibit 99.

Distance between filaments about 12 millimeters.

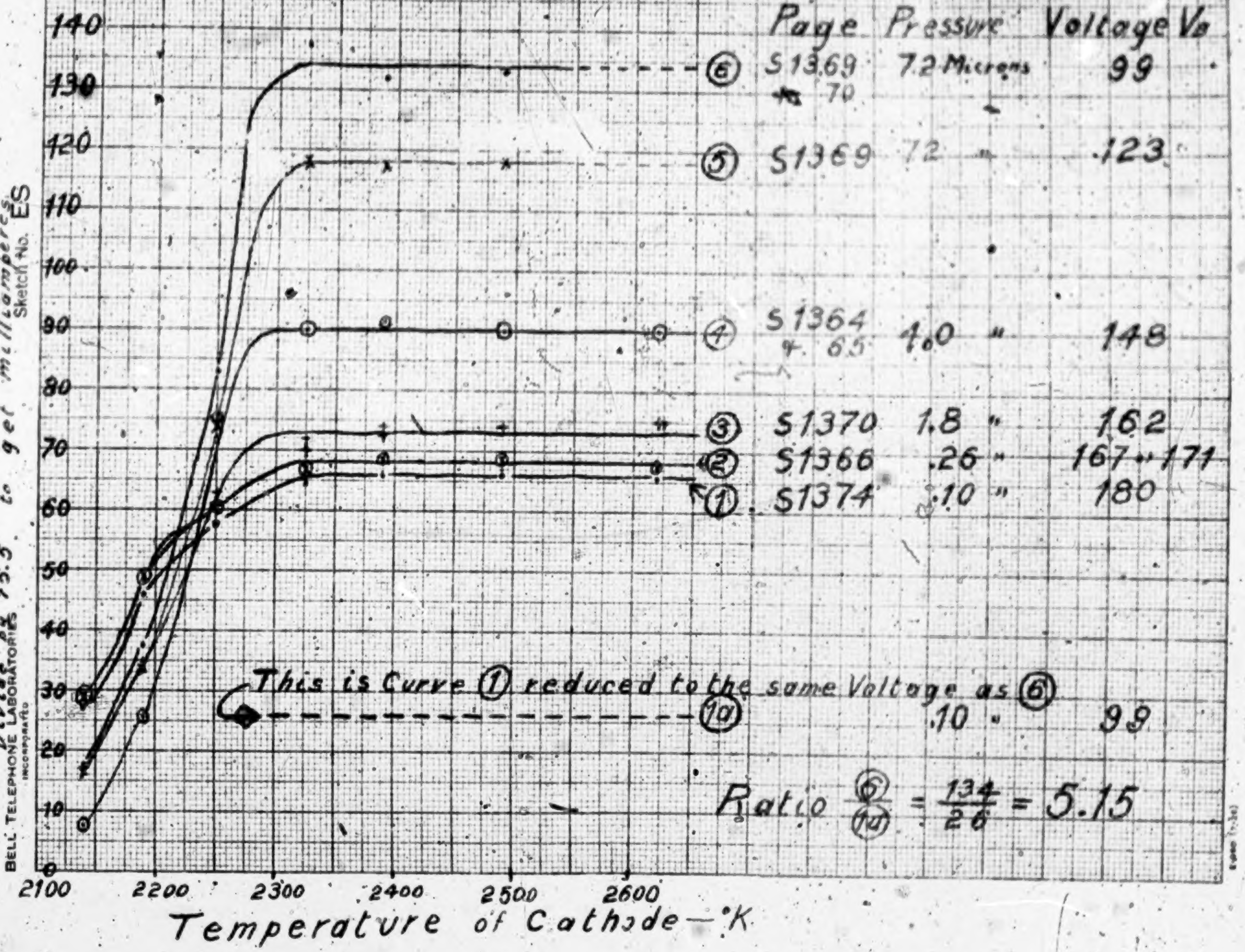
DEFENDANT'S EXHIBIT No. 298.

Becker Current Temperature Diagrams for Hydrogen for Sweetser Notes for November and December 1912.

Flat-topped Current-Temperature Curves.

Compiled from Plaintiff's Exhibit 100 (Dec. 1912) for Hydrogen.

Distance between filaments about 3 millimeters.

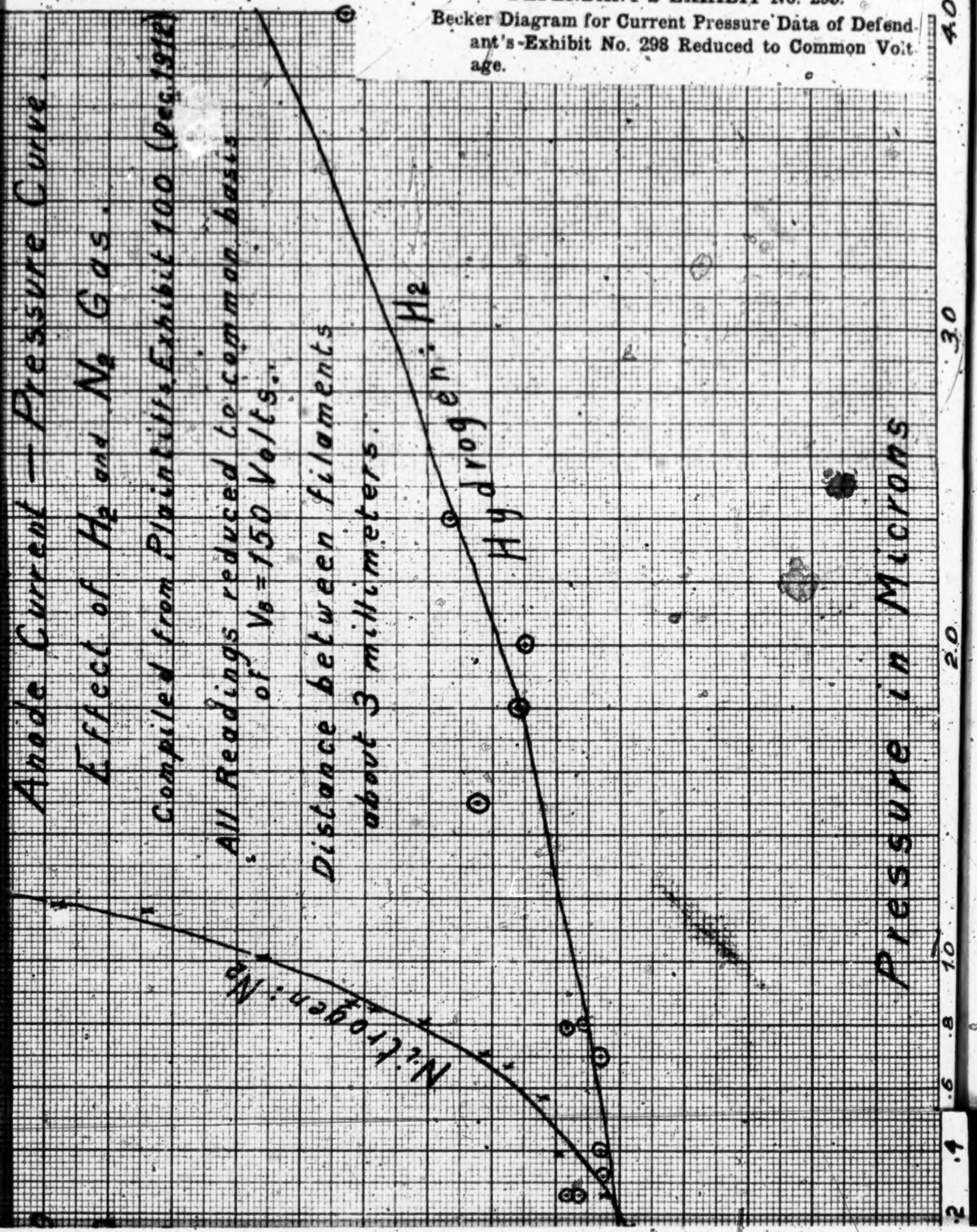


	Page	Pressure	Voltage Va
⑥	S1369 + 70	7.2 Microns	99
⑤	S1369	7.2 "	123
④	S1364 + 65	4.0 "	148
③	S1370	1.8 "	162
②	S1366	.26 "	167 + 171
①	S1374	.10 "	180
⑩		.10 "	99

$$\text{Ratio } \frac{⑥}{⑩} = \frac{134}{26} = 5.15$$

DEFENDANT'S EXHIBIT No. 299.

Becker Diagram for Current Pressure Data of Defendant's Exhibit No. 298 Reduced to Common Voltage.



DEFENDANT'S EXHIBIT No. 300.

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper, Contents and Drawings, in the matter of the

Letters Patent of

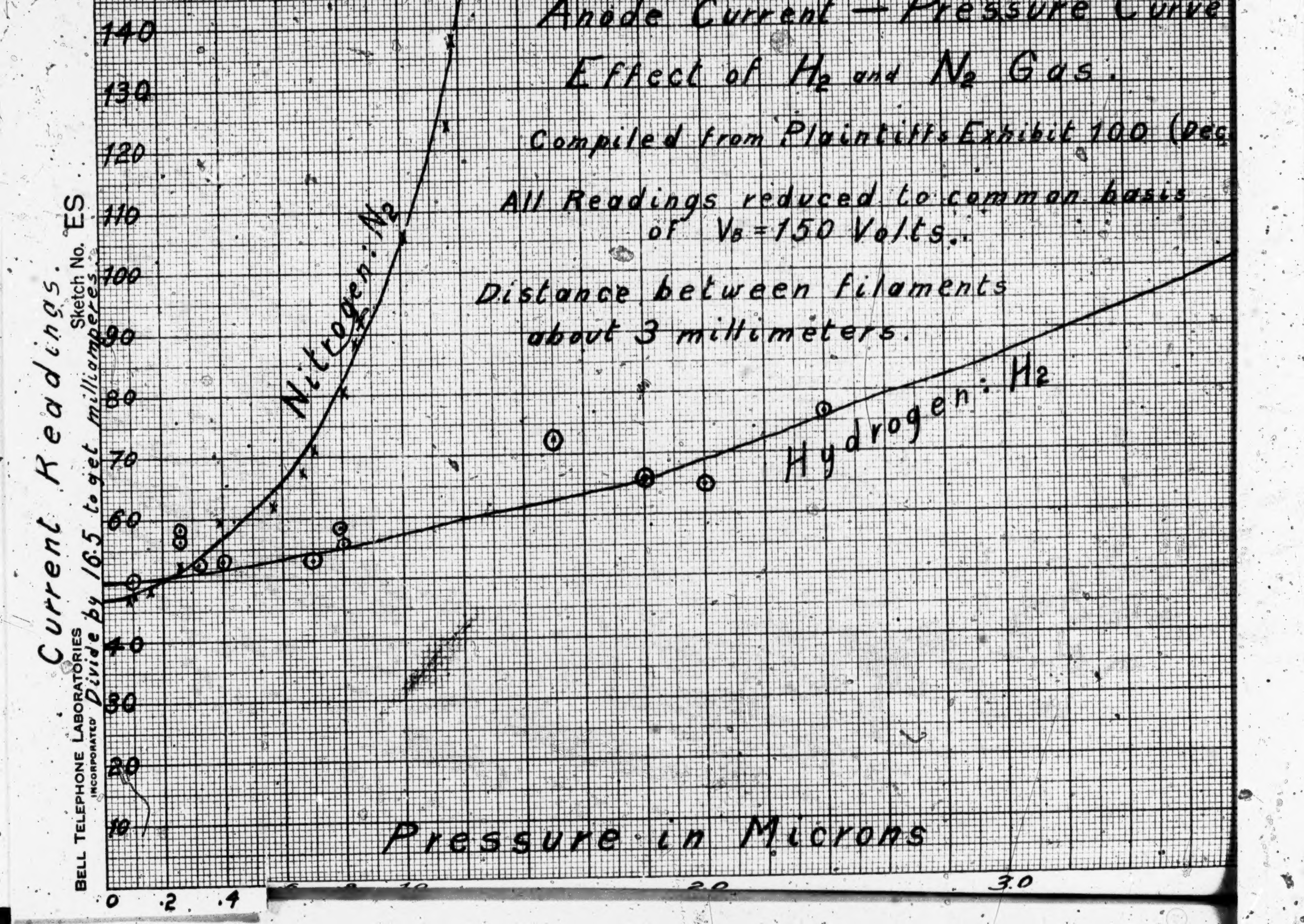
Irving Langmuir, Assignor to
General Electric Company,

Number 1,558,437, Granted October 20, 1925,

for
Improvement in Electrical Discharge Apparatus.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-seventh day of October in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

ATTEST: Willis B Magruder


Anode Current — Pressure Curve
Effect of H_2 and N_2 Gas.
Compiled from Plaintiffs Exhibit 100 (Dec
All Readings reduced to common basis of V_B = 150 Volts.
Distance between filaments about 3 millimeters.
Nitrogen: N_2
Hydrogen: H_2
Current Readings.
Divide by 16.5 to get milliamperes
Pressure in Microns
140
130
120
110
100
90
80
70
60
40
30
20
10
0
.2
.4
2.0
3.0
BELL TELEPHONE LABORATORIES INCORPORATED
Sketch No. ES

DEFENDANT'S EXHIBIT No. 300.

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of the File Wrapper, Contents and Drawings, in the matter of the

Letters Patent of

Irving Langmuir, Assignor to
General Electric Company,

Number 1,558,437, Granted October 20, 1925,

for
Improvement in Electrical Discharge Apparatus.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-seventh day of October in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

ATTEST: Willis B Magruder
Chief of Division.

Thomas E. Robertson
Commissioner of Patents.

GOVERNMENT PRINTING OFFICE
11—5639

RENEWAL

1208

NUMBER (Series of 19~~15~~20),

797,986

1917

(EX'R'S BOOK) ~~9-1-6~~ 2-1-1

DIV. ~~76~~ 51

PATENT No. 1558437

Name Irving Langmuir
Assor. to General Electric Company,
a Corp of N. Y.

of Schenectady

County of

State of New York

Invention Electrical Discharge Apparatus

PARTS OF APPLICATION FILED	ORIGINAL		RENEWED	
Petition	Oct 29	, 1913	FEB 29 1924	, 191
Affidavit		, 1913		, 191
Specification		, 1913		, 191
Drawing 2 sheets		, 1913		, 191
Photo Copy	Oct 29 Jan 23 1921	, 1913		, 191
First Fee Cash	$15 Oct 29	, 1913	$20 FEB 29 1924	, 191
" " Cert.		, 191		, 191
Appl. filed complete	Oct 29	, 1913	FEB 29 1924	, 191

Examined and Passed for Issue	April 19, 1922		Mch 24, 1924
O. W. Bowen	Exr. Div. 16		Exr. Div. 51
Notice of Allowance	Apr 20 1922 By Commissioner.	Mar 24	, 1924 By Commissioner
Final Fee Cash	, 191	$20 Sept 24	, 1924
" " Cert.	, 191		, 191

Patented , 191

Attorney Albert G. Davis, c/o Genl Electric Co.,
Schenectady N. Y.

Associate Attorney Alexander D. Lunt
c/o Gen. Elec. Co., Schenectady, N. Y.

(No. of) Claims Allowed ~~22~~ 33 Title as Allowed Electrical Discharge Apparatus

Clms 1, 2, 15 & 33 in O.G.
O.K. H.H.S.

(Cl. ~~25~~ - 2.

DIV. ~~31~~ 16 26 ~~27~~ ~~16~~ 51 **1913** 1209

NUMBER (Series of 1900), (EX'R'S BOO ~~1~~ ~~250~~

~~9-1-6~~ 2-1-1 ~~117~~

797,986 **PATENT No.**

Name Irving Langmuir

Assor to General Electric Company
a corp of N. Y.

of Schenectady,

County of

State of New York

Invention Electrical Discharge Apparatus

Division of App., No. , *Filed* , 191

PARTS OF APPLICATION FILED.

	ORIGINAL	RENEWED
Petition	Oct. 29, 1913.	Feb. 29 1924, 191
Affidavit	" ", 1913.	, 191
Specification	" ", 1913.	, 191
Drawing 2 sheets	" ", 1913	, 191
Photo Copies	Oct. 29, 1913. Jan. 23, 1920 Dec. 15, 1919	, 191
First Fee Cash	$15 Oct. 29, 1913.	$20 Feb. 29, 1924, 191
" " *Cert*	, 191	, 191
Appl. filed complete	Oct 29, 1913	Feb. 29, 1924, 191
Examined and Passed for Issue	Apr. 19, 1922	Mar 24, 1925
	C D Backus *Exr. Div.* 16	D Dhorkus *Exr. Div.* 51
Notice of Allowance	Apr. 20, 1922 By Commissioner	Mar 24, 1925
Final Fee Cash	, 191	, 191
" " *Cert*	, 191	112 , 191
Patented		, 191

Attorney Albert G. Davis, c/o Gen'l Electric Co.
Schenectady N. Y.

Associate Attorney Alexander D. Lunt c/o Gen'l Elec Co.,
Schenectady N. Y.

(*No. of Claims Allowed* ~~23~~ 33) *Title as Allowed* Electrical Discharge Apparatus

Claims 1 & 22 in O. G. 2, 15 Cl. 250-27

O. K. H. C.

1210

C

PETITION

To the Honorable Commissioner of Patents:

Your petitioner Irving Langmuir

a citizen of the United States, residing at Schenectady

in the County of Schenectady State of New York

whose Post Office address is c/o General Electric Co., Schenectady N. Y.

prays that Letters Patent may be granted him for the improvement in

Electrical Discharge Apparatus (Docket No. 18,481)

set forth in the accompanying specification.

And he further prays that you will recognize Mr. Albert G. Davis, of Schenectady, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith

Irving Langmuir

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN, that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, County of Schenectady, State of New York, have invented certain new and useful improvements in ELECTRICAL DISCHARGE APPARATUS, of which the following is a specification.

The present invention relates to electrical discharge apparatus operating with an electron discharge and it concerns particularly the type of device operating without gas ionization and conduction.

Such a device consists essentially of an electron-emitting cathode, and one or more anodes thoroughly freed from gas, located in an envelope evacuated to such a high degree that an electron discharge can take place from the cathode to the anode or anodes without causing appreciable gas ionization by collision with residual gas molecules.

A pure electron discharge consists of negative charges of electricity, ordinarily called "electrons", moving from a cathode to an anode in a highly evacuated space. These electrons may be emitted by a highly incandescent solid or by certain metals illuminated by ultraviolet light, particularly the alkali metals. As each of these electrons is surrounded by a negative electrostatic field and, also when in motion, by a magnetic field, the motion of the electrons is subject to the influence of both electrostatic and electromagnetic forces. For this reason each of the electrons in a given space is influenced by the field of the other electrons in this space, an effect which will hereinafter be referred to as the "space charge". I have found that the effect of the "space charge" is to limit the current flowing with a given voltage to a value which is independent of the temperature of the cathode above a certain value. This limiting current is dependent upon the geometrical shape of the electrodes, the distance between the electrodes, and other factors. A negatively charged body located in the vicinity of the cathode will reduce the electron discharge current with a given impressed voltage and may also deflect the electrons dependent upon its position and configuration.

Some of the objects of the present invention are: to reduce the effect of the space charge in an electron discharge device; to modify or eliminate the effect of negatively charged bodies in the proximity of the cathode; to increase the discharge current with a given voltage; to furnish electrons having a relatively uniform velocity and to protect the cathode itself from mechanical injury or distortion by electrostatic forces.

With these objects in view the electron discharge apparatus is provided with a conductor located in the vicinity of the cathode and maintained at a predetermined positive potential. This conductor ordinarily assumes the form of a wire grid or grating surrounding the cathode and it is connected to a continuously maintained source of potential, preferably of low voltage.

My invention will be more fully explained in the following description taken in connection with the accompanying drawings in which Fig. 1 shows in perspective a discharge apparatus embodying my invention and suitable for converting direct current into alternating current; Figs. 2, 3 and 5 are diagrams illustrating various electrical systems of connection utilizing an electron discharge device made in accordance with my invention, and Fig. 4 illustrates a modified form of apparatus in which a positively charged plate is used instead of a grid.

In the electron discharge device shown in Fig. 1, the enclosing globe 1 has been shown as partly broken away to disclose the interior arrangement of the electrodes comprising a V-shaped filamentary cathode 2, and plate-shaped anodes 3 and 4. Surrounding the cathode is a frame 5, consisting conveniently of glass, upon which is wound fine wire constituting a grid 6 with closely adjacent turns surrounding the cathode 2. Located respectively between this grid and each of the anodes are grids 7 and 8, the function of which will be hereinafter explained.

29

The cathode conductor is attached to terminal supports 9 and 10 which are in turn connected to leading-in wires 11 and 12, sealed into the stem 13 of the enclosing globe in the usual manner. The cathode filament is maintained taut by being anchored by its bight by means of the spring 14 attached to the frame 5. The electrodes and grid wires consist preferably of ductile tungsten. The cathode and grids are all carried by glass stems attached to a pedestal 15. The anode stems 16 and 17 consist of tungsten or molybdenum and are held in position in the ~~extension~~ extensions 18 and 19 of the bulb by springs 20, which grip the walls of the bulb. Connection is made to the anodes in the usual manner by the leading-in wires 21 and 22. Connection to the grid surrounding the cathode is made by a leading-in wire 23. The grids 7 and 8 are preferably wound upon metallic frames 24 and 25 consisting, for example, of ferro-chrome which thus short-circuit the turns of the grid. Electrical connection is made thereto by conductors 26 and 27. The relative position of the anodes the cathode and the grids is more clearly indicated in a diagrammatic manner in Fig. 2; Fig. 1 illustrates particularly the structural features.

In a

As shown in Figs. 2 and 3, the cathode 2 is maintained at incandescence by means of a battery 29, or other suitable externally located source of energy. ~~the negative terminal being connected to the cathode.~~ The surrounding grid 6 is attached to the positive terminal of a source of potential, for example a battery 30, the negative terminal of which is connected to the cathode.

The discharge device is evacuated to the highest obtainable vacuum, the electrodes being freed from gas by operating the device while on the pump at a voltage below the value at which harmful gas ionization, as indicated by blue glow, takes place. As gas is driven out of the anode by electron bombardment, the impressed voltage is progressively increased, the removal of gas by the pump being continued. The impressed voltage thus attained before sealing-off should ordinarily be higher than the voltage at which the device is intended to operate. The degree of vacuum in the completed device while depending somewhat upon the character of the device should ordinarily be as low as a few hundred thousandths of a millimeter of mercury, preferably even lower. ~~Novel features of the device and its method of preparation are described and claimed in my copending applications Serial Nos. filed~~

The system shown in Fig. 2 is adapted particularly for the conversion of direct current into alternating current and for this purpose the anodes 3 and 4 are connected by means of conductors 31, 32 to the primary winding of a transformer 33. Energy is supplied by a direct current source of energy 34, for example, a dynamo, or a battery connected at its negative terminal by means of conductor 35 to the cathode and at its positive terminal by means of conductor 36 to an intermediate point upon the primary of the transformer 33. The grids 7 and 8 are connected by means of the conductors 37 and 38, to a source of alternating current 39 having the frequency desired for the alternating current to be produced by the device. This source has been diagrammatically indicated as a transformer altho of course any suitable alternating current source may be used. The cathode 2 is connected by means of a conductor 40 to an intermediate point on the secondary of the transformer 39.

The operation of the system above described is as follows:- When the cathode 2 is brought to incandescence it emits electrons, which travel under the influence of the impressed electromotive force to a positive electrode. When, however, a conductor, located between the cathode and an anode between which electrons are passing, is negatively electrified, the electrons are repelled in accordance with the degree of negative charge, thereby decreasing or interrupting entirely the discharge current. On the other hand, when a conductor, located between an electron-emitting cathode and an anode, is positively electrified the discharge is assisted and the current increased. Some of the electrons go to the positively charged conductor, but when this conductor has a relatively small obstructing surface, as in the case when a fine filament serves as the grid or other conducting body, very little energy will be absorbed thereby. For example, a tungsten wire having a diameter of about .0004 to .0010 of one inch wound with about 100 turns to the inch may be used but the turns per inch vary widely. When the impressed electromotive force between cathode and anode is high the amount of energy lost by the absorption of electrons by a grid having a relatively low positive charge is negligible.

117

As the grids 7 and 8 are made alternately negative and positive by the alternating source 39, the discharge current, or stream of negative charges, passes in turn to anodes 3 and 4, thereby setting up an alternating current in the primary of the transformer 33, Ⓒ B' If desired a condenser 41 may be provided in order to absorb current variations and to neutralize the inductive effect of the transformer and provide a more rapid rise and fall of current. At any given instant either ~~grid~~ of input electrodes 7 or 8 will be negatively charged, and being in close proximity to the cathode, will tend to reduce the electron current flowing. However, when a positive field is established in the vicinity of the filament by the

Per B

Insert B'

B

Insert B²

grid 6, this grid screens the cathode from the negative field, and assists the flow of electron current. ③/B The electrons are emitted by the cathode at variable speed but all being subject to the same static field which greatly increases the speed of all an equal amount, the differences of speed represent a relatively small fraction of the impressed resultant speed. As the positive field near the cathode opposes the current-reducing effect of the space charge, the distance between the cathode and the anodes may be increased without sacrifice of efficiency.

Some energy is lost by the absorption of the electrons by the positively charged grid 6 but as its surface is small and the positive potential may be made relatively small as compared with the voltage impressed between the cathode and the anodes, this loss will form but a relatively small proportion of the total amount of energy in the output circuit.

Ret B

It is desirable that the rise of static potential of the grid becoming negative, should be rapid so as to shut off the flow of electron current completely to its corresponding anode. This result can be effected by making the alternating source 39 of high potential but this also increases the positive charge on the commutation grid. A high positive grid potential increases the absorption of energy by the grid. By including a battery 75 or other source of potential in the conductor ~~76~~ 40 connected to the cathode and an intermediate point of the secondary of the transformer 39, with its negative terminal connected to the transformer, the potential on the grid negatively charged is increased, and the potential on the grid positively charged is diminished, providing, of course, that the potential of the source 75 does not exceed the potential of the source 39. If desired resistances 77, 78, may be included in the grid circuits 37, 38, or these resistances may be replaced by a single resistance in conductor 40 to reduce current flow therein without reducing the potential. In some cases such resistances may make a separate superimposed negative potential unnecessary.

In the system illustrated by Fig. 3, an electron discharge tube is employed to rectify alternating current furnished by the primary of a transformer 42, the terminals of which are connected to the anodes 3 and 4, respectively, by conductors 43 and 44. The conductor 45 of the direct current consumption circuit is connected to the cathode 2 and the conductor 46 of the direct current circuit is connected to a ~~neutral~~ point of intermediate potential upon the secondary of the transformer 42. It will be observed that the electrodes 3 and 4 will be in turn made positive and negative, current passing from the cathode to the positive electrode. Here likewise the electrode which is connected to the opposite terminal of the source, and hence is negative, would act to cut down the current passing from the cathode to the positive electrode. This effect, however, is prevented by the positively charged grid 6. In the case of a rectifier having a plurality of electrodes functionating as anodes, the current-reducing effect of the electrodes when negatively charged is especially marked as the drop of potential in the direct current load will reduce the potential of the positive electrode which is taking current. As no current is flowing to a negative electrode, it will have the full potential of the source. For this reason also the mechanical distortion of the cathode located in the unsymmetrical field would be serious were the positive grid 6 not present, whereby the cathode is screened and protected.

The positively charged body need not necessarily be grid-shaped. Fig. 4 illustrates somewhat diagrammatically a rectifying device in which a plate 47 is located between an electron-emitting cathode 48 and an anode 49. Heating current is supplied the cathode conductor by a battery 50, and a source of energy for example, a transformer 51 is connected between the cathode and the anode. Surrounding the cathode is a concave dished plate 52, which is maintained negatively charged, conveniently by connecting it to the cathode by means of a conductor 53. This ring serves to modify the static field so as to focus the electrons into a fairly well-defined stream which passes through an aperture in the plate 47 to the anode.

By maintaining the plate 47 positively charged, for example, by means of a battery 54, the passage of the electrons from the cathode to the anode is assisted. The potential of the battery 54 and hence the charge on the plate 47, may be only a fraction of the potential between supply conductors 55, 56. The electrons will be attracted to the plate 47 but will largely pass through the aperture in the same as this represents the center of static attraction. By making the potential of the plate 47 relatively low the loss of energy by the absorption of electrons on the part of the plate 47 will be relatively small, and will be more than compensated by the increase in discharge current. The rectified current may be utilized by load devices 57. If it is desired to utilize both half waves of the alternating current, two sets ~~[illegible]~~ of the devices illustrated are used. ④ C'

iC
rt C'

As indicated in Fig. 5 the positively charged conductor may be used to advantage in a device for amplifying or repeating weak variable currents, such as signals in radio-telegraphy, or telephony. The repeater or electron discharge tube 58 is provided with a local source of energy, for example a battery 59, which may be of very low voltage, and is connected between the cathode 60 and the anode 61. The grid 62 and the cathode 60 are connected to the secondary of a transformer 63, the primary of which is included in the antenna circuit. The latter has as usual an aerial antenna 64, and a grounded condenser 65. The grid 62 may be maintained at a definite potential by a battery 66. The cathode is surrounded by a grid 67, maintained at a predetermined positive potential with respect to the cathode by a battery 68. When the cathode is heated by a local source of energy 69, a current will tend to flow from the cathode to the anode but this current is either prevented from flowing or is greatly reduced when the field of the grid 62 is negative. As the electrons are drawn away from the cathode 60 by the positive field furnished by the grid 67, a very low voltage may be used in the plate circuit, in fact, I prefer in some cases

iB
B

to use but a single cell for the battery 59, as indicated. A negative potential on the grid 62 on the other hand may be made relatively high. The current variations in the electrode circuit 72 due to the signal impulses impressed upon the grid circuit, are correspondingly great. The signals may be received by a telephone 70, or other suitable receiver, connected in shunt with a condenser 71.

The sensitiveness of this arrangement is especially marked as the electrons leave the grid 67 at substantially uniform velocity and hence are all affected to an equal extent by the variations in the negative charge of the grid 62.

What I claim as new and desire to secure by Letters Patent of the United States is:- m

In a
Sub. C²
Cl!
" a Sub C
" a
add a'

1. ~~The combination of a~~ A discharge apparatus operating with ~~an~~ electron discharge comprising a highly evacuated envelope, an electron-emitting cathode, ~~and~~ an anode, a conductor therein located near the cathode, ~~and~~ mea for maintaining said conductor at a substantially uniform positive potential, a 1

2. An electrical discharge apparatus, comprising an electron-emitting cathode, an anode, an envelope therefor, said electrodes and the space in said envelope being freed from gas to a degree permitting a substantially pure electron-discharge to take place therein without gas ionization, a conducting body in said envelope located near the cathode, and a source of potential having its positive terminal connected to said body and its negative terminal directly to the cathode.

a
135
C
Insert C³
a
a
add a²

3. An electron discharge device comprising a highly evacuated container, a ~~an electron-emitting~~ cathode, C³ an anode, a conductor located in part at least between said cathode and anode, ~~and~~ means for maintaining said conductor at a uniform positive potential with respect to the cathode, a 2 (3)

4. An electrical discharge apparatus comprising an evacuated container, an electron-emitting cathode, a cooperating anode and a conductor in part surrounding the cathode, means

for maintaining said conductor at a uniform positive polarity with respect to the cathode, and means for producing a negative charge in the vicinity of said cathode.

Pu A

5. The combination of an electron discharge device comprising an evacuated container, an electron-emitting cathode, an anode, a conductor coiled about said cathode but spaced apart therefrom, and a source of potential having its positive terminal connected to thesaid conductor and its negative terminal connected directly to the cathode.

a

a

6. The combination of an electron-discharge apparatus comprising a cathode, means for heating said cathode, cooperating anodes located on opposite sides of said cathode, a grid surrounding the cathode but spaced apart therefrom, a source of potential having its positive terminal connected to said grid, grids located respectively between said surrounding grid and the anodes, and a source of ~~means to sources of~~ alternating potential connected to said intermediate grids.

C

7. The combination of a discharge device, comprising an envelope, an electron-emitting cathode and an anode, a conductor located near said cathode means for maintaining said conductor at a positive potential with respect to said cathode ~~anode~~, a second conductor located near said cathode, and means for maintaining said second conductor at a negative potential with respect to said cathode.

8. The method of operating an electron

~~discharge apparatus comprising an electron-emitting cathode and an anode located in a space evacuated to such degree that gas ionization is substantially absent, which consists in subjecting the electrons emitted by the cathode first to a static field positive with respect to said cathode and then controlling the motion of the electrons by a field independent of said positive field.~~

sul C4

C4

e A3

Ic

IN WITNESS WHEREOF, I have hereunto set my hand this 27th day of October 1913.

WITNESSES.

WCG/W Saul Dushman
Helen Oxford

Irving Langmuir

1225

AFFIDAVIT

STATE OF New York }
COUNTY OF Schenectady } SS:

Irving Langmuir, the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Schenectady, in the County of Schenectady, State of New York, and that he verily believes himself to be the original, first, and sole inventor of the improvements in

Electrical Discharge Apparatus

described and claimed in the annexed specification; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any foreign country on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any foreign country.

Irving Langmuir

Sworn to and subscribed before me this 27th

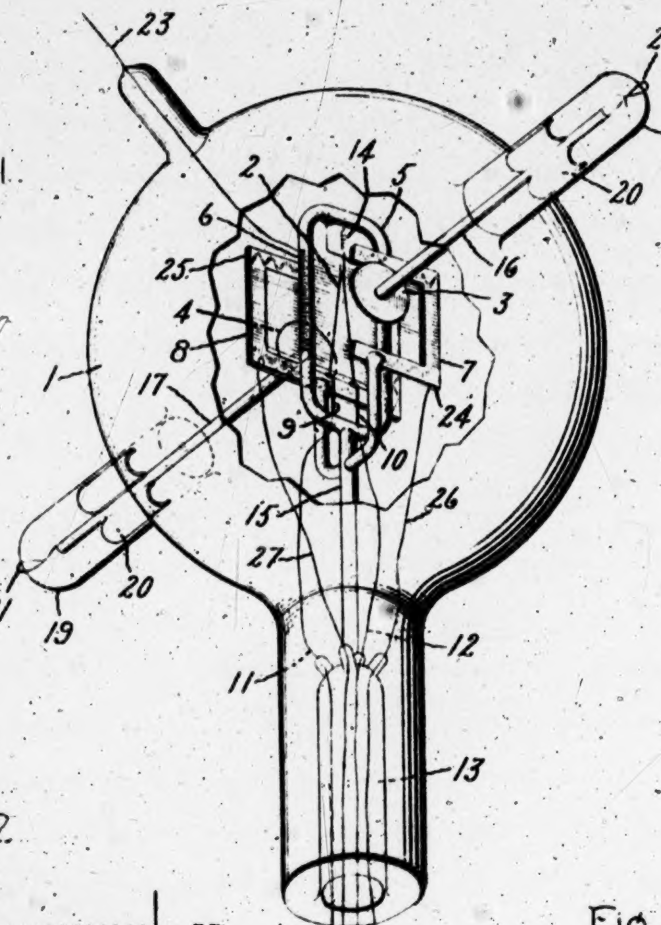
day of October, 1913

Helen D. Vogel
Notary Public

Cert Appln as filed 4000

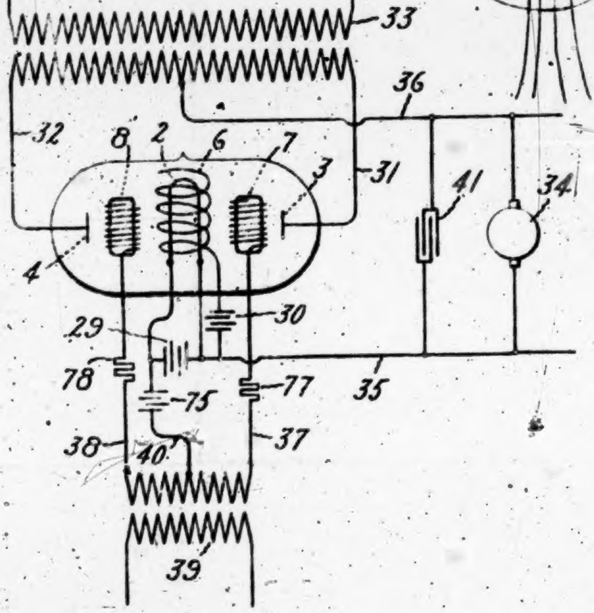
GO-181 500 7-29-12

Fig. 1.



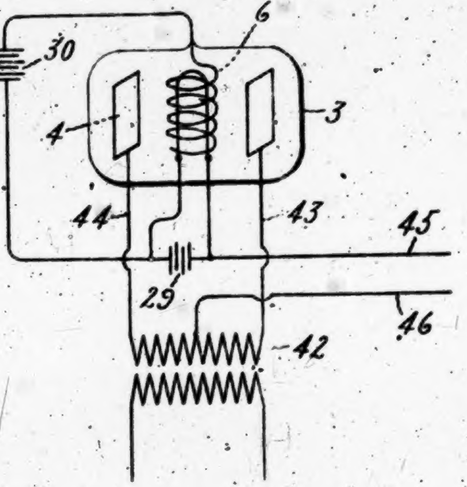
23
22
18
14
5
2
6
20
16
25
3
4
8
7
1
17
24
9
10
15
26
27
21
20
19
12
11
13

Fig. 2.



33
36
32
8
2
6
7
3
31
41
34
4
30
29
78
77
35
75
38
40
37
39

Fig. 3.



6
30
3
4
44
43
45
29
46
42

Witnesses:
Chas B Stokes
J. Ellis Glen.

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

Fig. 4.

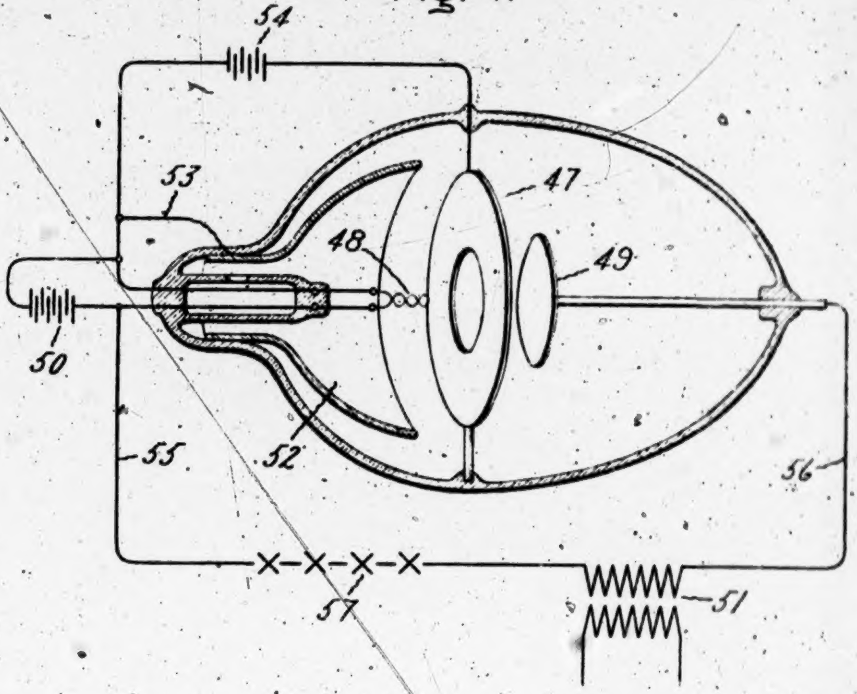
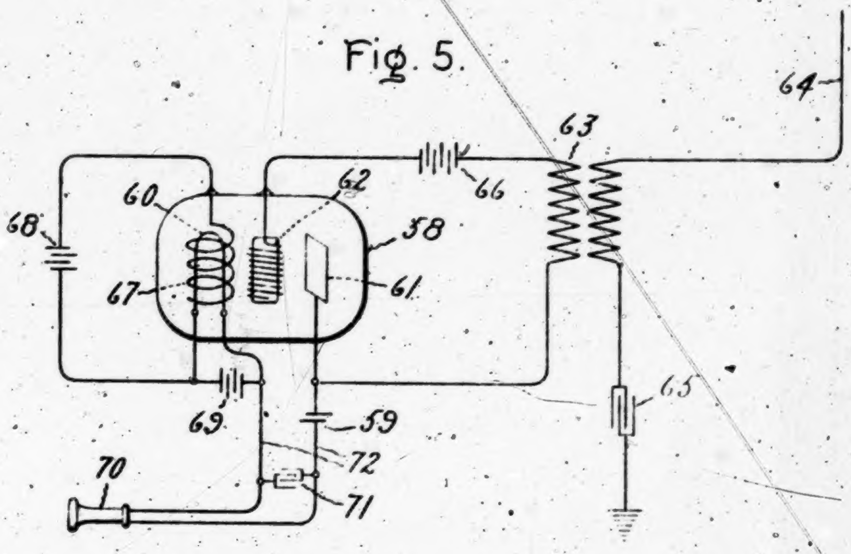

54
53
48
47
49
50
52
55
56
57
51

Fig. 5.


64
63
66
62
60
68
58
67
61
65
69
59
72
70
71

Witnesses:

George H. Tilden

J. Ellis Glen.

Inventor

Irving Langmuir,

by Albert G. Davis

His Attorney.

DEFENDANT'S EXHIBIT No. 301.

DEPARTMENT OF COMMERCE

UNITED STATES PATENT OFFICE

To all persons to whom these presents shall come, Greeting:

THIS IS TO CERTIFY that the annexed is a true copy from the records of this office of Amendment B, filed November 29, 1915, in the matter of the

Letters Patent of

Irving Langmuir, Assignor to
General Electric Company,

ber 1,558,437, Granted October 20, 1925,

for

Improvement in Electrical Discharge Apparatus.

IN TESTIMONY WHEREOF I have hereunto set my hand and caused the seal of the Patent Office to be affixed, at the City of Washington, this twenty-sixth day of October in the year of our Lord, one thousand nine hundred and twenty-six and of the Independence of the United States of America the one hundred and fifty-first.

ATTEST: Willis B. Magruder.
Chief of Division.

Thomas E. Robertson
Commissioner of Patents.

GOVERNMENT PRINTING OFFICE
11—8626

PAPER NO. 3
AMENDMENT B

UNITED STATES PATENT OFFICE

In re Application of :
IRVING LANGMUIR, :
Serial No. 797,986, : ELECTRICAL DISCHARGE APPARATUS
Filed October 29, 1913, :
Div. 16, Room 109. :

13470

B

Honorable Commissioner of Patents,

Sir:-

In response to the Office Action of October 12, 1915, please amend the above-entitled application as follows:-

Page 6, line 22, after "current" add - or stream of negative charges, -

Line 24, after "transformer 33" change the period to a comma and add - and in that manner repeating in the divided output circuit, acting as the primary of the transformer, with amplified energy the electric waves in the divided input circuit, acting as the secondary of the transformer 39. -

B1

Line 28, cancel "grid" and substitute - of input electrodes -

Page 7, line 2, after "current" change the period to a comma and add - thus making possible the combination of two repeating elements in a single electron discharge apparatus. -

B2

Line 19, after "energy" (and before the period) insert - in the output circuit -

Page 10, line 10, after "amplifying" insert - or repeating -

Line 11, before "electron" insert - repeater or -

Add the following claims:

FC5
B3

11. An electric wave repeating apparatus comprising divided input and divided output circuits, means for producing two ionized streams, said streams being oppositely included in said output circuit, and two electrodes for controlling said ionized streams respectively and oppositely connected in said input circuit.

12. An electric wave repeating apparatus comprising divided input and divided output circuits, means for producing an ionized stream included in each division of said output circuit, and electrodes one in each division of said input circuit for controlling said ionized streams respectively.

13. An electric wave repeating apparatus comprising input and output circuits and two vacuum discharge repeater elements oppositely connected in said circuits, whereby the positive and negative portions of electric waves in said input circuit are repeated by said repeater elements respectively in said output circuit.

14. In an electric wave repeating apparatus, the combination with input and output circuits, of two vacuum discharge repeater elements oppositely connected in said circuits whereby one of said elements is adapted to repeat certain parts, and the other, the remaining parts of said input waves.

15. In an electric wave repeating apparatus, the combination of two repeating elements comprising ionizing means, an anode and an input electrode for each said element, an input repeating coil the secondary winding of which is connected at an intermediate

~~point to said ionizing means and at its opposite terminals to said input electrodes respectively.~~

~~16. In an electric wave repeating apparatus, the combination of two repeating elements comprising ionizing means and an anode and an input electrode for each said element, an input repeating coil and an output repeating coil, the secondary winding of said input repeating coil being divided and the divisions connected to said input electrodes respectively, and the primary winding of said output repeating coil being divided and the divisions connected to said repeating elements respectively.~~

~~17. In an electric wave repeating apparatus, the combination with input and output circuits and a repeating coil in each of said circuits, of two repeating elements together comprising a common source of ionization, an anode for each said element, and two input electrodes, said source of ionization being connected to an intermediate point in the secondary winding of the input repeating coil and also to an intermediate point in the primary winding of the output repeating coil, the opposite terminals of said secondary winding being connected to said input electrodes respectively, and the opposite terminals of said primary winding being connected to said anodes respectively.~~

REMARKS

The above amendment is made for the purpose of securing an interference between the present application and U. S. patent No. 1,128,292 issued to Edwin Henry Colpitts on February 16, 1915, and filed on January 3, 1914, subsequent to the filing of the present application. Each claim of patent No. 1,128,292 has been copied for the purpose of contesting priority.

It is requested that the prosecution of the application be suspended until the termination of the interference.

Respectfully submitted,

Albert G. Davis

Attorney for Langmuir.

Schenectady, N. Y.
November 27, 1915.

WGG/GAL

DEFENDANT'S EXHIBIT No. 302.

E. F. W. ALEXANDERSON.

TELEPHONE SYSTEM.

APPLICATION FILED APR. 14, 1913.

1,102,628. **Patented July 7, 1914.**

3 SHEETS-SHEET 1.

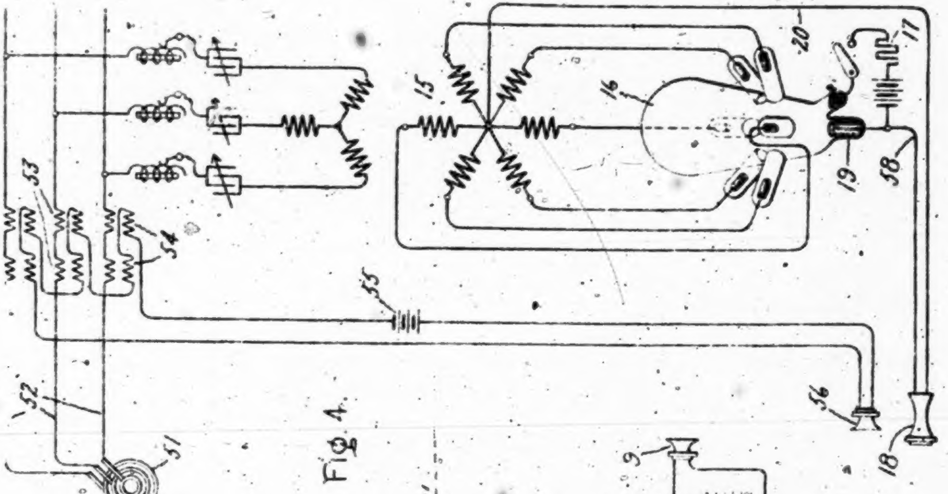

15
16
20
17
19
58
53
54
55
56
18
52
51

Fig. 4.

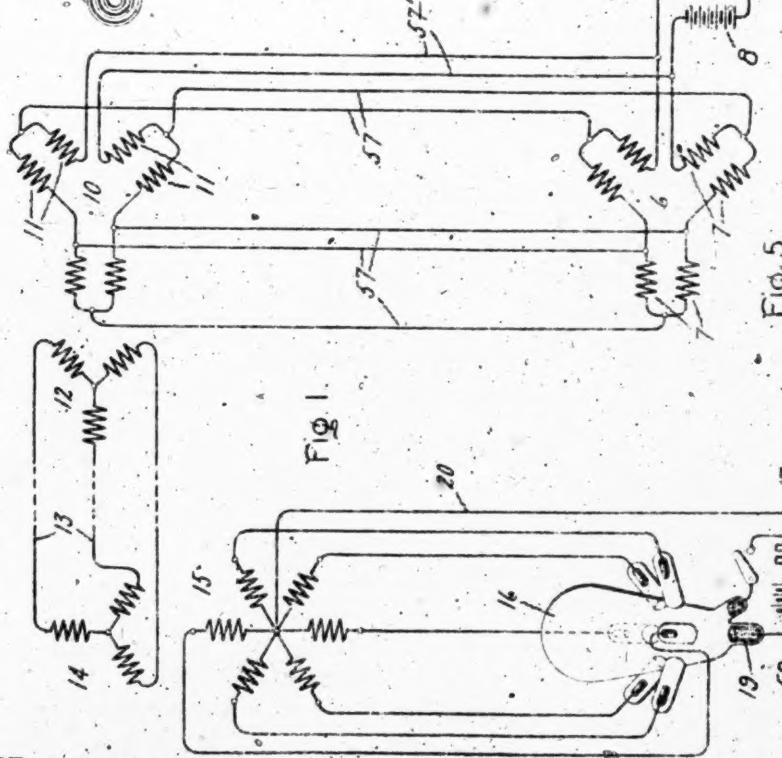

9
8
57'
57
57
57
10
11
11
6
7
7
12
13
14
15
16
20
17
19
58
18

Fig. 1

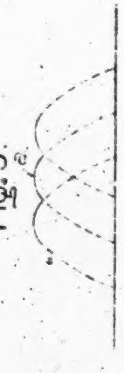


Fig. 5.

WITNESSES:
J. Earl Ryan
J. Ellis Glen

INVENTOR:
ERNST F. W. ALEXANDERSON,
BY Albert G. Davis
HIS ATTORNEY.

1234

E. F. W. ALEXANDERSON.

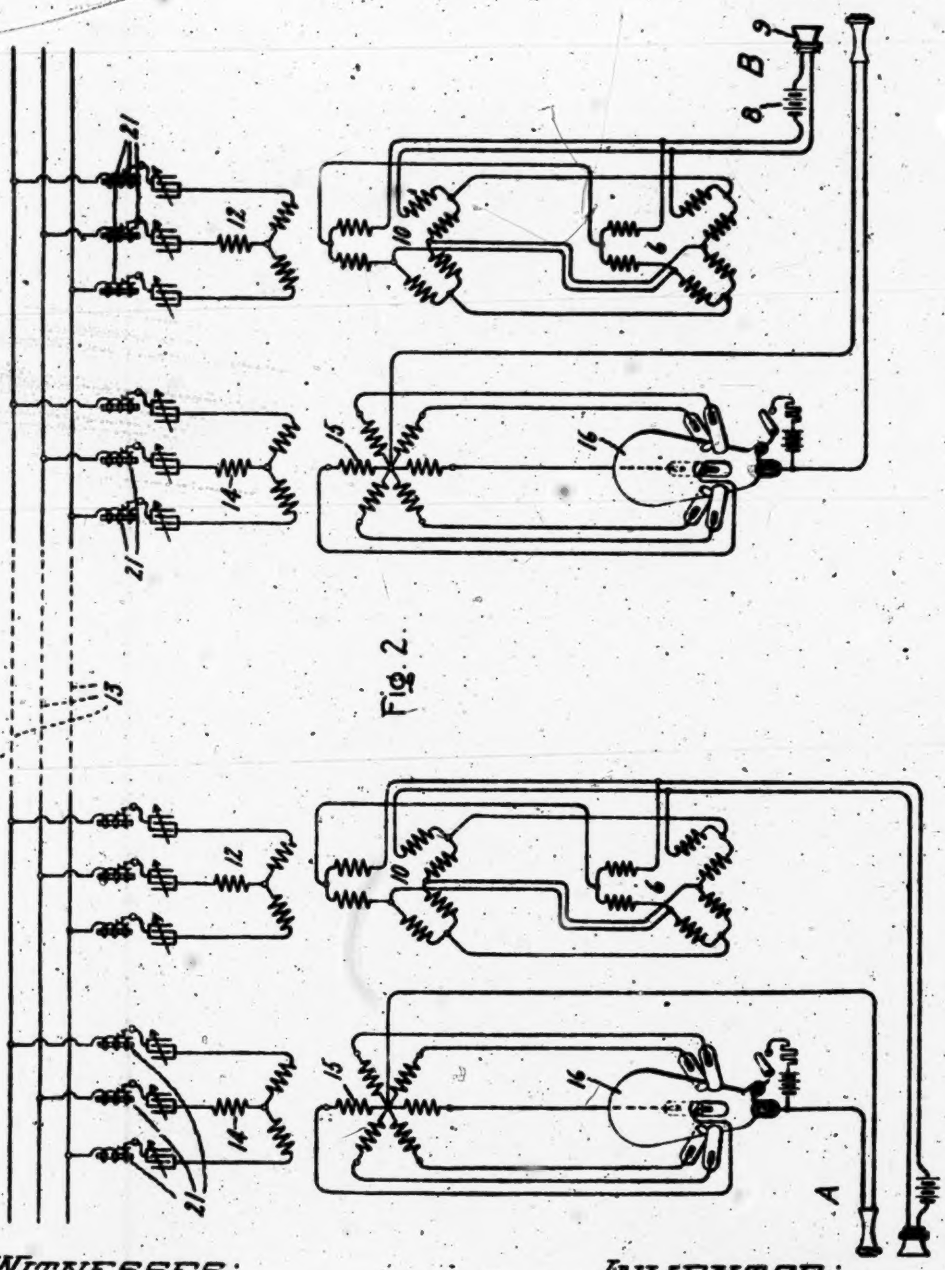
TELEPHONE SYSTEM.

APPLICATION FILED APR. 14, 1913.

1,102,628.

Patented July 7, 1914.

3 SHEETS—SHEET 2.



21
12
10
6
8
B
9
15
16
14
21
13
12
10
6
15
16
14
21
A

Fig. 2

WITNESSES:

J. Earl Ryan

J. Ellis Glen

INVENTOR:

ERNST F. W. ALEXANDERSON,

BY Albert G. Davis

HIS ATTORNEY.

E. F. W. ALEXANDERSON.

TELEPHONE SYSTEM.

APPLICATION FILED APR. 14, 1913.

1,102,628.

Patented July 7, 1914.

3 SHEETS-SHEET 3.

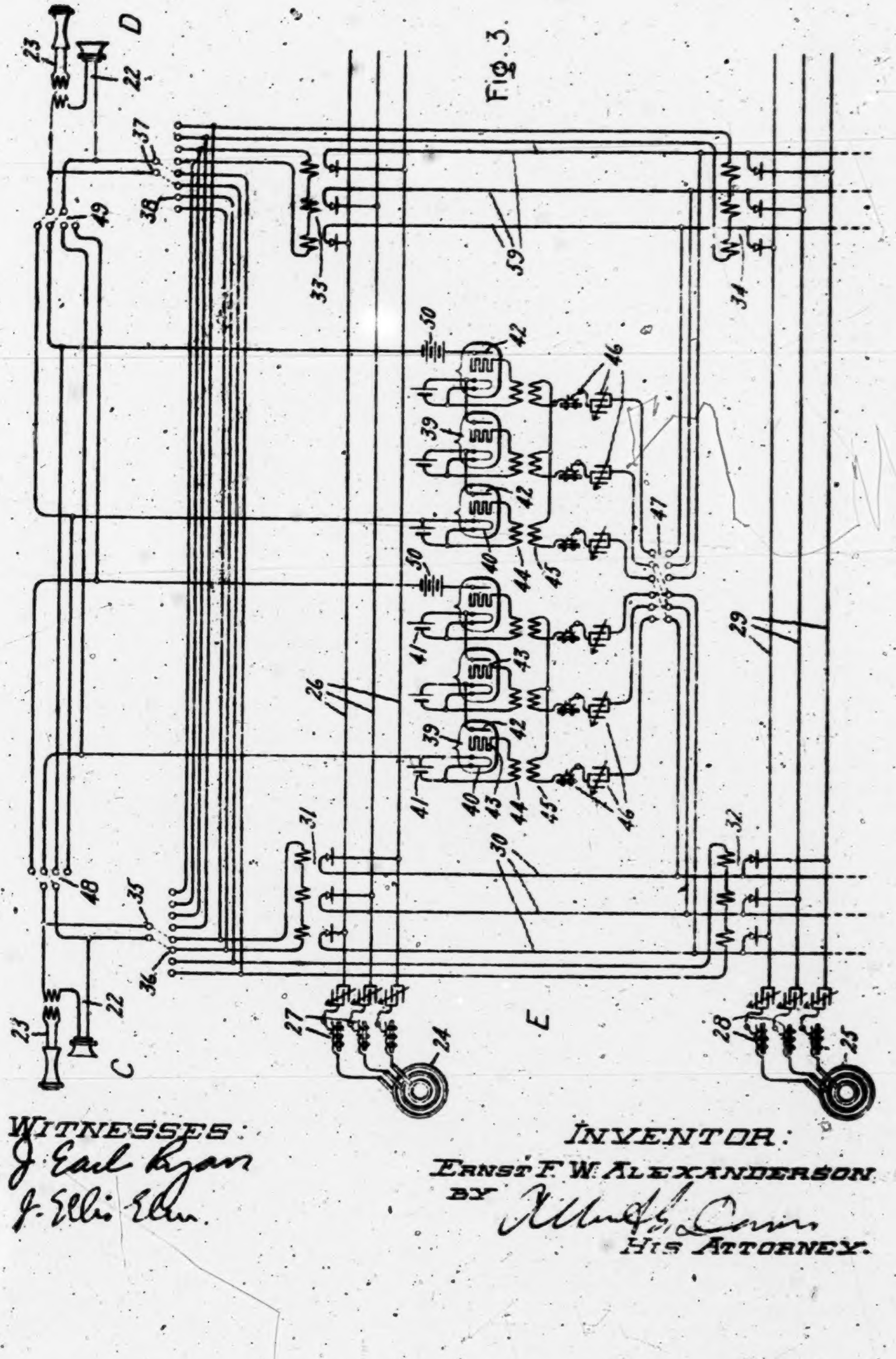

D
23
22
37
38
49
33
59
50
42
39
46
47
40
43
44
45
41
26
29
34
31
30
32
48
35
36
22
23
27
24
E
28
25
C

Fig. 3

WITNESSES:
J. Earl Ryan
J. Ellis Elen

INVENTOR:
ERNST F. W. ALEXANDERSON
BY Albert G. Davis
HIS ATTORNEY.

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

TELEPHONE SYSTEM.

1,102,628. Specification of Letters Patent. **Patented July 7, 1914.**

Application filed April 14, 1913. Serial No. 760,976.

To all whom it may concern:

Be it known that I, Ernst F. W. Alexanderson, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Telephone Systems, of which the following is a specification.

My invention relates to telephone systems, and particularly to such systems in which the calling station and the answering station are located at a considerable distance apart.

More particularly, my invention relates to multiplex telephony systems in which it is necessary to transmit the telephone currents over long distances.

The principal problem, heretofore, in the development of a system of telephony and particularly a multiplex telephony system, using tuned alternating current circuits, has been the transmission of high frequency alternating currents over long distances. I have described in Patent No. 996,445, granted July 27, 1911, a system of telephony in which a high frequency alternator is employed as a telephone relay to amplify or reinforce telephone currents. I have found by experiment that in such a system employing frequencies above 10,000 cycles no disturbance is produced in the telephone message, while with frequencies as low as 6,000 cycles the disturbance produced is so great that the message can scarcely be understood. Telephone lines are usually constructed for frequencies considerably lower than those mentioned, and it is very desirable to employ, if possible, these lower frequencies. To this end, my invention contemplates a system of transmission in which relatively low frequencies may be employed and in which the usual disadvantages of these frequencies are avoided.

When a single phase alternating current is rectified a unidirectional current is produced having a pulsation with a frequency twice that of the fundamental alternating current. If a quarterphase alternating current is rectified the rectified current has a pulsation with a frequency four times the frequency of the fundamental current, and if a three phase current is rectified, the pulsation of the rectified current has a frequency six times as great as the frequency of the fundamental current. Furthermore, the amplitude of pulsation is decreased as the number of phases is increased. With three phase transmission a frequency of 3,000 cycles can, therefore, be employed to transmit a telephone message as satisfactorily as a single phase current of 9,000 cycles.

The object of my invention is accordingly to provide a telephone system in which the telephone currents are amplified and transmitted as polyphase alternating currents.

A further object of my invention is to provide a system of multiplex telephony employing polyphase alternating currents for the effective transmission of the telephone currents from one station to another.

My invention consists in the use of a polyphase alternator as a relay in a telephone system, together with means for the polyphase transmission of the telephone currents between the calling and the answering stations. I preferably provide a plurality of polyphase alternators of different frequencies at each central exchange. Each alternator is arranged to be operatively connected as a telephone relay to any subscriber's circuit. I also provide at each central exchange a plurality of polyphase current rectifying detectors which are also arranged to be operatively connected to any subscriber's circuit. The circuit of each rectifying detector is provided with tuning instrumentalities, so that the detector at one exchange can be tuned for the frequency of an alternator at the other exchange.

The novel features which I believe to be patentably characteristic of my invention are definitely indicated in the claims appended hereto. The application of my invention to a telephone system and the mode of operation thereof will be understood by reference to the following description taken in connection with the accompanying drawings, in which:

Figure 1 is a diagrammatic explanatory view of one embodiment of my invention; Fig. 2 is a diagrammatic view of the embodiment of my invention shown in Fig. 1 with the necessary apparatus for transmitting and receiving telephone messages between two stations; Fig. 3 is a diagrammatic view of a multiplex system of telephony, embodying the features of my invention; Fig. 4 is another modification of my invention; and Fig. 5 is an explanatory view.

The principle of operation of my invention will be most readily understood by reference to Fig. 1 of the drawings. In this figure, I have represented diagrammatically the stator winding of a polyphase alternator 6. This alternator is preferably of the inductor type having a single winding serving as both a field and armature winding and an inductor arranged to rotate at high speed. Each phase of the stator winding of the alternator comprises a plurality of sections 7. All the sections of the winding are connected in series with respect to the transmitting circuit which includes a source of direct current 8 and a transmitter or microphone 9.

The sections 7 of each phase of the alternator winding are connected in parallel with respect to an external circuit, which supplies current to the primary winding 10 of a polyphase transformer. Each phase of the primary winding of the transformer consists of a plurality of sections 11, and these sections are connected in parallel with respect to the winding of the alternator by means of conductors 57 and conductors 57'. The sections 11 are, furthermore, connected in series with respect to the transmitting circuit by means of conductors 57'.

The pulsating telephone current flowing through the sections 7 of the winding of the alternator will cause, by the rotation of the inductor of the alternator, an amplified or reinforced polyphase alternating current of predetermined frequency to be induced in the winding. This current will be transmitted as a polyphase current to the primary winding 10 of the transformer. The connection of the sections 7 of the winding of the alternator in series with the transmitting circuit and the similar connection of the sections 11 of the primary winding 10 of the transformer provide an arrangement in which the alternating voltages induced in or impressed on the sections of each phase of these windings are in opposition and hence neutralize each other in the transmitting circuit. The parallel connections of the sections 7 and 11 of each phase of the alternator and transformer windings respectively permit the effective utilization in an external circuit of the currents induced in the winding of the alternator.

A secondary winding 12 is arranged in operative relation with the primary winding 10 and is connected by polyphase transmission conductors 13 to a primary winding 14 of a transformer at the answering station. The secondary winding 15 of this transformer is operatively connected to the terminals of a polyphase rectifying device 16 which acts as a detector for the alternating current flowing in the transmission conductors. In this figure I have illustrated a mercury vapor rectifying device of well known construction. A starting circuit 17 of the usual type is provided in conjunction with the rectifying device. A receiving circuit including a telephone receiver 18 is completed through the rectifying device by means of a conductor 58 connected to one terminal 19 of the device and a second conductor 20 connected to the neutral point of the secondary winding 15.

The operation of the system diagrammatically illustrated in Fig. 1 will, it is believed, be obvious from the foregoing description. The pulsating telephone current produced in the transmitting circuit by speaking into the transmitter 9 flows through the stator winding of the alternator 6 and causes to be induced in this winding a polyphase alternating current of a definite frequency. This polyphase alternating current is sent out over the polyphase transmission conductors 13 at relatively high voltage by means of the sending transformer, and is rectified by means of the polyphase current rectifying device 16. A unidirectional current, therefore, flows through the receiving circuit producing the usual sound waves in the receiver 18.

The character of the unidirectional current is shown in Fig. 5. This figure shows graphically the rectified currents of a three phase alternating current for one-half period. It will be noted from an examination of this figure that the amplitude of pulsation is relatively small and a unidirectional current is produced of a character indicated by the full line *a* of this figure.

The application of my invention to a complete telephone system having both transmitting and receiving circuits at the calling and answering stations is shown in Fig. 2 of the drawings. In this figure, I have shown two stations A and B. The transmitting circuit of each station includes the battery 8 and transmitter 9, and is connected to the stator winding of the alternator 6 and the primary winding 10 of the sending transformer in the same manner as described in connection with Fig. 1. The secondary winding 12 of each sending transformer is connected through tuning instrumentalities 21 to the polyphase transmission conductors 13. The primary windings 14 of the receiving transformers at each station are connected through similar tuning instrumentalities to the transmission conductors. The alternators thus act as relays or amplifiers for the telephone currents flowing in the transmitting circuits of their respective stations. The telephone currents, when thus amplified, are sent out over the transmission conductors 13 as polyphase alternating currents.

The alternator at the station A is designed to generate a current of different frequency from that generated by the alternator at the station B. The tuning instrumentalities 21, in operative relation with the primary winding 14 of the receiving transformer at each station, will be tuned to receive currents of the frequency generated by the alternator at the other station. In this manner the telephone current flowing in the transmitting circuit at station B will be amplified and sent out over the transmission conductors 13, detected and rectified, and sent through the receiving circuit of the station A. At the same time and without interference, the telephone current in the transmitting circuit of station A will be amplified. sent out over the transmission conductors 13, detected and rectified, and passed through the receiving circuit of the station B.

In Fig. 3, I have shown diagrammatically the application of my invention to multiplex telephony. I have shown in this figure only one central exchange, but it will be understood that the arrangement of the apparatus at the other central exchange is precisely the same as that shown for the exchange illustrated. In Fig. 3 I have represented two subscriber's stations C and D, each having a transmitting circuit 22 and a receiving circuit 23. Each subscriber's station is connected to a central exchange E as will be more fully described hereinafter.

A plurality of polyphase alternators of different frequencies are located at each central exchange. In the figure I have shown two alternators 24 and 25 at the exchange E. The alternator 24 is connected to polyphase bus bars 26 through tuning instrumentalities 27. The alternator 25 is connected through tuning instrumentalities 28 to the polyphase bus bars 29. The tuning instrumentalities 27 and 28 may, obviously, be omitted if desired. When employed they serve to tune the sending circuit so that this circuit can be given a minimum impedance corresponding to the frequency of the sending alternator. The bus bars 26 and 29 are connected to polyphase transmission conductors 30 through microphone relays 31 and 32 respectively. The microphone relays are of the usual construction and comprise a variable resistance arranged to vary in proportion to the strength of the current flowing in a coöperating relay coil. The bus bars 26 and 29 are also connected to polyphase transmission conductors 59 through similar microphone relays 33 and 34 respectively. The terminals 35 of the transmitting circuit of subscriber C are arranged to be electrically connected to any pair of coöperating contacts 36, so that this transmitting circuit may be operatively connected to the microphone relay 31, 32, 33 or 34. The transmitting circuit of the subscriber D is similarly provided with terminals 37 which are arranged to be electrically connected to any pair of coöperating contacts 38. The connection indicated by dotted lines in the drawings is such that the transmitting circuit of subscriber C is operatively connected to relay 31, and the transmitting circuit of subscriber D is operatively connected to relay 32.

A plurality of polyphase current rectifying detectors are located at the central exchange and each detector is arranged to be operatively connected to the receiving circuit of any subscriber. In the drawings I have illustrated vacuum valve rectifying devices of well known construction. These vacuum valve rectifiers comprise an evacuated chamber 39 in which is arranged a cathode wire 40 adapted to be maintained in a highly heated or incandescent state by a source of direct current 41. An anode plate 42 and a grid 43 are arranged within each vacuum chamber. For the rectification of three phase currents three vacuum valve devices are necessary one device being operatively related to each phase. These devices are connected in series in the receiving circuit, as indicated in the drawings, through terminals leading to the cathode wire 40 and the anode plate 42. The grids 43 within each vacuum chamber are operatively connected to secondary windings 44, which are operatively related to primary windings 45 arranged for connection through tuning instrumentalities 46 to either of the polyphase transmission conductors 30 or 59. The polyphase current rectifying detectors are arranged for connection to either of the transmission conductors through the switch 47. The receiving circuit of subscriber C is further provided with a switch 48 which permits either of the rectifying detectors to be operatively connected in this circuit. The receiving circuit of the subscriber D is similarly provided with a switch 49. As indicated by the dotted line connections in the drawings, the receiving circuit of subscriber C is operatively connected through the left hand rectifying detector to the polyphase transmission conductors 30, and the receiving circuit of subscriber D is connected through the right hand rectifying detector to the same transmission conductors. A source of direct current 50 is provided in connection with each rectifying detector, and the pulsations of the current flowing through the receiving circuit vary in direct proportion to the amplitude of the currents flowing in the primary winding 45 of the transformer operatively connected to the rectifying detector. This is accomplished by the effect of the electrostatic charge on the grids upon the conductivity of the evacuated chamber 39.

The operation of the multiplex system of telephony shown in Fig. 3 is as follows: The transmitting circuit of subscriber C is operatively connected to the transmission conductors 30 through a relay comprising the alternator 24 and microphone relay 31. The magnitude of the current sent out over the transmission conductors 30 from the alternator 24 will, therefore, be varied directly as the pulsations of the telephone current. Similarly the current in the transmitting circuit of subscriber D will be sent out over the same transmission conductors through the coöperation of the alternator 25 and microphone relay 32. As the alternators 24 and 25 generate currents of different frequencies, there will be no interference of these currents in the transmission conductors. At the receiving exchange rectifying detectors tuned respectively to selectively receive currents of a frequency corresponding to alternator 24 and alternator 25 will be provided, and these currents will be directed to the receiving circuits of the answering subscribers, as described in the next paragraph in connection with the calling subscribers.

As previously stated, only one central exchange is illustrated in Fig. 3 of the drawings, since the other exchange is exactly the same as the exchange E. That is the bus bars 26 and 29 are connected by transmission conductors to two similar sets of bus bars in the other exchange, and the apparatus of the other exchange and of the subscriber's stations are related to these latter bus bars in the same way as heretofore explained in connection with the exchange E. Thus, the reception at the other exchange of a message sent from the exchange E can be readily explained and understood by assuming that the message or messages are coming from the other exchange and are being received at the exchange E. Assuming a receiving message for each subscriber, the receiving circuit of subscriber C is connected through the polyphase rectifying detector at the left in the figure to the transmission conductors 30, and the receiving circuit of subscriber D is connected through the right hand rectifying detector to the same transmission conductors. The tuning instrumentalities 46 of these rectifying detectors will be tuned to selectively receive currents corresponding to the frequency of the relay employed at the answering exchange and operatively connected to the transmitting circuit of the answering subscriber. The sending and receiving currents of each subscriber are preferably of different frequencies, whereby no interference is occasioned between these two currents in the transmitting and receiving apparatus of the two talking subscribers. Thus while subscriber C is sending messages with a current having a frequency corresponding to the frequency of alternator 24, he is receiving messages by a current of a different frequency determined by the frequency of the sending alternator at the other exchange. Similarly, the frequency of the alternator 25 with which subscriber D is sending messages is different than the frequency of the alternator at the other exchange by which messages are sent to the subscriber D. It will thus be seen that the transmission conductors 30 are carrying alternating currents of four different frequencies and that these currents are directed to their proper paths by means of tuned circuits.

In Fig. 4 of the drawings I have illustrated a modified type of relay to be employed in the transmitting circuit. In this figure, a polyphase alternator 51 is operatively connected to the transmission conductors 52. Transformer coils 53 are included in series with each transmission conductor. Operatively related to each pair of transformer coils 53 are transformer coils 54. The coöperating transformer coils 54 of each pair are connected in opposition so that the voltages induced in the coils 54 will be opposite in effect. All of the coils 54 are connected in series in the transmitting circuit which includes a source of direct current 55 and a microphone transmitter 56. In this type of relay the pulsating telephone currents will flow through the coils 54 and impart to the same a certain magnetization. This magnetization varies the impedance of the coöperating transformer coils 53 and hence the magnitude of the currents sent out over the transmission conductors 52 from the alternator 51.

The receiving apparatus shown in Fig. 4 is of the same type as that described in connection with Figs. 1 and 2. It will be understood, of course, that an answering station having a similar arrangement of apparatus as that shown in Fig. 4 will be provided. This answering station has been omitted in order to simplify the drawings.

It will be evident from the foregoing description that I have provided a system of telephony, making use of polyphase alternating currents for the transmission of telephone currents from one station to another. The particular advantage in the use of polyphase currents is, as heretofore explained, that frequencies considerably lower than those required with single phase currents can be employed. This is of decided advantage inasmuch as the present telephone systems are designed for lower frequencies than can be satisfactorily employed with single phase transmission. I have in addition provided a system of multiplex telephony which makes use of polyphase alternating currents for simultaneously transmitting two or more telephone currents.

It will be obvious to those skilled in the art that my invention may be embodied in many different forms and arrangements of apparatus than that illustrated and de-in operative relation with the primary winding 14 of the receiving transformer at each station, will be tuned to receive currents of the frequency generated by the alternator at the other station. In this manner the telephone current flowing in the transmitting circuit at station B will be amplified and sent out over the transmission conductors 13, detected and rectified, and sent through the receiving circuit of the station A. At the same time and without interference, the telephone current in the transmitting circuit of station A will be amplified, sent out over the transmission conductors 13, detected and rectified, and passed through the receiving circuit of the station B.

In Fig. 3, I have shown diagrammatically the application of my invention to multiplex telephony. I have shown in this figure only one central exchange, but it will be understood that the arrangement of the apparatus at the other central exchange is precisely the same as that shown for the exchange illustrated. In Fig. 3 I have represented two subscriber's stations C and D, each having a transmitting circuit 22 and a receiving circuit 23. Each subscriber's station is connected to a central exchange E as will be more fully described hereinafter.

A plurality of polyphase alternators of different frequencies are located at each central exchange. In the figure I have shown two alternators 24 and 25 at the exchange E. The alternator 24 is connected to polyphase bus bars 26 through tuning instrumentalities 27. The alternator 25 is connected through tuning instrumentalities 28 to the polyphase bus bars 29. The tuning instrumentalities 27 and 28 may, obviously, be omitted if desired. When employed they serve to tune the sending circuit so that this circuit can be given a minimum impedance corresponding to the frequency of the sending alternator. The bus bars 26 and 29 are connected to polyphase transmission conductors 30 through microphone relays 31 and 32 respectively. The microphone relays are of the usual construction and comprise a variable resistance arranged to vary in proportion to the strength of the current flowing in a coöperating relay coil. The bus bars 26 and 29 are also connected to polyphase transmission conductors 59 through similar microphone relays 33 and 34 respectively. The terminals 35 of the transmitting circuit of subscriber C are arranged to be electrically connected to any pair of coöperating contacts 36, so that this transmitting circuit may be operatively connected to the microphone relay 31, 32, 33 or 34. The transmitting circuit of the subscriber D is similarly provided with terminals 37 which are arranged to be electrically connected to any pair of coöperating contacts 36. The connection indicated by dotted lines in the drawings is such that the transmitting circuit of subscriber C is operatively connected to relay 31, and the transmitting circuit of subscriber D is operatively connected to relay 32.

A plurality of polyphase current rectifying detectors are located at the central exchange and each detector is arranged to be operatively connected to the receiving circuit of any subscriber. In the drawings I have illustrated vacuum valve rectifying devices of well known construction. These vacuum valve rectifiers comprise an evacuated chamber 39 in which is arranged a cathode wire 40 adapted to be maintained in a highly heated or incandescent state by a source of direct current 41. An anode plate 42 and a grid 43 are arranged within each vacuum chamber. For the rectification of three phase currents three vacuum valve devices are necessary one device being operatively related to each phase. These devices are connected in series in the receiving circuit, as indicated in the drawings, through terminals leading to the cathode wire 40 and the anode plate 42. The grids 43 within each vacuum chamber are operatively connected to secondary windings 44, which are operatively related to primary windings 45 arranged for connection through tuning instrumentalities 46 to either of the polyphase transmission conductors 30 or 59. The polyphase current rectifying detectors are arranged for connection to either of the transmission conductors through the switch 47. The receiving circuit of subscriber C is further provided with a switch 48 which permits either of the rectifying detectors to be operatively connected in this circuit. The receiving circuit of the subscriber D is similarly provided with a switch 49. As indicated by the dotted line connections in the drawings, the receiving circuit of subscriber C is operatively connected through the left hand rectifying detector to the polyphase transmission conductors 30, and the receiving circuit of subscriber D is connected through the right hand rectifying detector to the same transmission conductors. A source of direct current 50 is provided in connection with each rectifying detector, and the pulsations of the current flowing through the receiving circuit vary in direct proportion to the amplitude of the currents flowing in the primary winding 45 of the transformer operatively connected to the rectifying detector. This is accomplished by the effect of the electrostatic charge on the grids upon the conductivity of the evacuated chamber 39.

The operation of the multiplex system of telephony shown in Fig. 3 is as follows: The transmitting circuit of subscriber C is operatively connected to the transmission conductors 30 through a relay comprising the alternator 24 and microphone relay 31. The magnitude of the current sent out over the transmission conductors 30 from the alternator 24 will, therefore, be varied directly as the pulsations of the telephone current. Similarly the current in the transmitting circuit of subscriber D will be sent out over the same transmission conductors through the coöperation of the alternator 25 and microphone relay 32. As the alternators 24 and 25 generate currents of different frequencies, there will be no interference of these currents in the transmission conductors. At the receiving exchange rectifying detectors tuned respectively to selectively receive currents of a frequency corresponding to alternator 24 and alternator 25 will be provided, and these currents will be directed to the receiving circuits of the answering subscribers, as described in the next paragraph in connection with the calling subscribers.

As previously stated, only one central exchange is illustrated in Fig. 3 of the drawings, since the other exchange is exactly the same as the exchange E. That is the bus bars 26 and 29 are connected by transmission conductors to two similar sets of bus bars in the other exchange, and the apparatus of the other exchange and of the subscriber's stations are related to these latter bus bars in the same way as heretofore explained in connection with the exchange E. Thus, the reception at the other exchange of a message sent from the exchange E can be readily explained and understood by assuming that the message or messages are coming from the other exchange and are being received at the exchange E. Assuming a receiving message for each subscriber, the receiving circuit of subscriber C is connected through the polyphase rectifying detector at the left in the figure to the transmission conductors 30, and the receiving circuit of subscriber D is connected through the right hand rectifying detector to the same transmission conductors. The tuning instrumentalities 46 of these rectifying detectors will be tuned to selectively receive currents corresponding to the frequency of the relay employed at the answering exchange and operatively connected to the transmitting circuit of the answering subscriber. The sending and receiving currents of each subscriber are preferably of different frequencies, whereby no interference is occasioned between these two currents in the transmitting and receiving apparatus of the two talking subscribers. Thus while subscriber C is sending messages with a current having a frequency corresponding to the frequency of alternator 24, he is receiving messages by a current of a different frequency determined by the frequency of the sending alternator at the other exchange. Similarly, the frequency of the alternator 25 with which subscriber D is sending messages is different than the frequency of the alternator at the other exchange by which messages are sent to the subscriber D. It will thus be seen that the transmission conductors 30 are carrying alternating currents of four different frequencies and that these currents are directed to their proper paths by means of tuned circuits.

In Fig. 4 of the drawings I have illustrated a modified type of relay to be employed in the transmitting circuit. In this figure, a polyphase alternator 51 is operatively connected to the transmission conductors 52. Transformer coils 53 are included in series with each transmission conductor. Operatively related to each pair of transformer coils 53 are transformer coils 54. The coöperating transformer coils 54 of each pair are connected in opposition so that the voltages induced in the coils 54 will be opposite in effect. All of the coils 54 are connected in series in the transmitting circuit which includes a source of direct current 55 and a microphone transmitter 56. In this type of relay the pulsating telephone currents will flow through the coils 54 and impart to the same a certain magnetization. This magnetization varies the impedance of the coöperating transformer coils 53 and hence the magnitude of the currents sent out over the transmission conductors 52 from the alternator 51.

The receiving apparatus shown in Fig. 4 is of the same type as that described in connection with Figs. 1 and 2. It will be understood, of course, that an answering station having a similar arrangement of apparatus as that shown in Fig. 4 will be provided. This answering station has been omitted in order to simplify the drawings.

It will be evident from the foregoing description that I have provided a system of telephony, making use of polyphase alternating currents for the transmission of telephone currents from one station to another. The particular advantage in the use of polyphase currents is, as heretofore explained, that frequencies considerably lower than those required with single phase currents can be employed. This is of decided advantage inasmuch as the present telephone systems are designed for lower frequencies than can be satisfactorily employed with single phase transmission. I have in addition provided a system of multiplex telephony which makes use of polyphase alternating currents for simultaneously transmitting two or more telephone currents.

It will be obvious to those skilled in the art that my invention may be embodied in many different forms and arrangements of apparatus than that illustrated and described in this application. I accordingly aim in the appended claims to cover all modifications which are within the spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In a telephone system, a transmitting circuit adapted to carry a pulsating telephone current, means for producing a polyphase alternating current proportional to said telephone current, polyphase transmission conductors arranged to carry said alternating current, means for rectifying said polyphase alternating current, and a receiving circuit adapted to carry the rectified current.

2. In a telephone system a transmitting circuit, a receiving circuit, a telephone relay comprising a polyphase alternator operatively connected to said transmitting circuit, a polyphase current rectifying detector operatively connected to said receiving circuit, and polyphase transmisison conductors between said relay and said rectifying detector.

3. In a multiplex telephony system, a plurality of transmitting circuits each adapted to carry a pulsating telephone current, means for producing a polyphase alternating current proportional to each of said telephone currents, each of said alternating currents so produced being of a different frequency, polyphase transmission conductors arranged to simultaneously carry all of said alternating currents, means for selectively rectifying each of said polyphase alternating currents, and a plurality of receiving circuits each adapted to carry a rectified current.

4. In a telephone system, a plurality of subscriber's circuits, a central exchange, a plurality of telephone relays each comprising a polyphase alternator of different frequency, and means controlled at the central station for operatively connecting any relay to any subscriber's circuit.

5. In a telephone system, a calling station and an answering station, each station having a transmitting circuit and a receiving circuit, a telephone relay comprising a polyphase alternator operatively connected to the transmitting circuit of each station, polyphase transmission conductors between said stations and operatively connected to said relays, and polyphase current rectifying detectors operatively connected to the receiving circuit of each station and to the transmission conductors.

6. In a telephone system, a subscriber's circuit including a transmitting device and a receiving device, a second subscriber's circuit also including a transmitting device and a receiving device, a telephone relay comprising a polyphase alternator operatively connected to each of said subscriber's circuits, a polyphase rectifying detector operatively connected to each of said subscriber's circuits, polyphase transmission conductors electrically connecting the relay and rectifying detector in one subscriber's circuit to the relay and rectifying detector in the other subscriber's circuit, and means for tuning the circuit of the rectifying detector in each subscriber's circuit for the frequency of the alternator of the relay in the other subscriber's circuit.

7. In a telephone system, a plurality of subscriber's circuits in connection with a central exchange, a plurality of subscriber's circuits in connection with a second central exchange, polyphase transmission conductors between said exchanges, a plurality of polyphase alternators of different frequencies at each exchange and arranged for operative connection as telephone relays to any subscriber's circuit in connection with said exchange, a plurality of polyphase current rectifying detectors at each exchange and arranged for connection to any subscriber's circuit in connection with said exchange, and means for tuning the circuits of the rectifying detectors of one exchange for the frequencies of corresponding alternators of the other exchange.

8. In a telephone system, a plurality of subscriber's circuits in connection with a central exchange, a plurality of subscriber's circuits in connection with a second central exchange, polyphase transmission conductors between said exchanges, a plurality of polyphase alternators of different frequencies at each exchange and arranged for operative connection as telephone relays to any subscriber's circuit in connection with the latter subscriber's exchange, a plurality of polyphase current rectifying detectors at each exchange and arranged for connection to any subscriber's circuit in connection with the latter subscriber's exchange, and means coöperating with said polyphase alternators and said polyphase current rectifying detectors for simultaneously connecting through said polyphase transmission conductors two or more of the subscriber's circuits of one exchange in operative relation with a corresponding number of subscriber's circuits of the other exchange.

In witness whereof, I have hereunto set my hand this 12th day of April, 1913.

ERNST F. W. ALEXANDERSON.

Witnesses:

Benjamin B. Hull,
Helen Orford.

DEFENDANT'S EXHIBIT No. 303.

W. C. WHITE.

CIRCUIT CONNECTION OF ELECTRON DISCHARGE APPARATUS.

APPLICATION FILED AUG. 23, 1915.

1,195,632. Patented Aug. 22, 1916.

Fig. 2

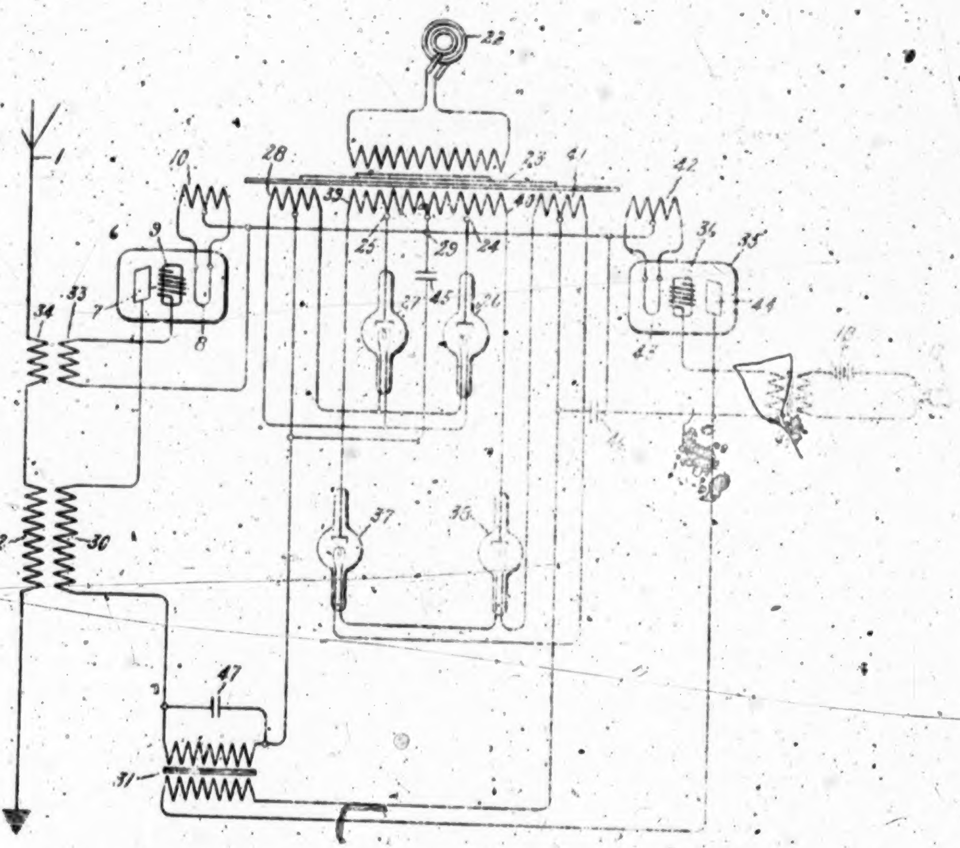
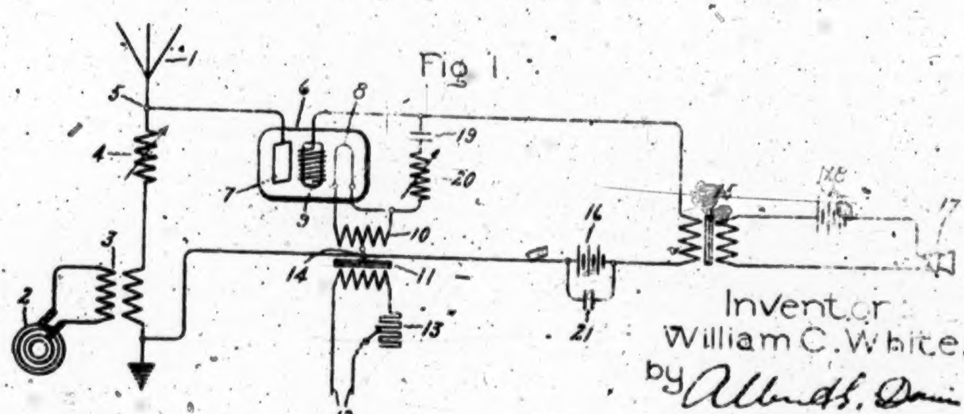

22
1
10
28
23
41
42
39
40
6
9
25
29
24
34
35
33
34
7
8
27
45
26
44
43
18
46
37
36
32
30
47
31

Fig 1


1
5
6
8
19
4
20
7
9
10
3
14
11
16
15
18
17
2
13
21
12

Inventor:
William C. White,
by Albert G. Davis
His Attorney

UNITED STATES PATENT OFFICE.

WILLIAM C. WHITE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

CIRCUIT CONNECTIONS OF ELECTRON-DISCHARGE APPARATUS.

1,195,632. Specification of Letters Patent. Patented Aug. 22, 1916.

Application filed August 23, 1915. Serial No. 46,770.

To all whom it may concern:

Be it known that I, WILLIAM C. WHITE, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Circuit Connections of Electron-Discharge Apparatus, of which the following is a specification.

This application is a continuation in part of my prior application, Serial No. 32,367, filed June 5, 1915.

My present invention relates to circuit connections for electron discharge apparatus and more especially electron discharge apparatus of the type in which a filamentary cathode inclosed in an evacuated envelop is provided with means for heating to incandescence to cause it to emit electrons which may serve to convey negative electricity to a coöperating anode inclosed in the same envelop. Such devices may be used for producing X-rays or rectifying alternating current or, when provided with a controlling grid, for amplifying variable currents, detecting wireless signals and for various other purposes.

It has been customary prior to my invention to provide for heating the cathode a direct current source such as a battery or direct current generator. The external circuit connections to the cathode have been made to one side of the filament and as a result all parts of the filament have not been at the same potential with respect to the anode or the grid, the difference between extreme ends being equal to the potential impressed upon the filament. Where a source of direct current is employed, this difference of potential is constant and, therefore, will not produce variations in the operation of the device. It is, however, more convenient in many cases to employ an alternating current for heating the filament, and, when this is done and the connections made to one side of the filament, the potential variations which are thereby introduced may seriously affect the efficient operation of the device.

The object of my invention is to provide an improved circuit connection for electron discharge devices whereby alternating current may be employed for heating the filament and the disadvantage above mentioned, as well as others which will hereinafter appear, may be overcome.

In the practical application of my invention, current for heating the filament is obtained from the secondary of a transformer and the connections from anode and grid to the cathode are made to the middle point of the secondary winding. When the connections are made in this way the average difference of potential at any instant between different portions of the cathode and the grid and anode, due to the heating current, will be zero.

My invention will best be understood by reference to the following description taken in connection with the accompanying drawing in which—

Figure 1 shows one organization for transmitting wireless signals in which the filament of the electron discharge device is supplied with alternating current and in which my invention may be employed to advantage; and Fig. 2 shows a different transmitting system in which a source of alternating current is utilized for other purposes as well as heating the cathodes of the various electron discharge devices used.

In the organization illustrated in Fig. 1, the antenna 1 is grounded as usual and has connected thereto a source of high frequency oscillations which in this case consists of a high frequency alternator 2. This may be inductively connected to the antenna by means of the transformer 3 or may be connected directly thereto, if desired. An inductance 4 which may be varied to tune the antenna circuit to the desired frequency may be placed in series with the antenna. An energy consuming device 6 which, in the present case, consists of an electron discharge relay comprising an exhausted envelop containing an anode 7, a cathode 8 and a conducting grid shaped body 9 interposed between the cathode and anode is connected to two points in the antenna circuit between which there is normally a large difference of potential. In the present case it is connected between the point 5 in the antenna and ground. The cathode 8 is of filamentary form, preferably of tungsten, and is provided with current for heating it to incandescence by the secondary 10 of the transformer 11 which may be supplied with alternating current from the mains 12. The temperature of the cathode may be adjusted by means of a variable resistance 13 in the primary circuit of the transformer. The connection between the cathode of this device and ground is brought to the point 14 which is the middle point in the winding of the secondary 10. A second connection to this same point is made from the grid 9 through the secondary of the transformer 15 and battery 16. The primary circuit of the transformer 15 includes a telephone transmitter 17 with local battery 18. A second circuit consisting of the condenser 19 and the variable inductance 20 is provided between the grid 9 and cathode 8. In the operation of this system to secure the best possible results it will usually be found desirable to adjust the current flowing through relay 6 so that about one-half of the energy of the source 2 is normally diverted from the antenna circuit. This may be done by adjusting the potential impressed upon the grid 9 by the battery 16. In order that the currents produced in the secondary of the transformer 15 may not be compelled to flow through the battery 16, condenser 21 may be inserted in shunt to this battery. When sound waves act upon the transmitter 17 potential variations are set up in the secondary of the transformer 15 and the potential of the grid 9 is thereby varied in accordance with the variations in the sound waves. As a result the amount of energy which is diverted from the antenna through relay 6 is varied accordingly and there is a corresponding variation in the energy radiated from the antenna.

In the preferred construction of the electron discharge relay 6, the anode 7 is made up of one or more plates of considerable area and the grid 9 consists of a number of turns of fine wire wound on a supporting frame work and located in parallel relation to the anode plate or plates. The cathode 8 is also preferably located in a plane parallel to the grid and anode. The distance between these members is preferably small and as a result there is an appreciable capacity between them. It will be seen that with the arrangement indicated the anode 7 is alternately positive and negative with respect to the cathode and that as a result the grid 9 will have induced thereon by electrostatic induction positive and negative charges. Although the grid and cathode are connected electrically reversals in polarity in the induced charges are so rapid that the potential difference between the two at times may become very large, the secondary of the transformer 15 offering high impedance to the flow of high frequency charging current between the grid and cathode. As a result the positive potential which may be induced on the grid 9 when the anode is also positive may become so great as to allow enough current to flow through the relay 6 to divert from the antenna nearly all of the energy from the high frequency source, even when no potential is induced upon the grid by means of the telephone transmitter. Also the potentials induced by the secondary of the transformer 15 are in most cases small in comparison to this induced potential and hence will produce little variation in the current flowing through the relay 6. In order to overcome this difficulty the circuit comprising the condenser 19 and inductance 20 is tuned to the frequency of the source 2 so as to serve as a short circuit between grid and cathode for these induced charges.

In case the connection from the grid to the cathode through the secondary of transformer 15 were made to one end of the secondary 10 which supplies current for heating the filament the difference of potential between the opposite end of the cathode and the grid would fluctuate by an amount equal to the filament voltage. As a result there would be a corresponding variation in the amount of energy diverted from the antenna. That is, in addition to the variations produced by the action of the sound waves there would be variations having a frequency equal to that of the source supplied to transformer 11. These variations of course would impair the transmission of the desired signals. This difficulty however is overcome by connecting the grid to the middle point of transformer 10 thereby neutralizing the effect of any differences of potential between grid and filament due to the potential alternations of the source used for heating the filament. The amount of energy diverted from the antenna also depends upon the difference of potential between the anode and cathode and with the connection from anode to cathode. Made to one side of the filament there would be the same variation in potential between anode and cathode as between cathode and grid. This difficulty is also overcome by connecting the anode to the middle point of secondary 10.

In the system illustrated in Fig. 2, electron discharge device 6 is employed to produce continuous waves in the antenna 1. In order to accomplish this, anode 7 and cathode 8 are connected to a source of direct current which is obtained by rectifying alternating current from the source 22 which supplies transformer 23, the secondary turns of which are subdivided to give different voltages. One group 10 of the secondary turns provides current for heating cathode 8. Current for the plate circuit of device 6 is derived from the secondary turns between points 24 and 25, electron discharge rectifiers 26 and 27 being employed to rectify the alternating current. The group of secondary turns 28 provides current for heating the cathodes of these rectifiers. Connection to cathode 8 is made between a neutral point 29 in the transformer secondary and the middle point of group 10 of secondary turns.

A connection is also provided from the anode 7 to the cathodes of rectifiers 26 and 27 through inductance 30 and the secondary of transformer 31 to the middle point of group 28. The inductance 30 is inductively related to the inductance 32 in the antenna. The circuit, which includes the cathode 8 and the grid 9, contains an inductance 33 which is coupled to a second inductance 34 in the antenna. The coupling between 30 and 32 is preferably close, while that between 33 and 34 may in some cases be made very loose. The circuit which comprises the direct current source of supply, the inductance 30, the cathode 8 and anode 7, for convenience of description I designate the plate circuit. The circuit which comprises the grid 9, inductance 33 and cathode 8, I designate the grid circuit. With this arrangement, when current starts to flow in the plate circuit, potential is induced in coil 32 and in the antenna. This produces a corresponding induced potential in coil 33 and varies the potential of the grid 9. This change in grid potential in turn produces a variation in the current in the plate circuit. When the potential produced in the grid circuit causes the grid to become more negative the current flowing in plate circuit is decreased while an induced potential which makes the grid more positive increases the current flow in the plate circuit. These variations in the current in the plate circuit produce an alternating current in the antenna, the frequency of which will be the same as the frequency to which the antenna is tuned. The amplitude of the high frequency waves thus produced in the antenna will, among other things, depend upon the potential of the direct current source and will be constant as long as this potential is constant and other conditions also remain unchanged but their amplitude will vary in accordance with any variations in potential supplied to the plate circuit. In order to vary the amplitude of these waves in accordance with sound waves, potential variations corresponding to those set up in the secondary of transformer 15 are impressed upon the plate circuit. The potential variations in the secondary of transformer 15 are in the present case amplified by a second electron discharge device 35 similar in structure to device 6. This is done by impressing the potential variations upon the grid 36 of device 35. The amplified potential variations thereby set up in the plate circuit of device 35 are impressed upon the plate circuit of device 6 by means of the transformer 31. A direct potential for the plate circuit of device 35 is obtained in the same manner as for device 6. In the operation of this particular system, I have found it desirable to employ a higher voltage for device 35 than for device 6. To provide this higher voltage, a larger number of secondary turns of the transformer are utilized and rectifiers 37 and 38 are connected to points 39 and 40 respectively. The group of secondary turns 41 provides current for heating the cathodes of these rectifiers. Connection is made from point 29 to the middle point of group 42, which provides current for heating cathode 43 and from the anode 44 of device 35 to the cathodes of rectifiers 37 and 38 through the primary of transformer 31 to the middle point of group 41. Condensers 45 and 46 may be employed to smooth out the variations in potential of the rectified current supplied to devices 6 and 35 and condenser 47 to provide a shunt path for the high frequency component of the current in the plate circuit of device 6 around the secondary of transformer 31. When high frequency variations of current are occurring in the plate or grid circuits of the different devices, this current passes through the central taps of the transformers to the filaments without undue impedance, and divides equally between the two legs of the filament loop, as the inductance of the two sides of the winding is neutralized.

While I have described the application of my invention to only two systems for transmitting wireless signals, it will be apparent to one skilled in the art that it will be of utility in many other organizations in which electron discharge devices are employed, for wireless signaling or other purposes, and that numerous applications thereof may be made without departing from the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is:—

1. The combination with an electron discharge device comprising an evacuated envelop having therein a filamentary cathode and a coöperating anode of a source of alternating potential applied to said cathode for heating it to incandescence and external circuit connections between said cathode and anode so arranged that the average potential difference between cathode and anode at any instant is independent of the potential applied to the cathode for heating purposes.

2. The combination with an electron discharge device comprising an evacuated envelop having therein a filamentary cathode and a coöperating anode of a transformer connected to a source of alternating current and having its secondary connected to said cathode for heating it to incandescence and an external circuit connection between said anode and the central point in the secondary winding of said transformer.

3. The combination with an electron discharge device comprising an evacuated envelop having therein a filamentary cathode, a coöperating anode, and a discharge controlling grid, of a source of alternating po-

tential applied to said cathode for heating it to incandescence and external circuit connections between said cathode and anode and between said cathode and grid so arranged that the average potential difference between cathode and anode and between cathode and grid at any instant is independent of the potential applied to the cathode for heating purposes.

4. The combination with an electron discharge device comprising an evacuated envelop having therein a filamentary cathode a coöperating anode and a discharge controlling grid of a transformer connected to a source of alternating current and having its secondary connected to said cathode for heating it to incandescence and external circuit connections between said anode and said grid, and the central point in the secondary winding of said transformer.

5. The combination with an electron discharge device comprising an evacuated envelop having therein a filamentary cathode and a discharge controlling grid of a source of alternating potential applied to said cathode for heating it to incandescence and external circuit connections between said cathode and so arranged that the average potential difference between cathode and grid at any instant is independent of the potential applied to the cathode for heating purposes.

6. The combination with an electron discharge device comprising an evacuated envelop having therein a filamentary cathode and a discharge controlling grid of a transformer connected to a source of alternating current and having its secondary connected to said cathode for heating it to incandescence and an external circuit connection from said grid to the central point in the secondary winding of said transformer.

In witness whereof, I have hereunto set my hand this 20th day of August, 1915.

WILLIAM C. WHITE.

DEFENDANT'S EXHIBIT No. 304.

I. LANGMUIR.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC CURRENTS OR POTENTIALS.

APPLICATION FILED FEB. 5, 1914.

1,273,627. Patented July 23, 1918.

Fig. 1.

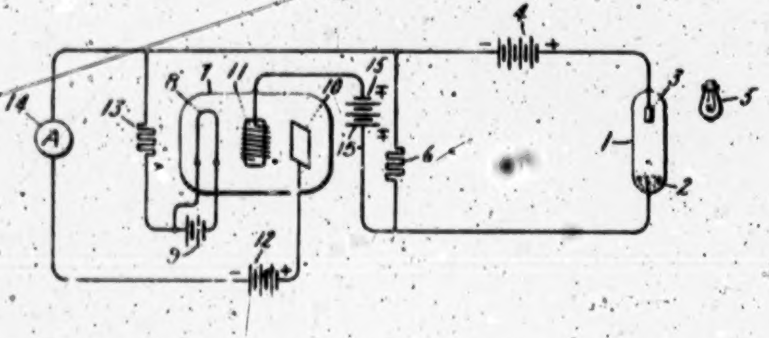

4
-
+
14
A
13
8
7
11
10
15
15
3
5
1
2
6
9
12
-
+

Fig. 2.

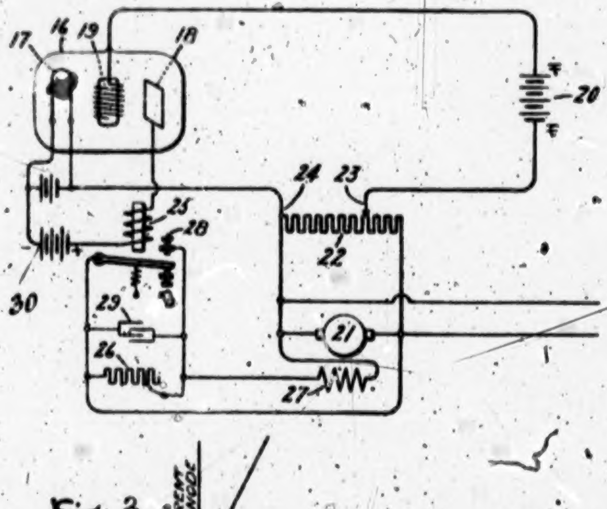
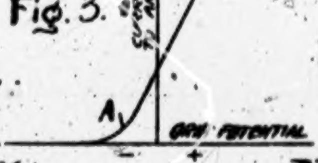

17
16
19
18
20
24
23
25
28
22
30
29
21
26
27

Fig. 3.



WITNESSES:

J. Ellis Glen

Anthony Mair

INVENTOR:

IRVING LANGMUIR

BY Albert G. Davis

HIS ATTORNE

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AND MEANS FOR CONTROLLING ELECTRIC CURRENTS OR POTENTIALS.

1,273,627. Specification of Letters Patent. Patented July 23, 1918.

Application filed February 5, 1914. Serial No. 816,836

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Methods of and Means for Controlling Electric Currents or Potentials, of which the following is a specification.

My present invention relates to means for controlling and regulating electric currents or potentials. I employ various and diverse agencies in such a way that variations of potential or current of one circuit are utilized to produce desired changes in the potential or current of another circuit suitably coupled with the first.

In one modification this effect may be employed in a system for controlling the value of a direct current of constant or slowly varying amplitude in the second circuit by means of a current of the same nature in the first circuit, in contra-distinction to the large class of devices which are in common use and which accomplish this result only in the case of alternating currents or pulsating direct currents.

In another modification variations in the potential of a source of electromotive force are utilized to produce variations in the current flow from another source. The variable current flow thus produced may be utilized in turn to operate suitable regulating means to maintain a constant potential in the first source.

In carrying my invention into effect I make use of some form of electron discharge apparatus arranged in coöperative relation with the source of potential or current which is to be controlled or regulated. I am not limited to the use of any particular form of electron discharge apparatus.

In the accompanying drawings in which Figure 1 shows diagrammatically one way in which my invention may be utilized for the amplification of electric currents, Fig. 2 shows a second modification thereof adapted to the operation of a constant potential regulator, and Fig. 3 shows a characteristic current curve of an electron discharge device which may be employed.

1 indicates a photo-electric cell having a cathode 2 of sodium, potassium or other metal which gives off electrons when subjected to the influence of light, and an anode 3. A battery 4 is placed in circuit with this cell and the current which passes through the cell when exposed to the influence of a light source 5 is caused to flow through the high resistance 6. In conjunction with this source of small currents I employ an electron discharge tube 7 comprising a cathode 8 of filamentary form provided with means for heating, consisting of a battery 9, an anode 10 and a conducting body 11 in the form of a grid interposed between the cathode and the anode. In circuit with the cathode and anode is placed a battery or other source of current 12 and a resistance 13, the value of which bears a given ratio to that of the resistance 6. In this circuit I may also place a suitable measuring instrument 14 for the purpose of measuring the amplified current.

The curve shown in Fig. 3 illustrates the relation between current between cathode and anode and grid potential in an electron discharge device which is suitable for my purpose. From this it will be seen that with a certain negative potential on the grid no appreciable current will flow between the electrodes. As this negative potential becomes less, current starts to flow and increases with decrease in the negative potential. Beyond a point A the curve becomes a straight line, that is, the change in current is directly proportional to the change in the grid potential and small changes in the grid potential produce large changes in the current.

Considering now the system shown in Fig. 1 and assuming that no current is flowing through the photo-electric cell 1, if current flows through the tube 7 there will be a drop of potential through the resistance 13 and this will cause the grid 11 to become negative with respect to the cathode 8. The greater the current the greater the drop in potential in the resistance 13 and the greater the difference in potential between the grid and cathode. Thus as the current increases the grid becomes more negative until a current value is reached at which further increase is prevented by the negative potential on the grid. The circuit should preferably be so adjusted that this value of the current will be small but will fall upon the straight portion of the current curve at some value above that represented by the point A. In order to keep the current in the tube at the value desired it may sometimes be necessary to employ a battery 15 to impose an extra potential on the grid 11 though if the tube is properly designed this may not be necessary.

If now current starts to flow through the photo-electric cell there will be a drop in potential through the high resistance 6 and this difference of potential will oppose that through the resistance 13; that is, the potential of the grid 11 will become less negative or positive with respect to that of the cathode 8. As a result more current will flow through the tube. This increased current in turn causes an increased drop in potential through resistance 13. A point is finally reached at which further increase in current is limited by the grid potential. When this point is reached the increase in the drop through resistance 13 is substantially equal to the drop through the resistance 6 and the increase in current through resistance 13 will bear a fixed ratio to the current through resistance 6, which ratio is approximately the same as the ratio between the resistances. Assume for example that the drop through resistance 6 is 25 volts. If the current curve of the device were perfectly vertical the current through resistance 13 would increase until the drop therethrough had increased 25 volts so that the grid potential would be the same as before. Since, however, the current curve has a certain slant the current may increase only to a point where the increased drop through resistance 13 is 24 volts, making the grid 11 one volt less negative or more positive than before. It will be apparent that the ratio between the current through resistance 6 and the increase in current through resistance 13 will be substantially the same as the ratio of resistance 13 to the resistance 6. If now the current through the photo-electric cell is increased so that the drop through resistance 6 increases to 50 volts the current through resistance 13 will increase until the drop therethrough has increased 48 volts from what it was originally and the grid will be two volts less negative or more positive than before. It will be apparent that there will be the same proportionality between the two currents as before and that this ratio will remain the same as long as the current falls on the straight portion of the curve.

If the system is to be used for photometric purposes the measuring device 14 may be calibrated to read directly in candle power or any suitable unit desired. It will of course be understood that this form of my invention is by no means limited to the measuring of currents derived from the photo-electric cell but will be useful in many cases for amplifying or measuring small electrical currents derived from other sources. It will also be apparent that many modifications of the system shown may be made without departing from the scope of my invention.

While my invention as illustrated in Fig. 1 is especially suitable for the amplification of feeble currents the principle involved in carrying it into effect may equally well be applied to the operation of a device for constant potential regulation. In Fig. 2 I have illustrated an organization whereby such a result may be accomplished. In this case I provide an electron discharge tube 16 with the usual cathode 17 and anode 18, and in circuit with the grid 19 of this tube may be connected two equal and opposing sources of electromotive force. The first of these, 20, consists preferably of a battery of standard cells the electromotive force of which is constant. The second source of electromotive force is the generator 21, the potential of which it is desired to maintain at a constant value. It may be desirable in some cases to use enough standard cells so that the constant electromotive force of the source 20 is substantially equal to the electromotive force of the generator 21. If this is not expedient, however, a resistance 22 may be connected across the terminals of the generator and a portion of this resistance shunted in such a way that the drop of potential between the shunt connections 23 and 24 is normally equal to the electromotive force of the source 20. As long as the drop in potential through the shunted resistance is equal to the electromotive force of the source 20 the current flow through the plate circuit of the electron discharge tube from a battery 30 will be constant. As soon, however, as this drop in potential varies there will be a change in the potential of the grid 19 with respect to the cathode 17. If the positive pole of battery 20 is connected to the grid more or less current will flow in the plate circuit of the tube according as to whether the drop of potential decreases or increases. If the negative pole of battery 20 is connected to the grid, an increase in the electromotive force of the generator will cause an increase in the plate current and vice versa. While it is not necessary that the electromotive force of the battery 20 should have the same value as the drop of potential in the shunted resistance 22, it should preferably have very nearly the same value in order that the grid 19 may normally be at substantially zero potential. In this case variations in the voltage of the generator 21 above or below normal produce corresponding positive or negative potentials on the grid 19 and a small change of potential will cause a large variation in the current flowing through the plate circuit of the tube. If, however, the value of the electromotive force of the battery 20 was appreciably greater or less than that of the equal potential drop through the shunted resistance 22 the grid 19 would normally have an appreciable voltage impressed thereon and the effect of small voltage variations of the generator 21 would be much less proportionally than before. This current variation may readily be caused to operate upon any suitable regulating means by means of a relay 25 in the plate circuit of the tube.

While my invention is not limited to any particular form of regulating device, I have indicated one simple way in which the regulation of the generator may be accomplished. A variable resistance 26 is normally in series with the shunt field 27 of the generator 21. The apparatus is so arranged, however, that when the voltage of the generator falls below the desired value the current through the plate circuit of the electron discharge tube increases, enabling the relay 25 to pick up its armature and make contact with the upper stop 28, thereby short circuiting all of the resistance and thus increasing the field strength of the generator. A condenser 29 may be connected across the relay contacts to prevent sparking when the relay drops its armature, by reason of the increase in voltage of the generator and the corresponding decrease in the current in the plate circuit.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination of an electron discharge tube having therein a cathode, an anode and a conducting grid, two sources of electromotive force connected in opposition to each other in an external circuit between the grid and the cathode, and means coöperating therewith whereby the two forces are maintained substantially equal to each other.

2. The combination of an electron discharge tube having therein a cathode, an anode and a conducting grid, two sources of electromotive force connected in opposition to each other in an external circuit between the grid and the cathode, and means coöperating therewith rendered operative by a change in one of the electromotive forces whereby the two forces are maintained substantially equal to each other.

3. The method of operating an electron discharge device comprising a cathode, anode and conducting grid which consists in causing current to flow in an external circuit between the anode and cathode of said device, applying two substantially equal and opposing potentials to the conducting grid, varying one of the potentials and utilizing the resulting current variations in the external circuit to maintain the two potentials substantially equal to each other.

4. Means for amplifying small unidirectional electric currents, comprising an electron discharge tube having grid and plate circuits, a resistance which is included in both of said circuits, and means coöperating therewith whereby an increase of current is produced in the plate circuit of an amount substantially equal to a given multiple of the value of the current to be amplified.

5. Means for amplifying small electric currents, comprising an electron discharge tube, a resistance in series therewith, and means coöperating with the tube and resistance to cause an increase in current flowing through the tube, which increase bears a predetermined definite ratio to the current which is to be amplified, which ratio is substantially independent of the operating characteristic of the tube.

6. Means for amplifying small electric currents, comprising an electron discharge tube and a resistance in series therewith, a second resistance through which the current to be amplified may be caused to flow, and means coöperating with the tube and resistances to cause an increase in the current flowing through the tube having a ratio to the current to be amplified substantially equal to the ratio of the second resistance to the first.

7. Photometric means comprising a photoelectric cell and an amplifying device electrically associated with and coöperating therewith whereby an increase in a normally small current in said device is produced of an amount equal to a given multiple of the value of the current flowing through the photoelectric cell.

8. Photometric means comprising a photoelectric cell, an electron discharge tube and means electrically associated with and coöperating therewith whereby an increase in current is produced in the tube of an amount equal to a given multiple of the value of the current in the photoelectric cell.

9. Means for amplifying small electric currents comprising an electron discharge tube, a resistance through which the current to be amplified may be caused to flow, and means coöperating with the resistance and the tube whereby an increase in current is produced in the tube of an amount equal to a predetermined given multiple of the value of the current to be amplified, which multiple is substantially independent of the operating characteristic of the tube.

10. Means for amplifying small electric currents comprising an electron discharge device having grid and plate circuits, a resistance which is included in both of said circuits, and a second resistance through which the current to be amplified may be caused to flow, and which is also included in said grid circuit.

11. Means for amplifying small electric currents comprising an electron discharge

device having grid and plate circuits, a resistance which is included in both of said circuits, and a second resistance through which the current to be amplified is caused to flow, said second resistance being included in the grid circuit in such a way that the drop in potential between its terminals opposes the drop in potential between the terminals of the first resistance when current is flowing therein.

12. Means for amplifying small electric currents comprising an electron discharge device having grid and plate circuits, a resistance which is included in both of said circuits, and a second resistance through which the current to be amplified may be caused to flow and which is also included in said grid circuit, said resistances being so related to each other that when the current to be amplified flows through the second resistance it will cause an increase in current through the first resistance of an amount equal to a given multiple of the value of the current to be amplified.

13. An electrical amplifying system comprising an electron discharge device having an incandescent cathode, an anode and a grid inclosed in an evacuated envelop, an external circuit connecting said cathode and said anode, a second external circuit connecting said cathode and said grid, means for impressing potential variations produced by the current to be amplified upon the second circuit and connections for impressing upon the second circuit potential variations produced by current changes in the first circuit, said connections being so arranged that the two sets of potential variations act in opposition to each other.

14. Means for amplifying electric currents comprising an electron discharge device having grid and plate circuits, means for impressing upon the grid circuit potential variations produced by the current to be amplified and a coupling between the two circuits whereby potential variations produced by changes in the current in the plate circuit act in opposition to the potential variations impressed upon the grid circuit by means of the current to be amplified.

15. Means for amplifying electric currents comprising an electron discharge device having a cathode adapted to be heated to incandescence, an anode and a grid inclosed in an evacuated receptacle, an external circuit connecting the cathode and grid, means for impressing a potential upon this circuit which is produced by the current to be amplified, and a second external circuit connecting the cathode and anode, and an ohmic resistance which is common to both circuits whereby current changes in the second circuit are effective in producing potential variations in the first circuit.

16. Means for amplifying small unidirectional currents comprising an electron discharge device having plate and grid circuits and an ohmic resistance included in the grid circuit through which the unidirectional current to be amplified is caused to flow.

17. The method of operating an electron discharge device comprising a cathode, anode and conducting grid which consists in causing current to flow in an external circuit between the anode and cathode of said device, and causing a small unidirectional current which is to be amplified to flow through an ohmic resistance which is included in an external circuit between the cathode and grid of said device.

In witness whereof I have hereunto set my hand this 4th day of February 1914.

IRVING LANGMUIR.

Witnesses:
William C. White,
Benjamin B. Hull.

DEFENDANT'S EXHIBIT No. 305.

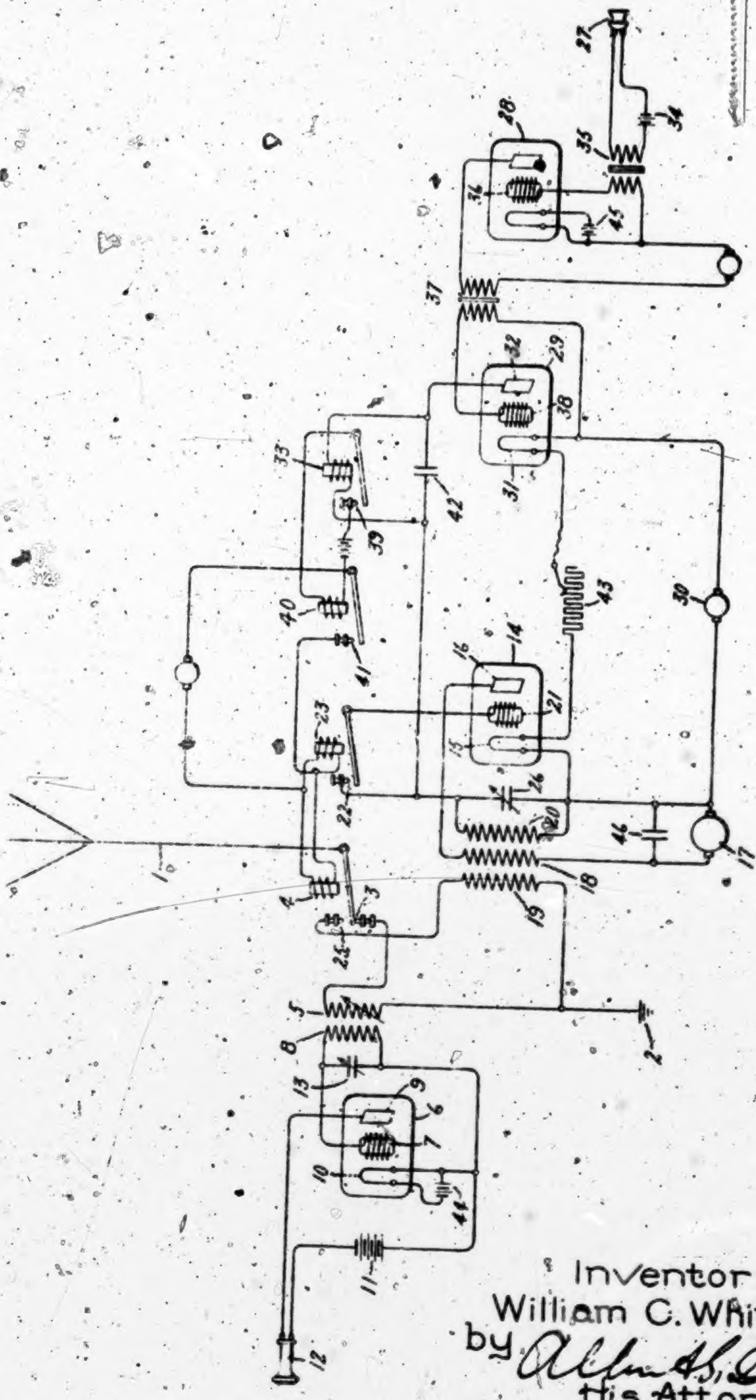
W. C. WHITE.

WIRELESS SIGNALING SYSTEM.

APPLICATION FILED APR. 23, 1915.

1,298,613.

Patented Mar. 25, 1919.


27
34
28
35
36
45
37
32
29
38
33
42
31
39
43
40
30
41
16
14
21
23
15
24
20
22
44
17
1
4
3
18
19
25
5
2
8
13
9
6
7
10
44
11
12

Inventor:
William C. White
by Albert G. Davis
His Attorney

UNITED STATES PATENT OFFICE.

WILLIAM C. WHITE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

WIRELESS SIGNALING SYSTEM.

1,298,613. Specification of Letters Patent. Patented Mar. 25, 1919.

Application filed April 23, 1915. Serial No. 23,352.

To all whom it may concern:

Be it known that I, WILLIAM C. WHITE, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Wireless Signaling Systems, of which the following is a specification.

My present invention relates to wireless signaling systems and more especially to those adapted to transmit sound by means of electromagnetic waves set up in the ether.

The object of my invention is to provide such a system in which either receiving apparatus or transmitting apparatus is automatically connected to an antenna when desired.

In carrying my invention into effect I provide suitable receiving apparatus which is normally connected to the antenna. I also provide a system of relays in connection with the transmitting apparatus which is automatically set into operation, as soon as the transmitter is influenced by sound waves, to disconnect the receiving apparatus from the antenna and connect the transmitting apparatus thereto. When the transmitter is no longer influenced by sound waves the transmitting apparatus is automatically disconnected and the receiving apparatus connected again to the antenna.

The features of my invention which I consider novel are pointed out with particularity in the appended claims. My invention itself, however, with further objects and advantages thereof will be best understood by reference to the following description taken in connection with the accompanying drawing in which I have illustrated diagrammatically a single embodiment thereof.

As indicated in the drawing, the antenna 1 is normally connected to ground at 2 through the lower contact 3 of relay 4 and the usual variable inductance 5. The receiving apparatus may be of any desired form. As here indicated it comprises an electron discharge device 6 having a controlling grid 7 which is inductively connected to the antenna by means of the coil 8. The circuit of the electrodes 9 and 10 of the electron discharge device 6, which for convenience of description I term the plate circuit, includes a battery 11 or other source of energy and a telephone receiver 12. A variable condenser 13 is employed in the circuit of the grid 7 and cathode 10 for tuning. The operating of receiving apparatus of this nature is too well known to require further description.

The transmitting apparatus which I employ in the present case comprises an electron discharge device 14 which may be so connected that it will produce continuous electrical waves of high frequency but which is normally inoperative. The plate circuit of this device includes between cathode 15 and anode 16 a source of energy 17 and a coil 18 inductively related to the coil 19 and also to the coil 20 which is connected to the controlling grid 21 when contact 22 of relay 23 is closed. While the three coils 18, 19 and 20 may be inductively related to each other as indicated other arrangements may equally well be used as, for example, a second coil may be employed in the antenna and coil 20 inductively related to this second coil. When relay 4 operates it breaks contact at 3 and makes a second contact at 25, thus connecting coil 19 between the antenna and ground and disconnecting the receiving apparatus from the antenna. With the transmitting apparatus connected to the antenna as described, and contact 22 closed, when current starts to flow in the plate circuit energy is transferred to the coil 20 and oscillations are set up in the grid circuit which includes the coil 20, grid 21, cathode 15 and variable condenser 26. These oscillations cause the potential of the grid 21 to vary. This variation in the grid potential in turn produces a variation in the current in the plate circuit. When the potential of the grid varies in a negative direction the current flowing in the plate circuit decreases and when it varies in a positive direction the current flow in the plate circuit increases. These variations in the current in the plate circuit produce an alternating current in the antenna and by varying the natural frequency of the grid circuit by varying the condenser 26 the frequency of the alternating current thus produced may be varied at will. When contact 22 is open the grid 21 being disconnected from the rest of the device, no oscillations will be produced and but little current will flow through device 14 by reason of the tendency of the grid 21 to become negatively charged.

In order to transmit sound by means of such waves it is necessary to vary the amplitude of the waves transmitted in accordance with variations in the sound waves which are to be transmitted. This may be done by varying the amplitude of the oscillations produced in the grid circuit of device 14 in accordance with the variations in the sound waves. The apparatus which I employ for this purpose comprises a telephone transmitter 27, an electron discharge device 28 which serves as an amplifier, and another electron discharge device 29 which serves to control the amplitude of the oscillations in the grid circuit of device 14.

The controlling device 29 has a source of energy 30 connected to its electrodes 31 and 32 and the plate circuit of this device also includes the winding of relay 33. When the transmitting apparatus is not in operation the current which flows through this relay winding is insufficient to operate the relay. As soon, however, as the transmitter 27 is influenced by sound waves current variations are produced in its local circuit which includes the battery 34 and the primary of transformer 35. These current variations produce potential variations in the grid 36 of the amplifier 28 and thereby corresponding current variations of greater amplitude are produced in the plate circuit of the amplifier. The variable current thus produced flows through transformer 37 and produces corresponding potential variations in the grid 38 of the controlling device 29, thereby reproducing in the plate circuit of the controlling device current variations corresponding to those produced by the transmitter 27. The current thus produced will of course be a pulsating current but the average value of it will be much greater than the normal current in the plate circuit of the controlling device and will be sufficient to operate the relay 33. When relay 33 operates it makes contact at 39 and closes the local circuit of relay 40. Relay 40 then operates and makes contact at 41 closing the local circuit of relays 4 and 23, thereby disconnecting the receiving apparatus and connecting the transmitting apparatus to the antenna. Relays 33 and 40 should be quick acting relays and relays 4 and 23 should be quick to close but should have an appreciable time lag in opening to prevent the transmitting apparatus from being disconnected during a momentary cessation of the sound waves acting upon transmitter 27. This time lag is preferably greater for relay 4 than for relay 23 in order that relay 28 may open and thus stop the production of oscillations before the antenna circuit is broken at 25. While I have indicated the telephone transmitter as being located close to the other apparatus it will be evident that it may equally well be connected thereto by a wire line of any length desired.

In the system I have described if the device 29 is not connected to the grid circuit of device 14 this grid circuit will oscillate freely and the oscillations therein will have a substantially constant amplitude. When, however, device 29 is connected as indicated to the grid circuit of device 14 some of the energy of the high frequency oscillations will be diverted from the grid circuit through the controlling device and as a result the oscillations set up therein will be damped, the amount of the damping of the oscillations of course depending upon the amount of energy diverted. The amount of energy thus diverted will vary in accordance with the variations in the potential of the controlling grid 38. As soon as energy is diverted from the grid circuit of device 14 and the oscillations therein are accordingly damped the current variations in the plate circuit of device 14 are correspondingly reduced and the high frequency current set up in the antenna is reduced. This in turn causes a further reduction in the amplitude of the oscillations in the grid circuit.

The winding of relay 33 is preferably shunted by a condenser 42 so that the alternating component of the current flowing in the plate circuit of the controlling device 29 will not have to pass through this winding. The source of energy 30 may conveniently be employed for heating the cathodes 15 and 31 of electron discharge devices 14 and 29 as indicated, the temperature of these being adjusted by the variable resistance 43. If desired the same source may be used for heating the cathodes of devices 6 and 28, although to avoid complications in the diagram I have shown separate batteries 44 and 45 for this purpose. I also find it desirable to employ a condenser 46 in shunt to the source of supply 17 in order that the high frequency component of the current in the plate circuit of device 14 will not be required to pass through the supply source.

While I have illustrated a single embodiment of my invention I do not wish to be limited to the precise form described as it will be apparent to one skilled in the art that many modifications thereof may be made without departing from the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. The combination in a wireless signaling system, of an antenna, receiving apparatus normally connected to said antenna, transmitting apparatus which is normally inoperative, and means whereby sound waves render said transmitting apparatus operative, automatically connect it to the antenna and disconnect the receiving apparatus.

2. The combination in a wireless signaling system, of an antenna, receiving apparatus normally connected to said antenna, trans-

mitting apparatus which is normally inoperative, a telephone transmitter, and means whereby the action of sound waves upon said transmitter render said transmitting apparatus operative, automatically connect it to the antenna and disconnect the receiving apparatus.

3. The combination in a wireless signaling system, of an antenna, receiving apparatus normally connected to said antenna, transmitting apparatus which is normally disconnected from the antenna, a telephone transmitter, a switch for disconnecting said receiving apparatus and connecting the transmitting apparatus to the antenna and means whereby the action of sound waves upon said transmitter causes said switch to operate.

4. The combination in a wireless signaling system, of an antenna, receiving apparatus normally connected to said antenna, transmitting apparatus which is normally disconnected from the antenna, a telephone transmitter, a switch for disconnecting said receiving apparatus and connecting the transmitting apparatus to the antenna, a relay for controlling the operation of said switch and means whereby the action of sound waves upon said transmitter causes said relay to act and operate said switch.

5. The combination in a wireless signaling system, of an antenna, receiving apparatus normally connected to said antenna, transmitting apparatus which is normally inoperative and disconnected from the antenna, a telephone transmitter, a switch for disconnecting said receiving apparatus and connecting the transmitting apparatus to the antenna, a second switch for rendering the transmitting apparatus operative, a relay for controlling the operation of said switches and means whereby the action of sound waves upon said transmitter causes said relay to act and operate said switches.

6. The combination in a wireless signaling system of an apparatus for producing continuous electrical waves which is normally inoperative, a switch for controlling the operation of said wave producing apparatus, and means actuated by sound waves to cause the closing of said switch to render said wave producing apparatus operative.

7. The combination in a wireless signaling system of apparatus for producing continuous electrical waves which is normally inoperative, a switch for controlling the operation of said wave producing apparatus, a telephone transmitter, and means whereby the action of sound waves upon said transmitter will cause said switch to close and render said wave producing apparatus operative.

8. The combination in a wireless signaling system of apparatus for producing continuous electrical waves which is normally inoperative, a switch for rendering said wave producing apparatus operative, a relay for controlling the operation of said switch, a telephone transmitter and means whereby the action of sound waves upon said transmitter will cause said relay to act and operate said switch.

9. The combination in a wireless signaling system of means for producing continuous electrical oscillations comprising an electron discharge device having a cathode, an anode and a discharge controlling grid, a normally open switch in the grid circuit of said device and means actuated by sound waves to cause said switch to close.

10. The combination in a wireless signaling system of means for producing continuous electrical oscillations comprising an electron discharge device having a cathode, an anode and a discharge controlling grid, a normally open switch in the grid circuit of said device, a telephone transmitter and means whereby the action of sound waves upon said transmitter will cause said switch to close.

11. The combination in a wireless signaling system of means for producing continuous electrical oscillations comprising an electron discharge device having a cathode, an anode and discharge controlling grid, a normally open switch in the grid circuit of said device, a relay for controlling the operation of said switch, a telephone transmitter and means whereby the action of sound waves upon said transmitter will cause said relay to act and close said switch.

12. The combination in a wireless signaling system of an antenna, transmitting apparatus which is normally inoperative and disconnected from the antenna, a switch for connecting said transmitting apparatus to the antenna, a second switch for rendering the transmitting apparatus operative, relays to close said switches and hold the same closed for an appreciable period after the force actuating the relays is withdrawn, and means rendered operative by sound waves for operating said relays.

13. The combination in a wireless signaling system of an antenna, transmitting apparatus which is normally disconnected from the antenna, a switch for connecting said transmitting apparatus to the antenna, a relay to close said switch quickly and hold it closed for an appreciable interval after the force actuating the relay is withdrawn, and means rendered operative by sound waves for actuating said relay.

14. The combination in a wireless signaling system of an antenna, normally inoperative means for producing continuous electrical waves in said antenna, a switch for rendering said wave producing means operative, means controlled by sound waves for closing said switch, and holding the same

closed during the continuance of the sound waves.

15. The combination in a wireless signaling system of an antenna, transmitting apparatus which is normally disconnected from the antenna and means actuated by sound waves for connecting said transmitting apparatus to said antenna.

16. The combination in a wireless signaling system of an antenna, transmitting apparatus which is normally disconnected from the antenna and means actuated by sound waves for connecting said transmitting apparatus to the antenna and holding it in that relation during the continuance of the sound waves.

17. The combination of normally inoperative means comprising an electron discharge device for producing continuous electrical waves and means comprising a second electron discharge device for rendering the wave producing means operative and varying the amplitude of the waves produced thereby.

18. The combination in a wireless signaling system of normally inoperative means for producing continuous electrical waves comprising an electron discharge device and means comprising a second electron discharge device for rendering said wave producing means operative and varying the amplitude of the waves produced thereby.

19. The combination in a wireless signaling system of an antenna, normally inoperative means comprising an electron discharge device for producing continuous electrical waves in said antenna, and means comprising a second electron device for rendering said wave producing device operative and varying the amplitude of the waves produced thereby in accordance with variations in sound waves.

20. The combination with normally inoperative means comprising an electron discharge device for producing continuous electrical waves, of means for rendering said wave producing means operative and varying the amplitude of the waves produced thereby.

21. The combination in a wireless signaling system of an antenna, means comprising an electron discharge device for producing continuous electrical waves in said antenna, said means being normally disconnected from said antenna and means for connecting said wave producing means to said antenna and varying the amplitude of the waves produced thereby.

22. The combination in a wireless signaling system of an antenna, means comprising an electron discharge device for producing continuous electrical waves in said antenna, said means being normally disconnected from said antenna and means comprising a second electron discharge device for connecting said wave producing means to said antenna and varying the amplitude of the waves produced thereby.

23. The combination in a wireless signaling system of an antenna, transmitting apparatus which is normally disconnected from the antenna and means comprising an electron discharge device for automatically connecting said transmitting apparatus to said antenna.

24. The combination in a wireless signaling system of an antenna, transmitting apparatus which is normally disconnected from the antenna and means comprising an electron discharge device for automatically connecting said transmitting apparatus to said antenna and varying the signals transmitted in accordance with variations in sound waves.

25. In a radio telephone system, an antenna, receiving and transmitting circuits, said antenna being normally connected to said receiving circuit, and means controlled by the voice for automatically connecting said transmitting circuit to said antenna when said system is used for transmission.

26. In a radio telephone system, an antenna, receiving and transmitting circuits, and means controlled by the voice for automatically connecting said transmitting circuit to said antenna only when said antenna is used for transmission.

27. In a radio telephone system, an antenna, receiving and transmitting circuits, voice controlled means for automatically connecting said transmitting circuit to said antenna and means for maintaining said connection only as long as transmissions are made.

28. In a radio telephone system, an antenna, receiving and transmitting circuits, voice controlled means for automatically connecting said transmitting circuit to said antenna and means for automatically breaking said connection when transmission ends.

29. In a radio telephone system, an antenna, receiving and transmitting circuits, and voice controlled means to connect said antenna to said transmitting circuit.

30. In a radio telephone system, an antenna normally connected to a receiving circuit, a normally open transmitting circuit, and voice controlled means to automatically open said receiving circuit and close said transmitting circuit.

31. In a radio telephone system, an antenna normally connected to a receiving circuit, a normally open transmitting circuit, and means controlled by sound waves to automatically open said receiving circuit.

32. In a radio telephone system, an antenna normally connected to a receiving circuit, a normally open transmitting circuit, and means controlled by sound waves to automatically close said transmitting circuit.

33. In a radio telephone system, a receiving system, a transmitting system and a common antenna therefor, a switch for connecting said antenna to either of said systems, and automatically operated voice controlled means for actuating said switch.

34. In a radio telephone system, a receiving system, a transmitting system and a common antenna therefor, a switch for connecting said antenna to either of said systems, and voice controlled means for automatically operating said switch.

35. In a radio telephone system, a receiving system, a transmitting system and a common antenna therefor, a switch for connecting said antenna to either of said systems, and voice controlled means for operating said switch, said means being operated by the closing of a normally open circuit.

36. In a radio telephone system, a receiving system, a transmitting system and a common antenna therefor, a switch for connecting said antenna to either of said systems, and means for operating said switch, said means being controlled by a make and break circuit device and voice controlled means for operating said device.

37. In a radio telephone system, a receiving system, a transmitting system and a common antenna therefor, a switch for connecting said antenna to either of said systems, and means for operating said switch, said means being controlled by a make and break circuit device, operated by sound waves.

In witness whereof, I have hereunto set my hand this 22nd day of April 1915.

WILLIAM O. WHITE.

DEFENDANT'S EXHIBIT No. 306.

I. LANGMUIR.

METHOD OF AND MEANS FOR CONTROLLING ELECTRICAL ENERGY.

APPLICATION FILED NOV. 20, 1914.

1,301,279.

Patented Apr. 22, 1919.

Fig. 1.

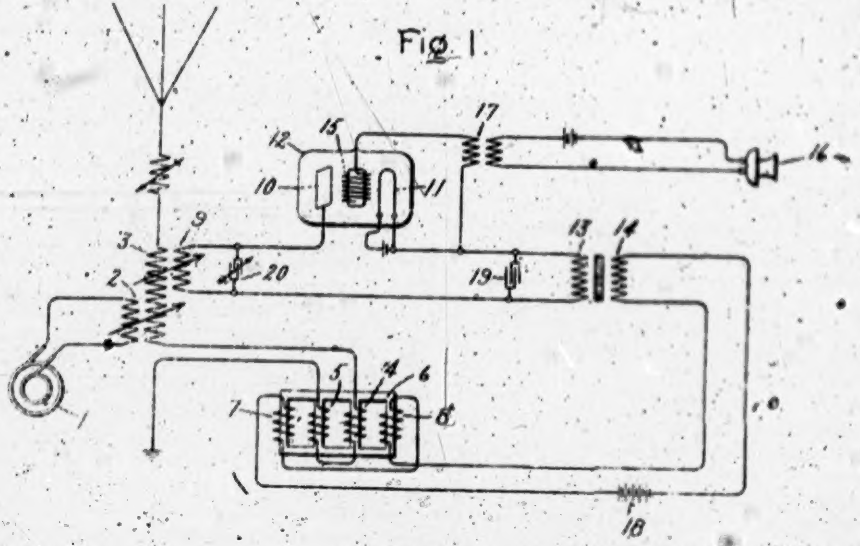
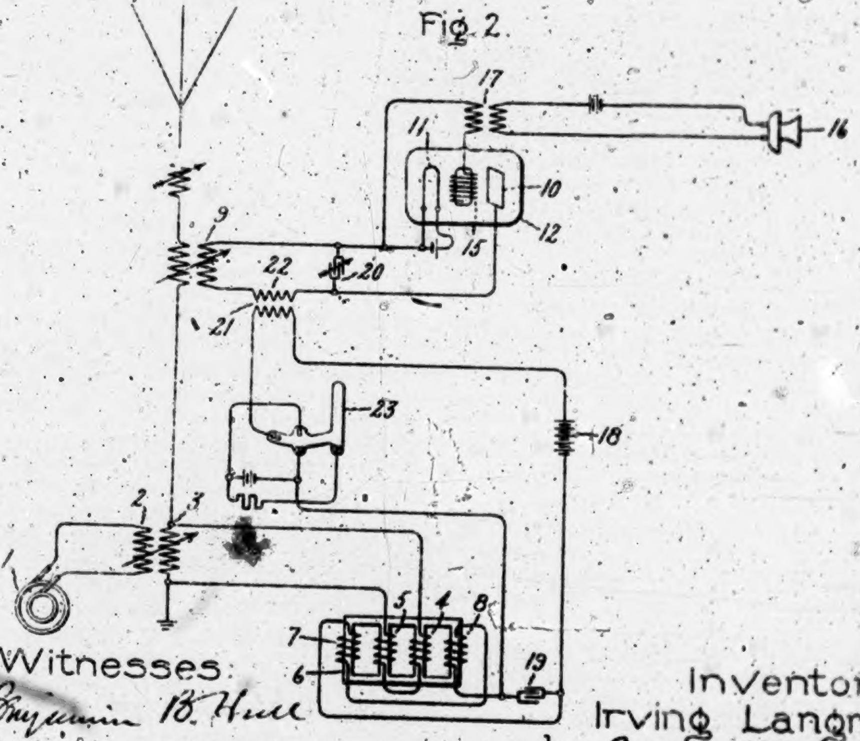

17
16
12
15
10
11
3
9
20
19
13
14
2
1
5
4
6
7
8
18

Fig. 2.


17
16
11
10
12
15
9
22
20
21
23
18
2
3
1
5
4
8
7
6
19

Witnesses:
Benjamin B. Hull
Helen Orford

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AND MEANS FOR CONTROLLING ELECTRICAL ENERGY.

1,301,279. Specification of Letters Patent. **Patented Apr. 22, 1919.**

Application filed November 20, 1914. Serial No. 873,115.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Methods of and Means for Controlling Electrical Energy, of which the following is a specification.

My present invention relates to a method of and means for controlling electrical energy, and more especially electrical energy in the form of high frequency alternating currents.

The object of my invention is to provide a system for controlling the flow of a high frequency alternating current in an electric circuit in such a way that large variations in the amplitude of the current may be produced by means of a variable controlling current of comparatively small magnitude flowing in a second circuit. A further object of my invention is to produce variable controlling current in the second circuit by means of energy derived from the source of energy which supplies the first circuit.

In carrying my invention into effect I subject a high frequency current derived from the source supplying the first circuit to the action of various modifying means in such a way as to produce a pulsating unidirectional current of the desired character to serve as a controlling current.

While in the description which follows I have illustrated the application of my invention to wireless telephony it is by no means limited to that use but is adapted to the transmission of other forms of signals by means of radiant energy or for the transmission of electric currents through wires.

The novel features which I believe to be characteristic of my invention are pointed out with particularity in the appended claims. The invention itself, however, with further objects and advantages will be best understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 is a simple diagrammatic representation of apparatus and circuit connections which may be employed in carrying my invention into effect, and Fig. 2 shows a modification thereof.

As indicated in Fig. 1 the source of high frequency alternating current 1 is inductively connected by means of the coil 2 to the coil 3 which is in series with the antenna. The amount of current flowing in the antenna is controlled by varying the inductance of the antenna circuit by variations in a controlling current flowing in a second circuit. As here indicated two reactance coils 4 and 5 wound around the magnetic core 6 are included in the antenna circuit. Wound upon the same core are two coils 7 and 8 through which a controlling current is caused to flow. The coils 7 and 8 are connected in opposition to each other, hence the magnetizing action of the current flowing in coil 7 upon coil 5 is opposite in effect to that of the current flowing in coil 8 upon coil 4. Furthermore, as coils 7 and 8 are connected in opposition the voltage induced in coil 7 by the high frequency current is opposite to that induced in coil 8. The respective coils are so designed that the voltage induced in coil 7 is equal to that induced in coil 8 and therefore the resultant effect of these voltages in the controlling circuit is zero. The combined inductance of coils 4 and 5 will vary as a function of the magnetization of the core 6, this change in inductance being due to the varying magnetic reluctance at varying magnetic densities. Since the coils 7 and 8 are connected in opposition the combined impedance of coils 4 and 5 in the antenna circuit will be uniform for the two alternations of a complete cycle of the current. It will thus be evident that the current flowing in the antenna can be controlled by varying the amount of current supplied to the coils 7 and 8. While the form of inductive device here described is the preferred form I do not wish to be limited to this specific arrangement as variations may be made therein without departing from the scope of my invention.

The greater the amount of energy which it is desired to radiate the greater will be the magnetizing force which must be supplied to the coils 7 and 8 to give the desired control. If the controlling current applied to coils 7 and 8 is the current flowing in an ordinary telephone transmitter the amplitude of the current flowing in the antenna may be varied in accordance with the variations in the amplitude of the telephone current. Inasmuch, however, as the energy variations which may be produced by an ordinary telephone transmitter supplied by a constant source of potential is comparatively small, it is not possible to produce in this way sufficiently large variations in the magnetizing force to control large enough amounts of energy to transmit sound waves over great distances. One of the objects of my invention is to produce a controlling current in the coils 7 and 8, the energy variations of which will be much greater than it is possible to produce by means of a telephone transmitter supplied by a constant potential source.

In the organization here illustrated the energy from which the controlling current is produced is diverted from the antenna circuit by means of the coil 9 which is coupled with the antenna. While I have here indicated an inductive coupling, other forms of coupling may equally well be employed. The terminals of coil 9 are connected to the anode 10 and cathode 11 of an electron discharge relay 12, and included in the circuit is the primary 13 of a transformer 14. With a device of this character it is well known that if a variable potential is applied to the grid 15 of the relay a variable current will flow through the circuit. To provide this variable potential the local circuit of the telephone transmitter 16 is inductively connected to the grid circuit of the electron discharge relay through the transformer 17. With this arrangement there will flow through the circuit comprising the coils 9 and 13 and the relay 12, a current which will vary in accordance with the variations in the telephone current. The current thus obtained will preferably be of high potential and small amplitude and this current may be stepped down in voltage by the transformer 14 and caused to flow through the magnetizing coils 7 and 8. Since the current in the secondary of the transformer 17 is an alternating current it will be necessary with this arrangement to provide an initial unidirectional magnetization of the core 6, and this may be done by means of a direct current source of energy 18 included in the controlling circuit, the potential of which must always be greater than that obtained from the secondary of transformer 14. The current flowing in the controlling circuit may be considered as a pulsating current superimposed on a constant direct current. The constant direct current will produce a constant magnetization while the pulsating current will produce a magnetization in the same direction which is proportional to the amplitude of the pulsations. The current derived from the secondary of the transformer 14 will be an alternating current of the frequency of the sound waves which act on the telephone transmitter. This current will vary in accordance with the variations in the telephone current and consequently will vary the inductance of the coils 4 and 5 thereby varying the amount of current flowing in the antenna. The current flowing in the circuit comprising coils 9 and 13 and the electron discharge relay 12 may be considered as consisting of a high frequency pulsating current produced by the rectification of every alternate half cycle, having superimposed thereon a low frequency pulsating current corresponding to the telephone current. Inasmuch as the coil 13 may offer a high impedence to the high frequency component of this current, it may be found desirable to shunt this coil by a condenser 19 of such capacity as to allow the high frequency component to pass therethrough without allowing an appreciable amount of the low frequency component to pass. A variable condenser 20 may also be employed for tuning the circuit which comprises this condenser and coil 9 to the same frequency as the source 1 in order to obtain high potentials for the operation of relay 12. The amount of current in the circuit may also be adjusted by varying the coupling between the coil 9 and the antenna.

In the operation of this system it will be seen that the energy diverted from the antenna in the coil 9 will vary in accordance with variations in the current flowing in the antenna. As the current through the relay 12 increases the current in the controlling coils will increase and there will be a corresponding increase in the antenna current. This will produce an increase in the amount of energy diverted from the antenna and will thus produce a further increase in the controlling current of the coils 7 and 8. By utilizing this reinforcing action a comparatively small variation in the telephone current may produce a large enough energy variation in the control circuit to control large amounts of energy in the antenna. This reinforcing action may in some cases become so great as to lead to instability in the operation of the system. If such is the case it will become necessary to reduce the amplitude of the variations in the energy diverted from the antenna. With the arrangement here shown, the coils 2, 3 and 9 all being coupled together, the desired effect may be produced by forming a closer coupling between coils 2 and 9, and decreasing the coupling between the coils 3 and 9, thus diverting a larger proportion of the energy used for the controlling current directly from the generator itself and a smaller portion from the antenna. It will of course be apparent that all of the energy for the controlling current may be taken directly from the generator, in which case if the potential of the generator remains constant no reinforcing action will be present. On the other hand a portion of the energy may be taken directly from the generator and the remainder from the antenna.

In the arrangement shown in Fig. 2 I have indicated the reactive coils 4 and 5 as connected in shunt to the secondary of the transformer 2. In this case as in the one already described energy is diverted from the antenna by means of the coil 9. The variable current produced in the circuit which comprises the coil 9 and the electron discharge relay 12 may be stepped down to low voltage in the coil 21 which is inductively related to coil 22 in the relay circuit and the low voltage, high frequency current thus obtained is rectified by the mercury rectifier 23 and caused to pass through the magnetizing coils 7 and 8. In this arrangement the battery 18 in the controlling circuit is connected so as to oppose the unidirection potential obtained by means of the coil 21 and the rectifier 23. As the current flowing through the coils 9 and 22 increases, the magnetization of the core 6 produced by the battery 18 will decrease. This will cause a decrease in the current flowing through coils 4 and 5 and an increase in the potential across coil 3 and in the antenna current. As the antenna current increases the amount of energy diverted from the antenna by the coil 9 will increase as in the first illustration.

While I have here indicated the coils 4 and 5 as being connected in shunt across coil 3, it will be apparent that they may equally well be connected in shunt to any two points in the antenna circuit between which there is a large enough difference of potential. It will also be apparent that instead of connecting them directly to the antenna they may be coupled therewith in other ways. Since the results which may be obtained in this way are similar to those which are secured with the series connection, I consider the two as equivalent and when I speak of the antenna circuit as including reactance, I mean to imply either the series or shunt connection.

While I have illustrated only two embodiments of my invention it will be apparent that by varying the methods of connecting the various parts thereof and by varying the particular type of apparatus employed many modifications may be made without departing from the scope of the appended claims.

Certain broad aspects of the apparatus and methods herein disclosed relating to the use of an electron discharge relay for diverting energy from an antenna and for supplying the controlling current to a variable inductance of the type herein described, are not of my invention, but are the invention of Ernst F. W. Alexanderson and are defined by the claims of his application, Serial No. 873,110, filed November 20, 1914.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a system for transmitting wireless signals of an antenna circuit supplied by a source of high frequency current, a reactance included in said antenna circuit, a second circuit including a magnetizing winding so related to said reactance that the impedance of the antenna circuit may be varied by varying the current in said magnetizing winding and means for diverting from the antenna circuit to said magnetizing winding an amount of energy sufficient to produce the desired variation in the current in said magnetizing winding.

2. The combination in a system for transmitting wireless signals of an antenna circuit supplied by a source of high frequency current, a reactance included in said antenna circuit, a second circuit including a magnetizing winding so related to said reactance that the impedance of the antenna circuit may be varied by varying the current in said magnetizing winding, and means for diverting from the antenna circuit to said magnetizing winding an amount of energy sufficient to produce the desired variation in the current in said magnetizing winding and which varies in accordance with variations in the antenna current.

3. The method of controlling the flow of high frequency alternating current in an electric circuit which consists in diverting a portion of the energy from the circuit, utilizing energy thus diverted to produce a magnetizing field, producing a pulsating current independently of the energy thus diverted, varying the magnetizing field in accordance with the variations in said pulsating current and subjecting the current in the circuit to the action of said magnetizing field.

4. The method of controlling the flow of high frequency alternating current in an electric circuit which consists in diverting from the circuit an amount of energy which varies in proportion to the amplitude of the current in said circuit, utilizing energy thus diverted to produce a varying magnetizing field and utilizing said varying magnetizing field to vary the inductive reactance of the circuit.

5. The method of controlling the flow of high frequency alternating current in an electric circuit which consists in diverting from the circuit an amount of energy which varies in accordance with variations in the amplitude of the current in said circuit, producing a pulsating current independently of the energy thus diverted, utilizing energy thus diverted to produce a magnetizing field, which varies in accordance with the variations in said pulsating current and subjecting the current in the circuit to the action of said magnetizing field.

6. The method of controlling the flow of high frequency alternating current in an electric circuit which consists in producing a pulsating current independently of the energy in said circuit, diverting from the circuit an amount of energy which varies in

accordance with variations in the amplitude of the current in said circuit and which also varies in accordance with variations in the amplitude of said pulsating current, utilizing energy thus diverted to produce a varying magnetizing field, and subjecting the current in the circuit to the action of said varying magnetizing field.

7. The combination in a wireless signaling system of an antenna circuit supplied by a source of high frequency current, a reactance coil in said antenna circuit, a second circuit including a magnetizing winding so related to said reactance coil that the impedance of the antenna circuit may be varied by varying the current in said magnetizing winding, means for diverting a portion of the energy from the antenna circuit, a third circuit having means therein for producing a pulsating current independently of the energy thus diverted, means for varying the amount of energy diverted from the antenna circuit in accordance with variations in the pulsating current flowing in said third circuit, and means for supplying energy thus diverted to the magnetizing coils.

8. The combination in a system for transmitting wireless signals of an antenna circuit supplied by a source of high frequency alternating current, a reactance included in said antenna circuit, a second circuit including a magnetizing winding so related to said reactance that the impedance of the antenna circuit may be varied by varying the current in said magnetizing winding, means for diverting from the antenna circuit an amount of energy which varies in accordance with the variations in the amplitude of the current in said circuit, and means for supplying energy thus diverted to the magnetizing coils.

9. The combination with an electric circuit supplied by a source of high frequency alternating current, of means for diverting a portion of the energy from said circuit, means for utilizing energy thus diverted to produce a varying magnetizing field, and means for utilizing said magnetizing field to vary the inductive reactance of the circuit.

10. The combination with an electric circuit supplied by a source of high frequency alternating current, of means for diverting a portion of the energy from said circuit, means for utilizing energy thus diverted to produce a magnetizing field which varies in accordance with variations in a pulsating current flowing in another circuit and means for utilizing said magnetizing field for varying the inductive reactance of the first circuit.

11. The combination with an electric circuit supplied by a source of high frequency alternating current, of means for diverting from said circuit an amount of energy which varies in accordance with variations in the amplitude of the current in said circuit, means for utilizing energy thus diverted to produce a varying magnetizing field, and means for utilizing said varying magnetizing field for varying the inductive reactance of the circuit.

12. The combination with an electric circuit supplied by a source of high frequency alternating current, of means for diverting from the circuit an amount of energy which varies in accordance with variations in the amplitude of the current in said circuit, means for utilizing energy thus diverted to produce a magnetizing field which varies in accordance with the variations in a pulsating current flowing in another circuit; and means for utilizing said magnetizing field for varying the inductive reactance of the first circuit.

13. The combination with an electric circuit supplied by a source of high frequency alternating current, of means for diverting from said circuit an amount of energy which varies in accordance with the variations in the amplitude of the current in said circuit, means for further varying the amount of energy thus diverted in accordance with the variations in an independently produced pulsating current flowing in another circuit, means for utilizing energy thus diverted to produce a varying magnetizing field, and means for subjecting the current in the first circuit to the action of said varying magnetizing field.

14. The method of controlling the flow of high frequency alternating current in an electric circuit which consists in producing a low frequency pulsating current independently of the energy in said circuit, producing by means of energy derived from the high frequency alternating current in the circuit a magnetizing field which varies in accordance with the variations in said low frequency current and subjecting the current in the circuit to the action of said magnetizing field.

15. The combination with an electric circuit supplied by a source of high frequency alternating current of a second circuit having means therein for producing independently of the energy in said first circuit a low frequency pulsating current, means for producing by energy derived from said first circuit a magnetizing field which varies in accordance with the variations in the low frequency current in said second circuit, and means for subjecting the current in the first circuit to the action of said magnetizing field.

16. The combination in a wireless signaling system of an antenna circuit supplied by a source of high frequency alternating current for transmitting wireless signals through space, means for diverting a portion of the energy from said antenna circuit,

means for utilizing energy thus diverted to produce a varying magnetizing field, and means for subjecting the current in the antenna circuit to the action of said magnetizing field.

17. The combination in a wireless signaling system of an antenna circuit supplied by a source of high frequency alternating current for transmitting wireless signals through space, a second circuit having means therein for producing a pulsating current, means for diverting a portion of the energy from said antenna circuit, means for utilizing energy thus diverted to produce a magnetizing field which varies in accordance with the pulsating current flowing in said second circuit and means for subjecting the current in the antenna circuit to the action of said magnetizing field.

18. The combination in a wireless signaling system, of an antenna circuit supplied by a source of high frequency alternating current for transmitting wireless signals through space, means for diverting from said antenna circuit an amount of energy which varies in accordance with variations in the amplitude of the current in said circuit, means for utilizing energy thus diverted to produce a varying magnetizing field, and means for subjecting the current in the antenna circuit to the action of said varying magnetizing field.

19. The combination in a wireless signaling system of an antenna circuit supplied by a source of high frequency alternating current for transmitting wireless signals through space, a second circuit having means therein for producing a pulsating current, means for diverting from the antenna circuit an amount of energy which varies in accordance with the variation in the amplitude of the current in said antenna circuit, means for utilizing energy thus diverted to produce a magnetizing field which varies in accordance with the variations in a pulsating current flowing in said second circuit, and means for subjecting the current in the antenna circuit to the action of said magnetizing field.

20. The combination in a wireless signaling system of an antenna circuit supplied by a source of high frequency alternating current for transmitting wireless signals, means for diverting from said antenna circuit an amount of energy which varies in accordance with the variations in the amplitude of the current in said circuit, means for further varying the amount of energy thus diverted in accordance with the variations in a pulsating current flowing in another circuit, means for utilizing energy thus diverted to produce a varying magnetic field and means for subjecting the current in the antenna circuit to the action of said varying magnetic field.

21. The method of controlling the flow of high frequency alternating current in an electric circuit which consists in producing by means of energy diverted from said circuit a magnetizing field which varies in accordance with variations in a low frequency pulsating current flowing in another circuit, and utilizing said magnetizing field to vary the inductive reactance of the first circuit.

22. The method of transmitting wireless signals through space which consists in impressing a radio frequency current upon an antenna, diverting from the antenna a portion of the energy thus supplied, utilizing the energy thus diverted to produce a varying magnetizing field and utilizing the magnetizing field thus produced to vary the current in the antenna.

23. The method of wireless signaling which consists in impressing a radio frequency current upon an antenna, diverting from the antenna a portion of the energy thus supplied utilizing the energy thus diverted to produce a varying magnetizing field and utilizing the magnetizing field thus produced to vary the inductive reactance of the antenna circuit.

24. The method of transmitting wireless signals through space which consists in impressing a radio frequency current upon an antenna, diverting from the antenna a portion of the energy thus supplied, utilizing the energy thus diverted to produce a magnetizing field which varies at an audio frequency, and utilizing the magnetizing field thus produced to vary the current in the antenna.

25. The method of wireless signaling which consists in impressing a radio frequency current upon an antenna, diverting from the antenna a portion of the energy thus supplied, utilizing the energy thus diverted to produce a magnetizing field which varies at an audio frequency, and utilizing the magnetizing field thus produced to vary the inductive reactance of the antenna circuit.

In witness whereof, I have hereunto set my hand this 18th day of November, 1914.

IRVING LANGMUIR.

Witnesses:
Ernst F. W. Alexanderson,
Benjamin B. Hull.

DEFENDANT'S EXHIBIT No. 307.

E. F. W. ALEXANDERSON.

WIRELESS SIGNALING SYSTEM.

APPLICATION FILED NOV. 28, 1917.

1,313,042.

Patented Aug. 12, 1919.

Fig. 1.

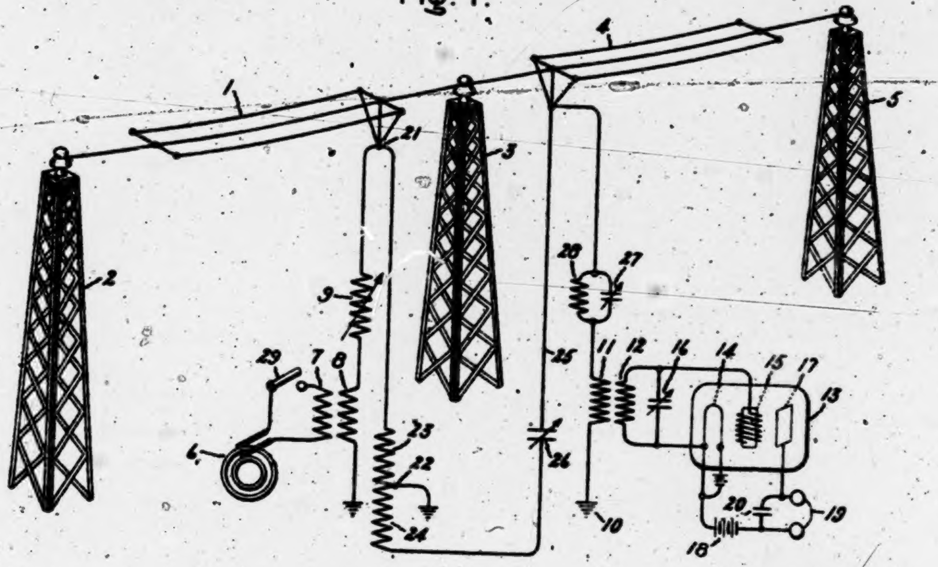

1
4
5
21
3
2
9
28
27
29
7
8
25
11
12
16
14
15
17
13
6
23
22
26
24
10
20
19
18

Fig. 2.

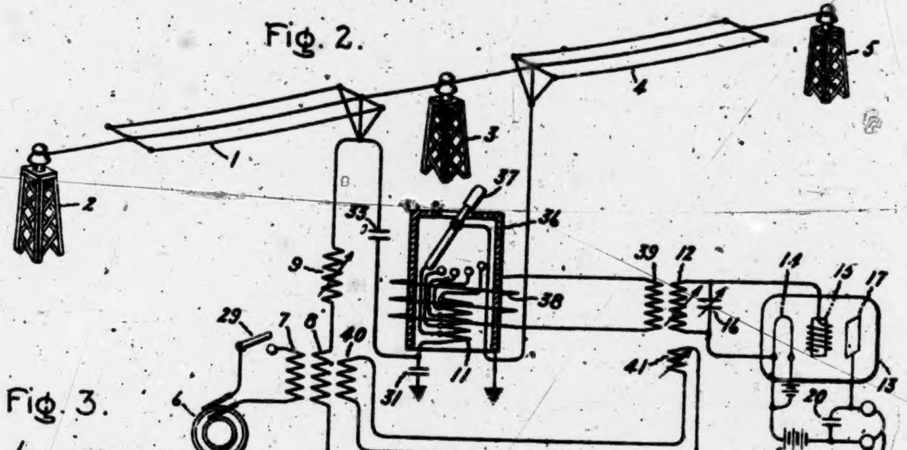
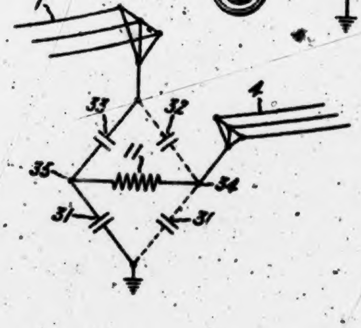

5
4
1
3
2
37
33
36
9
38
39
12
14
15
17
29
7
8
40
16
41
11
31
6
13
20
18
19

Fig. 3.


1
33
32
4
11
35
34
31
31

Inventor:
Ernst F. W. Alexanderson,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

WIRELESS SIGNALING SYSTEM.

1,313,042. Specification of Letters Patent. Patented Aug. 12, 1919.

Application filed November 26, 1917. Serial No. 203,915.

To all whom it may concern:

Be it known that I, ERNST F. W. ALEXANDERSON, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Wireless Signaling Systems, of which the following is a specification.

My present invention relates to wireless signaling systems, and more particularly to a so-called "duplex system" in which means is provided for simultaneously sending and receiving messages at a single station.

The object of my invention is to provide means for neutralizing in the receiving circuit or apparatus the effect of waves which are being transmitted from the same station. My present application is a continuation in part of my prior application, Serial No. 143,491, filed January 20, 1917.

In carrying my invention into effect I employ separate antennæ for transmitting and receiving purposes. Both of these antennæ may be suspended from the same towers in whole or in part, or may be located in fairly close proximity to each other upon separate towers. In order to overcome the effect in the receiving apparatus of the waves impressed upon the receiving antenna from the transmitting antenna, I derive from the transmitting antenna, an electromotive force equal in value and opposite in direction to the potential induced upon the receiving antenna from the transmitting antenna and impress this electromotive force upon the receiving circuit in such a manner as to neutralize in the receiving aparatus the effect of the induced potential.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to particular embodiments thereof and its mode of operation, will be best understood by reference to the following description taken in connection with the accompanying drawing in which Figures 1 and 2 show two modifications of my invention, and Fig. 3 is a diagram explanatory of the form shown in Fig. 2.

In Fig. 1, I have indicated a transmitting antenna 1 supported upon towers 2 and 3. A receiving antenna 4 which is insulated from the transmitting antenna is supported upon towers 3 and 5. The receiving antenna may be supported upon the towers 2 and 3 or may be supported independently of either of these towers but in close enough proximity to the transmitting antenna so that both antennæ may be readily connected to the operating station. The transmitting antenna may be supplied with signaling current from a high frequency alternator 6 coupled thereto by means of the coils 7 and 8. The tuning of this antenna may be accomplished by means of the usual variable inductance 9. The receiving antenna 4 is connected to earth at 10 through the coil 11 which is coupled to the coil 12 in the receiving circuit of the electron discharge device 13 which may serve as an amplifier and detector for the signals which it is desired to receive. The receiving circuit comprises the cathode 14 of the device, the grid 15 and a variable condenser 16 for tuning the circuit to the frequency of the waves to be received. The detector circuit of the device comprises the cathode 14, anode 17, a battery 18 for supplying the operating current, and the usual telephone receivers 19, these receivers being shunted by the condenser 20 which serves to by-pass the high frequency component of the current flowing in the circuit. While the arrangement shown is a preferred form of receiving device other forms may be employed if desired.

With the system thus far described, when signals are being transmitted potentials of such magnitude will be induced in the receiving antenna that the received signals will be unintelligible even though the two sets of signals may differ considerably in frequency. To overcome this difficulty I provide a shunt connection to the transmitting antenna from the point 21 to earth at 22 through the inductance 23. The inductance 24 is coupled to inductance 23 in such a way that the potential induced therein is equal and opposite to that induced from transmitting antenna 1 upon receiving antenna 4. The potential thus obtained is impressed upon the receiving antenna by means of the connecting wire 25, a variable condenser 26 being included in the circuit for tuning it to the frequency of the transmitting current. The two opposing potentials thus neutralize each other and as a result the receiving apparatus will not be affected by the waves transmitted from antenna 1. If any difficulty is experienced in adjusting the neutralizing circuit in such a way as to entirely overcome the effect of the transmitted waves a frequency trap consisting of a condenser 27 and inductance 28 may be inserted in the receiving circuit. If this frequency trap is tuned to the frequency of the waves transmitted it will offer a high impedance to waves of that frequency and a much lower impedance to received waves which differ somewhat in frequency from the waves transmitted. I have indicated as a means for controlling the current in the antenna a switch 29. It will, of course, be understood, however, the antenna current may be controlled in any desired way for transmitting either telegraphic or telephonic signals.

In the form of my invention shown in Fig. 2 the main neutralization of the induced potentials in the receiving antenna is accomplished by an arrangement of electrostatic condensers with an additional electromagnetic coupling for obtaining a final adjustment of the system. The neutralization effect in this case is to the highest possible degree independent of the frequency and, therefore, a higher degree of neutralization is possible. The neutralization is also substantially independent of fluctuations in the operation of the transmitting apparatus and the regulation of the system is simple. The operation of this system is based upon the Wheatstone bridge principle and will be best understood by reference to the diagram of Fig. 3. In this diagram the condenser 30 represents the capacity between the receiving aerial 4 and ground. The corresponding capacity on the other side is the condenser 31 which I term the "counterpoise" condenser. This is inserted in the ground connection of the receiving antenna as indicated in Fig. 2. The capacity of the receiving aerial is fixed by the antenna structure and the counterpoise condenser has a fixed capacity which is not changed during the operation of the system. The third arm of the bridge which I term the "exposure capacity of the receiving aerial" comprises the natural capacity between the transmitting and receiving antennæ and is represented by the condenser 32. This capacity also is determined by the antenna structure and is substantially constant. To balance this exposure capacity I employ a condenser 33 which I term the "exposure capacity of the counterpoise." The condenser 33 may be of such a value as to balance the system so that the points 34 and 35 at the ends of the receiving coil 11 are at substantially equal potentials in so far as the transmitted waves are concerned. In this arrangement the potential across the capacity 32 represents the induced potential on the receiving antenna and the potential across condenser 33 is a potential derived directly from the transmitting antenna which is connected to the receiving coil 11 in such a way as to neutralize therein the effect of the potential across capacity 32.

When the electrostatic balance which I have described is employed, I have found that it is desirable that the receiving set should be screened from the effect of any electrostatic field which may be produced in the receiving coil 11. In order to accomplish this purpose I have indicated in Fig. 2 a metallic shield 36 surrounding the coil 11, this shield being grounded and split vertically in such a way as to prevent the short circuiting of the magnetic lines of force. The switch 37 for adjusting the inductance of coil 11 is also inclosed within this shielding member 36. In this case instead of coupling the coil 11 directly to the coil 12 I may employ an intermediate coupling circuit comprising a coil 38, of a few turns wound around the shield 36 and a second coil 39 in circuit with coil 38 and which is coupled to the coil 12.

In actual practice it may be found desirable to proportion the condensers 31 and 33 so as to bring the system to an approximate balance. The final balancing adjustment may then be very conveniently made by the use of an additional electromagnetic coupling between the transmitting and receiving systems. I have indicated in Fig. 2 the manner in which this may be brought about. As here shown a potential is derived from the transmitting system by the coil 40 which is coupled to coil 8. The potential obtained by means of this coil is applied to the grid circuit of detector 13 by means of coil 41 which is coupled to the coil 12, the coupling between these two coils being adjustable so that by varying this coupling the desired balance between the systems may be effected.

It will be noted that in the arrangement shown in Fig. 1 the electromagnetic coupling is made to the primary of the receiving set. It may be found in practice that the receiving apparatus will be influenced by strays other than those received directly on the antenna. If this is the case, these strays will not vary in intensity in the same manner as the transmitted signals and in order to maintain a balance in the system frequent adjustment may be necessary. It will be found that less adjustment will be required and that the adjustment may be made more easily and conveniently if the electromagnetic coupling is applied to the secondary of the receiving set as indicated in Fig. 2, as in this arrangement the compensating electromotive forces do not have to pass through the transformation between primary and secondary of the receiving system but are applied directly to the part of the circuit where their effect is desired. For this reason, in case the electromagnetic coupling alone is used for compensation it may be desirable to arrange it in the manner indicated in Fig. 2.

While I have shown and described only two modifications of my invention, it will be apparent that many variations in the circuit arrangements used and the form of apparatus employed may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The combination in a wireless signaling system of a receiving antenna, a separate transmitting antenna in proximity thereto, and a receiving system comprising a receiving coil having one end connected to said receiving antenna and its opposite end connected to a point between two capacities, one of which is connected to earth and the other of which is connected to the transmitting antenna, and an electromagnetic coupling between the transmitting antenna system and the receiving system.

2. The combination in a wireless signaling system of a receiving antenna, a separate transmitting antenna in proximity thereto, a receiving system comprising a receiving coil having one end connected to said receiving antenna and its opposite end connected to a point between two capacities, one of which is connected to earth and the other of which is connected to the transmitting antenna, the two capacities being so proportioned with respect to the capacity of the receiving antenna and the mutual capacity between the antennæ, that the two ends of the coil are at substantially equal potentials with respect to the transmitted waves, and an electromagnetic coupling between the transmitting antenna system and the receiving system.

3. The combination in a wireless signaling system of a receiving antenna, a separate transmitting antenna in proximity thereto, a receiving system comprising a receiving coil having one end connected to the receiving antenna and its other end connected to a point which is of substantially equal potential, with respect to the transmitted waves, and an electromagnetic coupling between the transmitting antenna system and the receiving system.

4. The combination in a wireless signaling system of a receiving antenna system comprising primary and secondary circuits, a separate transmitting antenna in proximity thereto, the primary circuit of said receiving system comprising a receiving coil having one end connected to the receiving antenna and its opposite end connected to a point between two capacities, one of which is connected to earth and the other of which is connected to the transmitting antenna and an electromagnetic coupling between the transmitting antenna system and the secondary circuit of the receiving system.

5. The combination in a wireless signaling system of a receiving antenna system comprising primary and secondary circuits, a separate transmitting antenna in proximity thereto, the primary circuit of said receiving system comprising a receiving coil having one end connected to the receiving antenna and its opposite end connected to a point between two capacities one of which is connected to earth and the other of which is connected to the transmitting antenna, the two capacities being so proportioned with respect to the capacity of the receiving antenna and the mutual capacity between the antennæ that the two ends of the coil are at substantially equal potentials with respect to the transmitted waves, and an electromagnetic coupling between the transmitting antenna system and the secondary circuit of the receiving system.

6. The combination in a wireless signaling system of a receiving antenna system comprising primary and secondary circuits, a separate transmitting antenna in proximity thereto, the primary circuit of said receiving system comprising a receiving coil having one end connected to the receiving antenna and its other end connected to a point which is of substantially equal potential with respect to the transmitted waves and an electromagnetic coupling between the transmitting antenna system and the secondary circuit of the receiving system.

7. The combination in a wireless signaling system of a receiving antenna system comprising primary and secondary circuits, a separate transmitting antenna system in proximity thereto, the primary circuit of said receiving system comprising a receiving coil having one end connected to the receiving antenna and its other end connected to a point which is at substantially equal potential with respect to the transmitted waves and an electromagnetic coupling between a source of radiations and the secondary circuit of said receiving system whereby electromotive forces may be impressed upon the receiving system which are opposite in directions to the electromotive forces produced therein by radiation from the transmitting antenna system.

In witness whereof I have hereunto set my hand this 23rd day of November, 1917.

ERNST F. W. ALEXANDERSON.

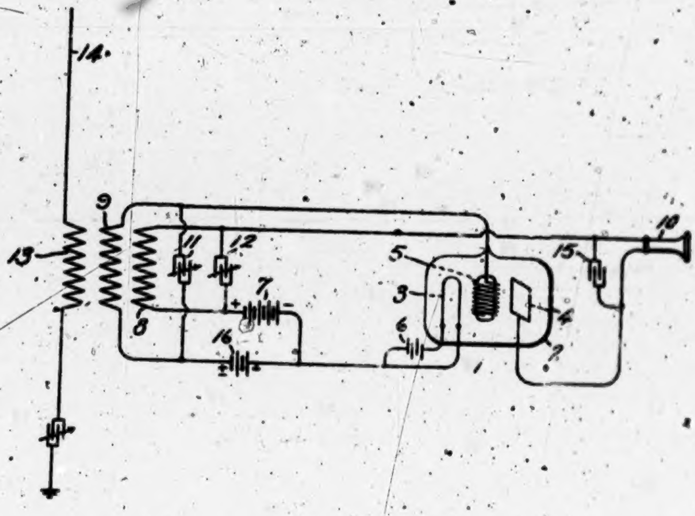
DEFENDANT'S EXHIBIT No. 308.

I. LANGMUIR.

WIRELESS SIGNALING SYSTEM.

APPLICATION FILED JAN. 29, 1920.

Reissued Nov. 21, 1922. 15,495.


14
9
13
11
12
7
8
16
5
3
6
1
4
2
15
10

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

Reissued Nov. 21, 1922. **Re. 15,495**

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

WIRELESS SIGNALING SYSTEM.

Original No. 1,313,093, dated August 12, 1919, Serial No. 83,637, filed March 11, 1916. Application for reissue filed January 29, 1920. Serial No. 354,928.

To all whom it may concern:

Be it known that I, Irving Langmuir, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Wireless Signaling Systems, of which the following is a specification.

My present invention relates to wireless signaling systems, and more particularly to an improvement in the so-called "heterodyne" system of wireless transmission. In this system it has been customary heretofore to provide at the receiving station a source of sustained oscillations having a frequency slightly different from that of the waves used for transmitting the signals which it is desired to receive. Oscillations from this local source have been caused to interact with the waves received from the distant station and produce, in a suitable device, signals, either visual or audible. In case the signals are rendered audible they may take the form of beats having a frequency dependent on the difference in frequency between the received and locally produced oscillations.

Various forms of apparatus for producing audible signals have been suggested. In my Patent 1,280,768, issued October 8, 1918, I have described a system in which the received and locally generated oscillations have been caused to interact and produce beats in a telephone receiver through the medium of an electron discharge device. In this case at least two separate agencies are required to effect the desired result, namely, a device for producing high frequency oscillations and an electron discharge device. I have discovered, however, that if an electron discharge device is used as a source of oscillations it may at the same time serve as the agency through which the two sets of oscillations interact to produce signals.

The novel features which I believe to be characteristic of my invention I have pointed out with particularity in the claims appended hereto. The invention itself, however, both as to the details of its organization and its mode of operation will be best understood by reference to the following description taken in connection with the accompanying drawing in which I have shown a single system of connections whereby the desired result may be accomplished.

In the drawing 1 represents an electron discharge tube which comprises an evacuated tube 2 having a cathode 3, an anode 4, and a conducting body 5 which is preferably in the form of a grid interposed between the cathode and anode. The cathode used in this case is in the form of a filament which may be raised to incandescence by current from any convenient source, as battery 6. The two electrodes are connected by an oscillatory circuit, containing an external source of current 7, which may be a battery, as shown, or any other direct current source, an inductance 8 and an indicating device which in this case takes the form of a telephone receiver 10. The circuit thus formed for convenience of description I call the plate circuit. The cathode is also connected externally with the grid 5 through an inductance 9. The oscillatory circuit thus formed I designate the grid circuit. The two circuits are coupled together by placing the inductance 8 in inductive relation with the inductance 9. With the circuit arrangement shown, if the inductances 8 and 9 are wound in the same direction, when current in the plate circuit begins to build up current tends to flow in the opposite direction in the grid circuit and the grid becomes negatively electrified. This cuts down the flow of current in the plate circuit and as the current decreases the grid loses its negative potential and becomes positive. This allows the current to increase again in the plate circuit. These changes may take place with great rapidity, their frequency depending upon the natural periods of the two circuits. The frequency of the current changes may be readily varied by varying the constants of the two circuits by means of the adjustable condensers 11 and 12 placed respectively in the grid and plate circuits. By this means sustained oscillations of any desired frequency may be obtained in the coil 9 and the frequency may easily be adjusted to a value slightly different from that of the waves which it is desired to receive.

Since an alternating current is produced in coil 13 there will in turn be an alternating potential induced in coil 8 in the plate circuit. Hence the total current in the plate circuit will be the resultant of the current flowing therein from the battery and the oscillatory current produced by this induced potential. The latter component may be so small that the total current in the circuit will always be in the same direction though in some cases it may be so large that there is a reversal in the direction of current flow. In any case, however, the total current may be considered as being made up of two components one of which is an oscillatory current.

Since in most cases it will be desirable to employ frequencies beyond the range of audibility of a telephone receiver, these locally produced current changes will have no effect in the receiver 10. If, however, the coil 9 is connected inductively with coil 13 of the grounded aerial 14, the received oscillations will be impressed upon the grid 5 of the electron discharge tube. These oscillations will produce a rapid variation in the potential of the grid which in turn will produce corresponding variations in the current flowing through the tube. Inasmuch as the frequency of the received oscillations differs from the frequency of the current changes set up locally in the plate circuit there will be certain periods when the two sets of oscillations are in phase with each other when they will act together and produce increased changes in the current flow through the plate circuit. There will also be periods when they are directly opposite in phase and the current changes in the plate circuit will be correspondingly reduced. As a result of this action the current flowing through the telephone receiver 10 instead of having a constant amplitude will have a regularly varying amplitude. Beats will consequently be heard in the receiver, the frequency of these beats being dependent upon the group frequency of the current variations produced in the plate circuit and this group frequency in turn being equal to the difference in frequency of the two sources. With this arrangement the only signals which can be received are those which are transmitted by means of waves which differ in frequency from the locally produced oscillations by an amount which is within the range of audibility of an ordinary telephone receiver. The waves which differ in frequency from the locally produced waves by a greater or less amount than the audible frequency of the receiver will produce no effect.

It will of course be understood that the current flowing in the plate circuit is made up of a large number of rapidly succeeding unidirectional impulses of brief duration. On account of the high frequency of these impulses the inductance of the receiver will tend to choke them back. To prevent this the condenser 15 may be shunted across the terminals of the receiver. In some cases it will be found desirable to employ a battery 16 in the grid circuit in order that normally the grid may have a certain definite potential with respect to the cathode. The amount of this potential will depend upon the design of the tube and upon the desired characteristics of the tube. It may be found advantageous in some cases to make the battery so large that the potential of the grid will always be negative. On the other hand it may be found desirable in some cases to so connect the battery that a positive potential will be imposed upon the grid. It will of course be understood that other suitable forms of current operated devices than a telephone receiver may be used for receiving the signals and in case the current fluctuations produced are not great enough to operate the indicating means, they may be amplified by means of any amplifying device desired.

While I have shown and described only a single organization whereby the desired result may be accomplished, it will be apparent that many modifications may be made without departing from the spirit of my invention. I do not wish to be limited to the particular forms of apparatus indicated as other forms may also be used for the same purpose.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a wireless receiving system of an antenna, an electron discharge device having resonant plate and grid circuits, inductances in each of said circuits which are coupled to each other whereby local oscillations may be produced of a different frequency from that of the oscillations to be received, and a coil in said antenna which is coupled to both of said inductances.

2. The combination in a wireless receiving system of an antenna, an electron discharge device having resonant plate and grid circuits, a coupling between said circuits whereby local oscillations may be produced of a different frequency from that of the oscillations to be received, and a coupling between each of said circuits and the antenna.

3. The combination in a wireless receiving system of an antenna, an electron discharge device having plate and grid circuits, one of said circuits being resonant, inductances in each of said circuits which are coupled to each other whereby local oscillations may be produced of a different frequency than that of the oscillations to be received and a coil

in said antenna which is coupled to both of said inductances.

4. The combination in a wireless receiving system of an antenna, an electron discharge device having plate and grid circuits, one of said circuits being resonant, a coupling between said circuits whereby local oscillations may be produced of a different frequency from that of the oscillations to be received, and a coupling between each of said circuits and the antenna.

In witness whereof, I have hereunto set my hand this 27th day of January, 1920.

IRVING LANGMUIR.

DEFENDANT'S EXHIBIT No. 309.

A. N. GOLDSMITH.
WIRELESS SIGNALING SYSTEM.
APPLICATION FILED JAN. 18, 1917.

1,323,759.

Patented Dec. 2, 1919.

Fig. 1

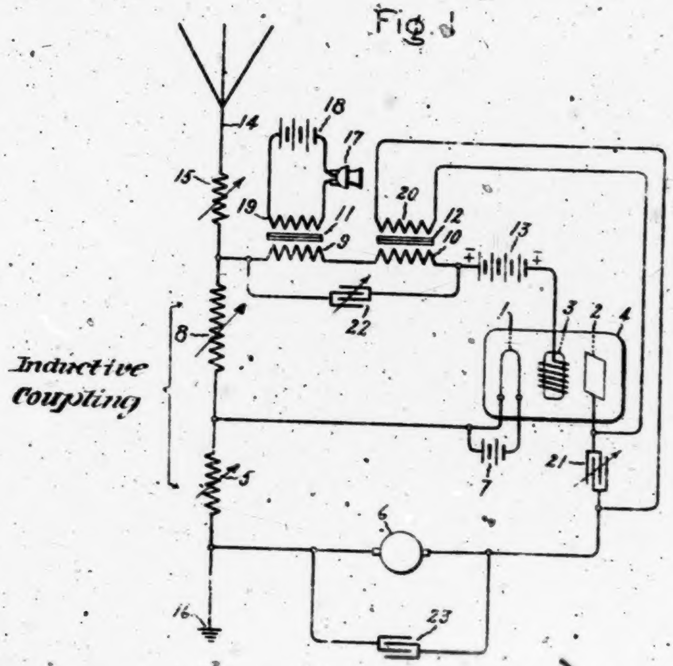

14
18
17
15
19
11
20
12
9
10
13
22
1
3
2
4
8
Inductive Coupling
7
21
5
6
16
23

Fig. 1A.

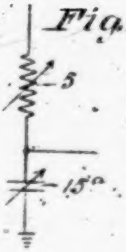
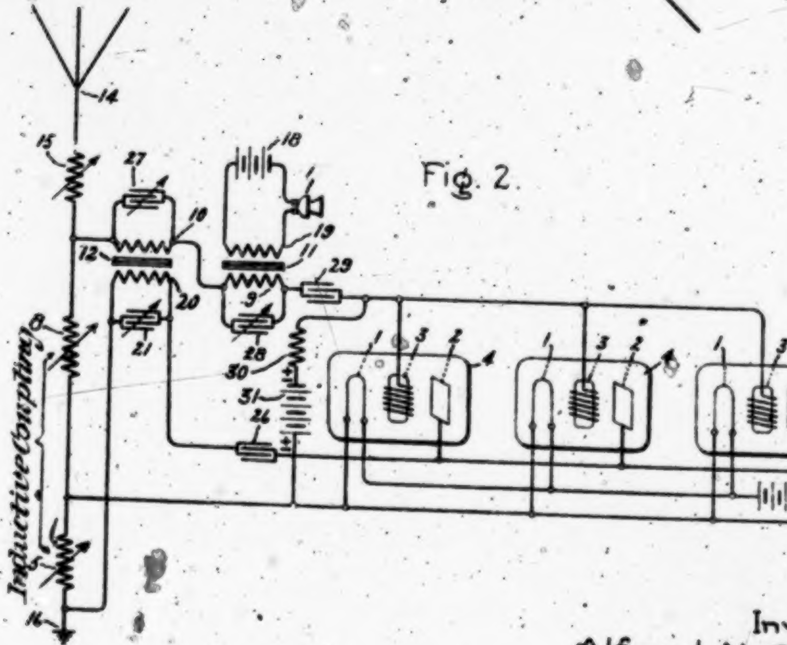


Fig. 2


14
15
27
10
18
12
19
11
29
20
9
8
21
28
30
31
24
1
3
2
4
25
6
Inductive Coupling
5
16

Inventor:
Alfred N. Goldsmith,
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

ALFRED N. GOLDSMITH, OF NEW YORK, N. Y., ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

WIRELESS SIGNALING SYSTEM.

1,323,759. Specification of Letters Patent. Patented Dec. 2, 1919.

Application filed January 18, 1917. Serial No. 143,035.

To all whom it may concern:

Be it known that I, Alfred N. Goldsmith, a citizen of the United States, residing at New York, county of New York, State of New York, have invented certain new and useful Improvements in Wireless Signaling Systems, of which the following is a specification.

My present invention relates to the efficient production of radio frequency continuous electrical oscillations in a radiating system, and to means for controlling the amplitude of such oscillations in accordance with the variations in the amplitude of a controlling current which may be produced by sound waves.

It has been found that an electron discharge device comprising an incandescent cathode, a coöperating anode, and a discharge controlling member or grid inclosed in an evacuated envelop may be employed for producing radio frequency oscillations. In order to secure this result a source of energy is placed in the plate circuit of the device, which includes the cathode, the anode, and an inductance, and this circuit is coupled with the grid circuit, which includes the cathode and grid, and a second inductance. If a suitable degree of coupling is provided between the two circuits enough energy is transferred from the plate circuit to the grid circuit to impress upon the grid the potential necessary to control the flow of current in the plate circuit in the desired manner. In some cases the electrostatic coupling between the two circuits, which is always present by reason of the capacity between the electrodes, is sufficient to bring about the desired result. In other cases this is supplemented in various ways, as, for example, by a coupling between the inductances in the two circuits, or by an additional electrostatic coupling consisting of a condenser between the grid and anode, or by a combination of the two forms of coupling. Because of the unidirectional conductivity of the electron discharge device, the current in the plate circuit will usually be pulsating in character. For practical purposes, however, it may be considered as being made up of two components, one a constant direct current, and the second an alternating current superimposed upon the direct current. In order to utilize this alternating component in a radiating system it has been customary to couple a coil in the antenna with the plate circuit inductance. It has also been customary to employ variable condensers in the plate or grid circuits, or in both circuits, for tuning the system to produce the desired frequency of oscillations. With the system heretofore employed in order to secure maximum efficiency of output, it has also been necessary that the antenna should be tuned to the same frequency as the system which produces the oscillations.

One of the objects of my invention is to provide a system in which the entire tuning may be accomplished by varying one of the constants of the antenna, and in which the necessity of an inductive coupling between the antenna and the system producing oscillations is avoided. In accomplishing this object I include the grid and plate circuit inductances directly in the antenna, and the capacity of the antenna is made use of in place of the condensers previously employed for tuning the grid or plate circuits.

In case it is desired to utilize the radio frequency oscillations produced by the electron discharge device for the transmission of sound waves, it has been proposed to superimpose upon the grid circuit of the device a variable current produced by means of the sound waves which it is desired to transmit. With this arrangement the degree of control which can be secured is limited to some extent by the amount of energy which can be controlled by an ordinary telephone transmitter. Hence it will be apparent that if means is provided for amplifying the current variations produced by the telephone transmitter a larger degree of control may be secured. A further object of my invention is to provide simple and efficient means for amplifying the audio frequency current produced by the telephone transmitter. In accomplishing this object I provide an audio frequency coupling between the grid and plate circuits. When the telephone current is superimposed upon the grid circuit corresponding but amplified variations are produced in the current in the plate circuit. These amplified current variations are, by means of the audio frequency coupling fed back into the grid circuit, and as a result the audio frequency potential variations upon the grid are made much greater than it is possible to secure by means of the original telephone current alone.

The features of my invention which I consider novel are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 shows diagrammatically one embodiment of my invention, Fig. 1^{A} shows a portion of the circuit of Fig. 1 slightly modified, and Fig. 2 shows a modification in which the possible output is increased by the use of a plurality of electron discharge devices in parallel for producing oscillations.

As indicated in the drawing, an electron discharge device is used which comprises an electron emitting cathode 1 of filamentary form, a plate-shaped anode 2, and a grid 3 interposed between the cathode and the anode, all inclosed in an evacuated envelop 4. The plate circuit of this device includes the cathode 1, anode 2, an inductance 5, and a source of energy 6, which may be a direct current generator, as indicated, or any other convenient source of direct current. Current for heating the cathode 1 to cause it to emit electrons is supplied by a battery 7, or any other convenient source of current, the means for regulating the heating current which is customarily used being omitted in order to simplify the drawing. The grid circuit comprises the cathode 1, grid 3, an inductance 8 and coils 9 and 10 of transformers adapted to the transformation of audio frequency currents, for example, the iron core transformers 11 and 12. I may also include a battery 13 for the purpose of giving the grid a normal potential at which the device operates most efficiently. The antenna 14 may be connected to the top of inductance 8 through a tuning coil 15, or directly connected to the top of coil 8, depending upon the antenna characteristics, as hereinafter explained, and the radiating system is grounded at 16 through inductances 8 and 5. With the connection thus far described the grid and plate circuits are coupled electrostatically by reason of the capacity between the electrodes 1, 2 and 3, and this coupling is supplemented by the capacity of the antenna which is in effect connected between the grid 3 and anode 2. The relative positions of coils 5 and 8 may also be made such as to furnish any desired degree of inductive coupling between the two circuits.

It is desirable to have the effective impedance in the output circuit of an oscillating discharge device, or several such devices in parallel or series, equivalent to the net internal impedance, which is mostly resistance, of such device or devices. This requires introducing the antenna reactance and resistance into the oscillating circuit of the device or devices with a transformer ratio which is, in general different from unity so as to obtain most efficient operation. The coil 15 provides such a means of varying the ratio of transformation whereby the antenna reactance and resistance are introduced into the oscillating circuit, and a condenser in the antenna circuit, usually in the ground lead, would provide a similar means of adjustment though in the opposite sense.

The arrangement thus described is adapted to produce radio frequency continuous oscillations, the frequency of which may be varied by varying the tuning of the system by means of the tuning coil 15. The tuning of the system may also be varied by varying the inductance of coil 8 or coil 5, or, if desired, a variable condenser 15^{a} may be connected between the bottom of coil 5 and ground as shown in Fig. 1^{A}. It will also be apparent that the desired result may be obtained by varying any two or more of the above-mentioned elements. In order to control the amplitude of the oscillations thus produced in accordance with the amplitude of the current produced by sound waves, current from the telephone transmitter 17 supplied by a local battery 18 is caused to flow through the primary 19 of the transformer 11. When the transmitter 17 is acted upon by sound waves, a variable telephone current will flow through the primary 19 of the transformer 11. The potential of the grid 3 is thus caused to vary in accordance with variations in the telephone current and the amplitude of the oscillations produced in the antenna will thereby be varied in accordance with the variations in the current through the transmitter. The current in the plate circuit will vary in the same way. This current will now have in addition to the radio frequency component an audio frequency component which varies in accordance with the variations in the telephone current, and this component is caused to flow through the primary 20 of transformer 12, and is thus superimposed upon the grid circuit causing a further increase in the amplitude of the audio frequency potential variations upon the grid, provided the coils 19, 9, 20 and 10, are connected in such a way as to give the proper polarity to secure the reinforcing action. Condenser 21 in the plate circuit which shunts the primary 20 is given such a value that it offers a low impedance to the radio frequency component of the plate circuit but a high impedance to the audio frequency component. The condenser 22 which shunts secondaries 9 and 10 of transformers 11 and 12 is also given such a value that it offers a low impedance path to the radio frequency component of the current in the grid circuit. Condenser 23 may be employed for shunting the source of current 6 in order that the radio frequency component of current in the plate circuit will not be compelled to pass through this source.

In the arrangement shown in Fig. 2 a plurality of electron discharge devices connected in parallel are employed for producing oscillations the cathodes of all of these devices being supplied with heating current by the common battery 24 or other suitable source. In this case the source of current 6 instead of being connected in series in the plate circuit is connected in a parallel branch, and the inductance 25 is employed to prevent the radio frequency component of the plate current from flowing through source 6 and to insure efficient production of radio frequency energy. The coil 25 acts as a maintaining inductance in that it gives rise to radio frequency potential differences at its terminals. The result is that the plate circuit voltage of the electron discharge device, that is, the voltage between filament and plate, is variable with a radio frequency component. Because of the phase of the grid potential control, the voltage is highest when the internal resistance in the bulb is highest between plate and filament, and the external voltage is least when the internal resistance is least. Therefore, less energy is absorbed per cycle in the discharge device, and increased efficiency results. Condenser 26 in the second branch of the plate circuit serves to prevent the direct current component of the plate current from flowing through this branch. In this case separate condensers 27 and 28 are employed for shunting the coils 9 and 10 instead of the single condenser 22 employed in the arrangement shown in Fig. 1. In this form of my invention, the grid circuit consists of two portions. The first portion is the inductance 30, which substantially prevents the passage of alternating current through this portion, and the battery 31 which replaces in function the battery 13, Fig. 1, for giving the grid a normal potential at which the device operates most efficiently. The second portion consists, as in Fig. 1, of the coil 8, coils 9 and 10 shunted by their respective condensers 28 and 27, and the condenser 29 which readily passes all alternating current but prevents the passage of current from battery 31 through the second portion.

While I have shown only two modifications of my invention, I do not wish to be limited to the exact circuit arrangement shown as it will be apparent that many modifications in the arrangement of the apparatus, as well as in the particular type of apparatus used, may be made without departing from the scope of my invention, as set forth in the appended claims. For example, in the arrangements shown the grid and plate circuits are supplied with internal and external capacitive coupling and external inductive coupling as well. The system will oscillate, however, if the external capacitive coupling is omitted or the internal capacitive coupling alone may be sufficient to produce the desired effect. It will also be apparent that the oscillating system which I have described may be employed for transmitting either telephonic or telegraphic signals over a transmission line.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a wireless signaling system of an antenna, and an electron discharge device having grid and plate circuits containing inductances, said antenna being connected to earth through said inductances, and said grid and plate circuits being so coupled together that radio frequency oscillations will be produced in said antenna.

2. The combination in a wireless signaling system of an antenna an electron discharge device having grid and plate circuits containing inductances connections between the antenna and earth through said inductances, said grid and plate circuits being so coupled together that radio frequency oscillations will be produced in said antenna, and means in said antenna circuit for tuning the same, thereby varying the frequency of the oscillations produced.

3. The combination in a wireless signaling system of an electron discharge device having grid and plate circuits so organized and coupled together that radio frequency oscillations will be produced therein, means for impressing an audio frequency current upon the grid circuit and thereby varying the amplitude of the oscillations produced at an audio frequency, a condenser in the plate circuit of the device which offers a low impedance to the radio frequency component of the current flowing therein, and a high impedance to the audio frequency component of the current in the plate circuit, a coil shunting said condenser through which the audio frequency component of the current in the plate circuit will flow, said coil forming the primary of an audio frequency transformer, the secondary of which is included in series in the grid circuit.

4. The combination in a wireless signaling system of an electron discharge device having grid and plate circuits containing inductances, said grid and plate circuits being so coupled together that radio frequency oscillations will be produced therein, means for impressing an audio frequency current upon the grid circuit for varying the amplitude of the oscillations produced at an audi-

ble frequency, and a coupling between said plate and grid circuits adapted to transfer energy from the plate circuit to the grid circuit at an audible frequency without transferring an appreciable amount of radio frequency energy from the plate to the grid circuit.

5. The combination in a wireless signaling system of an antenna, an electron discharge device having grid and plate circuits containing inductances, connections between the antenna and earth through said inductances, said grid and plate circuits being so coupled together that radio frequency oscillations will be produced in said antenna, means for impressing an audio frequency current upon said grid circuit for varying the amplitude of the oscillations produced in said antenna at an audible frequency and a coupling between the plate and grid circuits for transferring energy at the audio frequency from the plate to the grid circuit and thereby amplifying the effect in the grid circuit of the audio frequency current therein.

6. The combination in a system for transmitting signals of an electron discharge device having grid and plate circuits so coupled together that radio frequency currents will be produced therein. means for impressing a low frequency signaling current on the grid circuit and a coupling between the two circuits which is adapted to transfer energy at an audio frequency from the plate circuit to the grid circuit without transferring an appreciable amount of radio frequency energy.

7. The combination in a system for transmitting signals of an electron discharge device having grid and plate circuits so coupled together that radio frequency currents will be produced therein, means for impressing an audio frequency current upon the grid circuit and a coupling between the two circuits which is adapted to transfer energy at an audio frequency from the plate circuit to the grid circuit without transferring an appreciable amount of radio frequency energy.

8. The combination in a signaling system of an electron discharge device having grid and plate circuits, a coupling between said circuits for producing radio frequency currents in said circuits and for amplifying the radio frequency currents thus produced, and a coupling between the said circuits for transferring energy from the plate to the grid circuit at an audio frequency, and thereby amplifying the effect in the grid circuit of audio frequency current impressed thereon.

9. A system for producing alternating currents comprising an electron discharge device having grid and plate circuits which are so organized and coupled together that oscillations will be produced, the plate circuit of said device comprising two parallel branches, one of said branches including a source of unidirectional current and an inductance for maintaining an alternating potential upon the electrodes of the device, and the second branch including a capacity and an inductance which is coupled to an inductance in the grid circuit.

In witness whereof, I have hereunto set my hand this 12th day of January 1917.

ALFRED N. GOLDSMITH.

DEFENDANT'S EXHIBIT No. 310.

A. N. GOLDSMITH AND J. WEINBERGER.

SYSTEM FOR PRODUCING OSCILLATIONS.

APPLICATION FILED MAR. 23, 1918.

1,334,087. Patented Mar. 16, 1920

Fig. 1

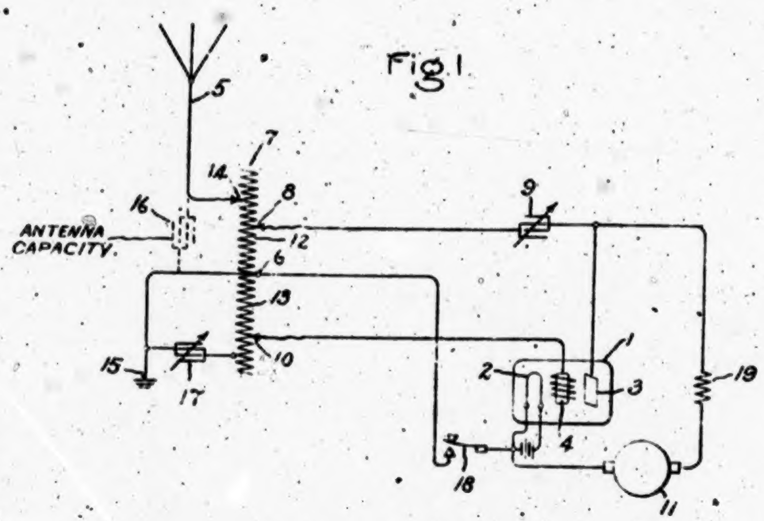
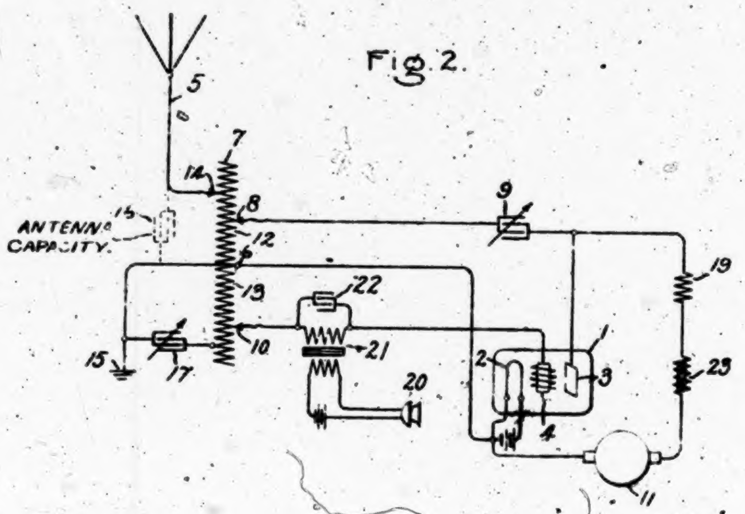

5
7
14
8
16
ANTENNA CAPACITY.
12
6
9
13
10
15
17
1
2
3
19
4
18
11

Fig. 2.


5
7
14
8
15
ANTENNA CAPACITY.
12
6
9
13
22
19
10
21
15
17
2
1
3
23
20
4
11

Inventors:
Alfred N. Goldsmith
Julius Weinberger
by Albert G. Davis
Their Attorney

UNITED STATES PATENT OFFICE.

ALFRED N. GOLDSMITH AND JULIUS WEINBERGER, OF NEW YORK, N. Y., ASSIGNORS TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

SYSTEM FOR PRODUCING OSCILLATIONS.

1,334,087. Specification of Letters Patent. **Patented Mar. 16, 1920.**

Application filed March 23, 1918. Serial No. 224,143.

To all whom it may concern:

Be it known that we, ALFRED N. GOLDSMITH and JULIUS WEINBERGER, citizens of the United States, residing at New York, in the county of New York, State of New York, have invented certain new and useful Improvements in Systems for Producing Oscillations, of which the following is a specification.

Our present invention relates to the production of electrical oscillations and particularly to the application of high frequency oscillations to radio signaling systems.

It has been found that an electron discharge device comprising an incandescent cathode, a coöperating anode, and a discharge controlling member or grid inclosed in an evacuated envelop may be employed for producing high frequency oscillations which are suitable for radio signaling purposes. It has also been found that when oscillations produced in this way are employed for radio transmission the simplest and most convenient way of applying them to the radiating system is to include the usual plate circuit inductance directly in the antenna circuit. We have found, however, that with the usual circuit arrangements employed for producing oscillations with an electron discharge device the efficiency of operation depends largely upon the values of the capacity, inductance and resistance of the oscillating circuits. In other words, for any given device, there is a certain adjustment of the values of these constants which will give the maximum output and the maximum efficiency. When the antenna is made a part of the system which produces the oscillations the capacity and resistance of the system are determined largely by the capacity and resistance of the antenna and the frequency of the oscillations is then adjusted to the desired value by varying the inductance. Under such conditions it will be found that the values of capacity, resistance and inductance thus imposed are not the values which would give maximum output and maximum efficiency for the particular device used.

The object of our invention is to overcome this disadvantage and provide a system of connections whereby the constants of the oscillating system may be made independent of the antenna constants and may be adjusted to those values which will give the best efficiency of operation.

The novel features which we believe to be characteristic of our invention are pointed out with particularity in the appended claims, the invention itself, however, both as to its organization and method of operation can best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 illustrates the application of our invention to a transmitting system for radio telegraphy, and Fig. 2 shows its application to a transmitting system for radio telephony.

As indicated in the drawing an electron discharge device 1 which comprises the usual incandescent cathode 2, plate-shaped anode 3 and grid 4, is employed for producing the high frequency oscillations which are to be supplied to the antenna 5. In the present system the cathode 2 is connected to the approximate middle point 6 of an inductance 7 and the anode 3 is connected by means of the variable connection 8 to another point in this inductance through the condenser 9. The grid 4 is connected to another point in the inductance 7 on the opposite side of the central point 6 by means of the variable connection 10. The energy for producing the oscillations is supplied by a direct current generator 11 connected between cathode 2 and anode 3. It will be apparent that portions 12 and 13 of the inductance 7 which are included in the plate and grid circuits respectively of the device 1 are inductively coupled to each other and that therefore oscillations will be produced in the circuits of the device. This coupling is variable at will and its value may be chosen within certain limits without affecting the operation. The frequency of oscillations may be adjusted by varying the condenser 9 and the points of connection 8 and 10 and the constants of the system at the same time may be adjusted to give the maximum efficiency of operation. The antenna 5 is connected to inductance 7 by the variable connection 14 and the central point 6 of the inductance is grounded at 15. Thus it will be seen that the portion of inductance 7 which is included in the plate circuit of the device is also included in the antenna circuit and that the capacity of the antenna, which is indicated in its approximate equivlent by the condenser 16 shown in dotted lines, will be in shunt to this inductance. As a result it will be apparent that the capacity of the antenna forms a part of the system in which the oscillations are produced and since this capacity is fixed it may not be possible to secure the adjustment of the constants of the system necessary for the best efficiency of operation. To overcome this disadvantage we compensate for the effect of the antenna capacity by the use of a capacity 17 which is connected in shunt to the inductance 13 in the grid circuit and which preferably has a value approximately equal to the value of the antenna capacity. When the final adjustments are made the portions 12 and 13 of the inductance 7 will preferably have an equal number of turns and under these conditions the effect of the antenna capacity will be completely neutralized by the condenser 17 and the adjustment of the system in which the oscillations are produced will be independent of the capacity of the antenna over a wide range of wave lengths.

In order to adapt the system which we have described for the transmission of radio signals, telegraph key 18 may be inserted as indicated in the plate circuit of the device. We also find it desirable to employ what we term a radio frequency choke coil 19 in series with the generator 11. This radio frequency choke coil is so designed that it is resonant to the frequency of the oscillations produced and under these conditions it will act as a substantially infinite impedance to the high frequency current, and at the same time permit of the free passage of the direct current which feeds the plate circuit.

In order to adapt the system which we have described for producing oscillations to the transmission of modulated signals, and particularly signals modulated by speech currents, the current produced in a telephone transmitter 20 may be applied to the grid circuit of the device by means of an audio frequency transformer 21, as indicated in Fig. 2. The secondary of the transformer 21 is preferably shunted by a condenser 22 in order to by-pass the high frequency component of the current in the grid circuit.

The operation of this system is as follows: Suppose the device 1 is producing sustained oscillations of a given amplitude in the antenna. When the telephone transmitter 20 is affected by sound waves voltages corresponding to these waves are induced in the secondary of the transformer 21 and thus directly impressed on the grid 4. The changes in grid potential cause exactly similar and much greater reactance voltages to be produced across the audio frequency choke coil 23 in the circuit which supplies the energy for producing oscillations. Therefore the plate voltage is varied as these reactance voltages add to or are subtracted from the direct current voltage of the generator 11. The radio frequency energy output is directly proportional to the energy input into the plate circuit of the device and the plate energy input is almost directly proportional to the plate voltage. It is therefore clear that as the plate voltage is varied by the reactance voltages across 23 the radio frequency energy output is varied in almost exact proportion. These are the conditions sought for in radio telephony and the method described gives extremely accurate and efficient reproduction of speech as well as being electrically efficient.

While we have described and illustrated our invention with especial reference to the transmission of telegraphic signals by the usual key and to the transmission of sound waves by the aid of the usual telephone transmitter, it will be apparent that our invention is by no means limited to the particular arrangements shown for controlling the antenna current, but that many other modifications may be made in the system of connections used without departing from the scope of the appended claims.

What we claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a system for producing electrical oscillations of an electron discharge relay having inductively coupled plate and grid circuits, a third circuit which includes an inductance in the plate circuit of said relay and a capacity which shunts said plate circuit inductance, and a capacity connected in shunt to an inductance in the grid circuit of said relay and having a value corresponding approximately to the capacity of the third circuit.

2. The combination in a system for producing electrical oscillations of an electron discharge relay having coupled plate and grid circuits, a radiating antenna connected to an inductance in the plate circuit of said relay in such a way that the capacity of said antenna shunts said plate circuit inductance, and a capacity connected in shunt to an inductance in the grid circuit of said relay and having a value corresponding approximately to the capacity of the antenna.

3. The combination in a system for producing electrical oscillations of an electron discharge relay having coupled plate and grid circuits, a third circuit which includes an inductance in the plate circuit of said relay and means for compensating for the capacity of the third circuit and thereby rendering the adjustment of the system in which oscillations are produced independent of the capacity of the third circuit.

4. The combination in a radio signaling

system of means for producing radio frequency oscillations comprising an electron discharge relay having coupled plate and grid circuits, a radiating antenna directly connected to an inductance in the plate circuit of said relay and means for compensating for the capacity of the antenna and thereby rendering the adjustment of the oscillation producing means independent of the capacity of the antenna.

5. The combination in a system for producing electrical oscillations of an electron discharge relay having a cathode, an anode and a grid, an inductance having its approximate central point grounded and connected to the cathode of said relay, adjustable connections between the anode and grid of said relay and points in said inductance on each side of the central point, whereby separate portions of said inductance are included in the plate and grid circuits of the relay, a third circuit which includes the inductance of the plate circuit and a capacity in shunt to the grid circuit inductance having a value corresponding approximately to the capacity of the third circuit.

6. The combination in a system for producing electrical oscillations of an electron discharge relay having a cathode, an anode and a grid, an inductance having its approximate central point grounded and connected to the cathode of said relay, adjustable connections between the anode and grid of said relay and points in said inductance on each side of the central point whereby separate portions of said inductance are included in the plate and grid circuits of the relay, a radiating antenna directly connected to the plate circuit inductance and a capacity in shunt to the grid circuit inductance having a value corresponding approximately to the capacity of the antenna.

In witness whereof we have hereunto set our hands this 18th day of March, 1918.

ALFRED N. GOLDSMITH.
JULIUS WEINBERGER.

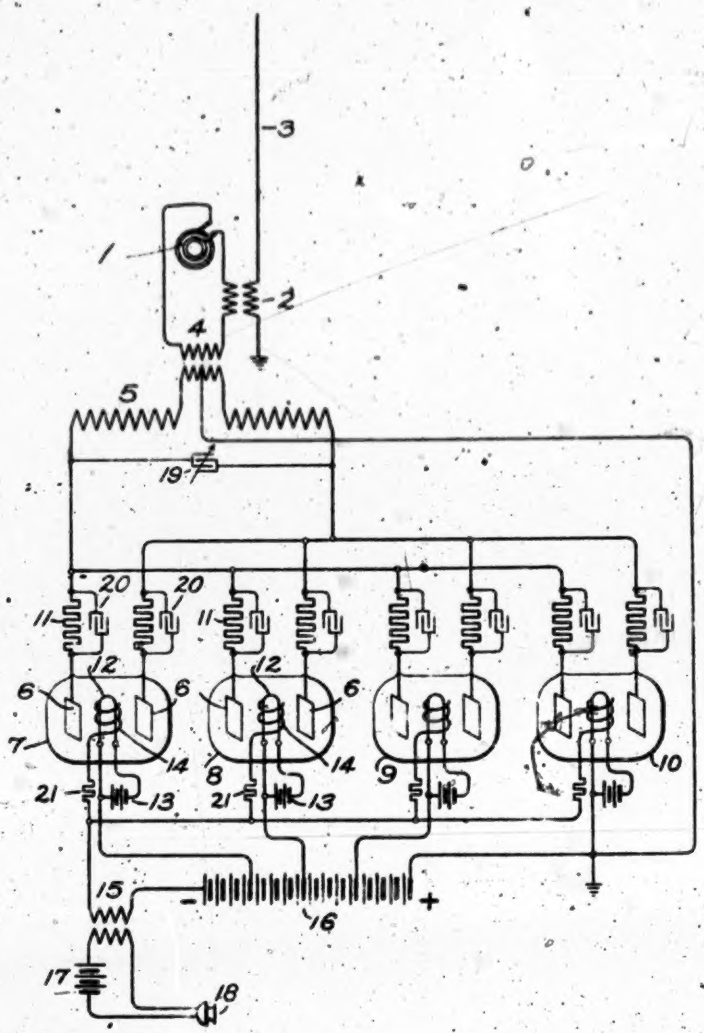
DEFENDANT'S EXHIBIT No. 311.

E. F. W. ALEXANDERSON.

METHOD OF AND MEANS FOR CONTROLLING ELECTRICAL ENERGY.

APPLICATION FILED JUNE 15, 1914. RENEWED SEPT. 24, 1919.

1,340,101. **Patented May 11, 1920.**


3
1
2
4
5
19
20
20
11
11
12
12
6
6
6
6
7
14
8
14
9
10
21
13
21
13
15
-
16
+
17
18

Witnesses:
Chas. B. Stokes
J. Ellis Glen.

Inventor:
Ernst F. W. Alexanderson,
by Albert G. Davis
His Attorney

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AND MEANS FOR CONTROLLING ELECTRICAL ENERGY.

1,340,101. Specification of Letters Patent. Patented May 11, 1920.
Application filed June 15, 1914, Serial No. 845,115. Renewed September 24, 1919. Serial No. 325,969.

To all whom it may concern:

Be it known that I, Ernst F. W. Alexanderson, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Methods of and Means for Controlling Electrical Energy, of which the following is a specification.

My present invention relates to a method of and means for controlling electrical energy and more particularly to the control of energy used for transmitting signals through space. While in the description which follows I have illustrated its utility when applied to wireless telephony, it is capable of use for other purposes as well.

In a copending application, Serial No. 835,433, filed April 30, 1914, I have described and claimed a system of wireless signaling in which a comparatively large amount of energy may be controlled by means of the feeble current set up in an ordinary telephone transmitter. In this case the amount of energy transmitted to the antenna from a local source of high frequency current is varied by means of a relay or electron discharge device which is controlled by the current from a telephone transmitter in such a way as to vary its conductivity. With this arrangement, in order to produce the desired variation in the antenna current, it is necessary that a considerable amount of the total energy of the local source shall be absorbed in the relay circuit. In all of the modifications shown in my prior application the greater part of the energy is absorbed in the relay itself. Hence the amount of energy which may be effectively communicated to the antenna is limited by the absorptive capacity of the relay used. At the present time this capacity is limited by difficulties which appear to be inherent in the manufacture of apparatus of this type.

The energy which may be controlled in such a system might be increased by connecting several relays in parallel, in which case the amount which could be controlled would vary directly as the number of relays used. By connecting the relays in parallel with resistance in series therewith according to my invention however the amount of energy which can be controlled will vary substantially as the square of the number of relays used.

My invention will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have shown diagrammatically a system of connections whereby the desired result may be accomplished. As here indicated a source of high frequency energy 1 is connected through the usual transformer 2 with the antenna 3. The primary 4 of an oscillation transformer is also connected in series with the source 1 and the primary of transformer 2. The terminals of the secondary 5 of the oscillation transformer are connected to the anodes 6 of a series of electron discharge devices or relays 7, 8, 9, 10 through resistances 11 as shown. These relays also comprise filamentary cathodes 12 with local sources of current 13 for heating the same. The cathodes are surrounded by grid-shaped conducting bodies 14. The grids are all connected to one terminal of the secondary of transformer 15, to the other terminal of which is connected a battery 16 and the cathodes are connected to various points in the battery. One end of the battery is preferably grounded as shown. The primary circuit of transformer 15 includes a source of direct current 17 and a telephone transmitter 18. The cathodes are also connected to the middle point of the secondary 5 of the oscillation transformer. An adjustable condenser 19 is preferably connected across the terminals of the secondary of the oscillation transformer 5, although in some cases the capacity of the relays may be great enough so that this will not be required.

With the arrangement here shown it will be seen that the current in the antenna will vary in accordance with the current through the primary 4 of the oscillation transformer. The amplitude of the current in the primary 4 will in turn depend upon the current flowing in the secondary circuit. It will be apparent that a certain proportion of the energy from the source 1 will be diverted to the secondary circuit and absorbed in the resistances and the relay devices therein. The system may be so designed and adjusted that the energy thus absorbed will in general bear a certain ratio to the total amount of energy derived from the source 1, hence by varying the amount of energy absorbed in the secondary circuit the amplitude of the antenna current will be varied in substantially the same proportion.

The relays used may assume a great variety of forms. In the form of relay indicated in the present case there will normally be a flow of negative electricity from the cathode to the anodes but no flow of current in the opposite direction. The amplitude of the current flow through the relay may be varied by varying the potential impressed upon the grids 14. If a large enough negative potential is impressed thereon the flow of current may be stopped altogether. If a positive potential is impressed upon the grids the current flow will be increased. For convenience of description let it be assumed that the potential of the grid 14 is such that little or no current will flow through the relay 7 when the high frequency potential of the secondary 5 of the oscillation transformer is applied to the electrodes. The negative potential of the grids of the relays 8, 9 and 10 with respect to their cathodes will be progressively greater. If now a current wave is produced in the transformer 15 of such a direction as to overcome the negative potential of the grids 14, current will begin to flow first through the relay 7 and will gradually increase to a maximum value. If the potential of the current wave is great enough it will gradually overcome the negative potential of all of the grids and current will begin to flow successively in relays 8, 9 and 10. It will of course be understood that when the voltage impressed upon the grids from the transformer 15 begins to decrease the reverse action will take place, that is, current will cease to flow first in relay 10, next in relay 9 and so on until the impressed potential falls to zero and no current will flow as in the begining. The relays may be so designed and the potentials applied thereto so chosen that when the current in relay 7 reaches its maximum, current will begin to flow in relay 8 and when the current in relay 8 reaches its maximum, current will begin to flow in relay 9 and so on.

Relay devices of the general type shown herein vary somewhat in their characteristics and in some cases the proportionality between the current flow and the voltage impressed upon the grid is constant only over a somewhat limited range. In such cases it may be desirable to so choose the potentials applied to the grids that before the current in one relay has reached its maximum, current will begin to build up in the next relay and so on. In this way the system may be so designed that the current flow therein will be substantially proportional to the voltage variation in the transformer 15 throughout the entire range.

When current first begins to flow in the relay circuit the greater part of the drop in potential will occur in the relay itself and hence the relay will be called upon to absorb most of the energy of the secondary circuit. As the current increases however the drop through the resistances 11 will increase and the proportionate amount of energy absorbed by the relay will decrease. The maximum energy which the relay will be required to absorb will be when the current has reached one-half of its maximum value and the relay is consuming one-half of the voltage. When the current reaches its maximum value in the relay the amount of energy which the relay will be required to absorb will be practically negligible, the principal drop being in the resistance.

Suppose, for example, that it is desired to control in the secondary circuit a maximum of 10 kilowatts of energy which may be represented by .5 ampere at 20,000 volts. If we do this with a single relay and secure a gradual regulation of the energy from no load to full load, the relay will be called on to consume a maximum of .25 ampere at 10,000 volts or 2.5 kilowatts. It will also be required to absorb energy during the entire period during which the change from minimum to a maximum takes place.

Suppose now it is desired to control a maximum of 160 kilowatts of energy which is represented by 8 amperes at 20,000 volts. If we use four relays as indicated in the drawing each relay will be called upon to take 2 amperes. The maximum amount of energy which any one relay will be called upon to absorb will be 1 ampere at 10,000 volts or 10 kilowatts. The change from minimum to maximum in each relay however will occur in one-quarter of the time required in the case where a single relay was used. Hence the average amount of energy absorbed will be only one-quarter of 10 or 2.5 kilowatts. Thus it will be seen that four relays of the same capacity will be able to control 16 times as much energy as the single relay.

In the type of relay here shown there is an appreciable capacity between the anodes. This results in considerable current flowing through the relay between the anodes when the system is not being used for transmitting signals. As a result a large amount of energy is needlessly wasted in the resistances 11. In order to avoid this it may be desirable to shunt each of these resistances by a condenser 20. This will cut down the high frequency alternating current but will not interfere with the unidirectional flow of current through the relay between the cathode and anodes. It will of course be understood that the resistance 11 may equally well be inserted in series with the cathode instead of in series with the anodes.

In order to prevent the grids 14 from consuming an unnecessary amount of current when they become highly positive, resistances 21 may be inserted in series therewith.

While in the preceding description I have described the application of my system with high vacuum relays which are especially adapted for use with high voltages and low currents, my invention is by no means limited to use with this type of relay. It is equally applicable with relays adapted for lower voltages and larger currents and in which there are appreciable amounts of gas or vapor present.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. The method of varying the amplitude of the current flow in a circuit comprising a plurality of parallel paths, each of which contains a relay device, which consists in gradually varying the conductivity of each one of the paths in succession by varying the electrical field of the relay device therein.

2. The method of varying the amplitude of the current flow in a circuit comprising a plurality of parallel paths each of which contains a resistance and a relay device, which consists in gradually varying the conductivity of each one of the paths in succession by varying the electrical field of the relay device therein.

3. The method of varying the amplitude of the current flow in a circuit which comprises a plurality of parallel paths each of which contains a relay device, which consists in gradually varying the conductivity of each one of the relay devices in succession.

4. The method of transmitting signals by varying the amplitude of the current flow in a circuit which comprises a plurality of parallel paths, which consists in gradually varying the conductivity of each one of the paths in succession between minimum and maximum values and maintaining the maximum value in at least one of the paths while varying the conductivity of the others.

5. The method of varying, in accordance with signals to be transmitted, the amplitude of current flow in an antenna having a source of energy connected thereto, which consists in diverting a certain proportion of the energy from said source through a circuit containing a plurality of parallel paths and gradually varying the conductivity of each one of said paths in succession in accordance with the signals to be transmitted.

6. The method of varying the amplitude of current flow in an antenna having a source of energy connected thereto, which consists in diverting a certain proportion of energy from said source through a circuit containing a plurality of parallel paths and gradually varying the conductivity of each one of said paths in succession.

7. The method of varying the flow of current in a circuit connected to a source of energy and having a series of relay devices connected thereto in parallel, which consists in so varying the electrical field in the relay devices that the current flow therein will vary successively in the entire series from a minimum to a maximum.

8. The combination in a wireless signaling system of a source of high frequency electrical energy, an oscillation transformer in series therewith, a plurality of relay devices connected in parallel to the secondary of said transformer and means for varying the electrical field in said relay devices to successively vary the current flow therethrough from a minimum to a maximum.

9. The combination in a wireless signaling system of an antenna, a source of energy connected thereto, a secondary circuit comprising a plurality of parallel paths for diverting a certain proportion of the energy from said source, a relay device in each of said parallel paths and means for varying the conductivity of each of said paths in succession.

10. The combination in a wireless signaling system of an antenna, a source of energy connected thereto, a secondary circuit comprising a plurality of parallel paths for diverting a certain proportion of the energy from said source, a relay device in each of said parallel paths, and means for successively varying the electrical field in each of said relay devices in accordance with the signals to be transmitted.

11. The combination in a wireless signaling system of an antenna, a source of energy connected thereto, a secondary circuit comprising a plurality of parallel paths for diverting a certain proportion of the energy from said source, and means for varying the conductivity of each of said paths in succession in accordance with the signals to be transmitted.

12. The combination in a wireless signaling system of an antenna, a source of energy connected thereto, a secondary circuit comprising a plurality of parallel paths for diverting a certain proportion of energy from said source, a relay device comprising a plurality of electrodes in each of said parallel paths, a conducting body interposed between the electrodes in each of said relay devices, means for normally impressing a different potential upon each of said conducting bodies, and means for varying the potential impressed upon said conducting bodies.

13. The combination in a wireless signaling system of an antenna, a source of high frequency electrical energy connected thereto, a secondary circuit comprising a plurality of parallel paths for diverting a certain proportion of the energy from said source, a relay device comprising a plurality of

electrodes in each of said parallel paths, a conducting body interposed between the electrodes of each of said relay devices, and means for successively varying the potential of said conducting bodies in such a way as to successively vary the current flow through said relay devices from a minimum to a maximum.

14. The combination in an electrical distribution system of a source of high frequency alternating current, a circuit connected thereto comprising a plurality of parallel paths each of which contains a relay device, and means for gradually varying the conductivity of each one of the relay devices in succession.

15. The combination in an electrical distribution system of a source of high frequency alternating current, a circuit connected thereto comprising a plurality of parallel paths each of which contains an electron discharge device, and means for varying the conductivity of each one of said electron discharge devices in succession.

16. The combination in a high frequency signaling system of a signaling circuit, a source of high frequency energy connected thereto, a secondary circuit for diverting a portion of the energy from said source, a relay device in said circuit for varying the amount of energy diverted and a resistance in series with said relay device for absorbing a portion of the energy diverted.

17. The combination in a high frequency signaling system of a signaling circuit, a source of high frequency energy connected thereto, a secondary circuit for diverting a portion of the energy from said source, a relay device comprising a plurality of electrodes interposed in said secondary circuit, a conducting body interposed between the electrodes of said relay, means for impressing a variable potential upon said conducting body to vary the amount of energy diverted from said source and a resistance in series with said relay device for absorbing a portion of the energy diverted.

18. The combination in an electrical distribution system of a source of high frequency alternating current, a circuit connected thereto for diverting a variable amount of energy from said source, an electron discharge device in said circuit, means for varying the conductivity of said electron discharge device to vary the amount of energy diverted and a resistance in series with said electron dischagge device for absorbing a portion of the energy diverted.

19. The combination in an electrical distribution system of a source of high frequency alternating current, a circuit connected thereto comprising a plurality of parallel paths each of which contains an electron discharge device, means for varying the conductivity of each one of said electron discharge devices in succession and resistances in series with said electron discharge devices for absorbing a portion of the energy in the circuit.

20. Means for controlling the flow of high frequency alternating current in a circuit comprising a plurality of parallel paths comprising a relay device having a cathode and an anode in each of said paths, a current controlling member interposed between said cathode and anode in each of said devices for gradually varying the current flow therethrough, means for impressing a variable potential upon said controlling members and resistances in series with said relay devices for absorbing a portion of the energy in the circuit.

In witness whereof I have hereunto set my hand this 12th day of June, 1914.

ERNST F. W. ALEXANDERSON.

Witnesses:

BENJAMIN B. HULL,
HELEN ORFORD.

Correction in Letters Patent No. 1,340,10

It is hereby certified that in Letters Patent No. 1,340,101, granted May 11, 1920, upon the application of Ernst F. W. Alexanderson, of Schenectady, New York, for an improvement in "Methods of and Means for Controlling Electrical Energy," an error appears in the printed specification requiring correction as follows: Page 3, line 19, claim 5, for the word "low" read *flow;* and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 6th day of July, A. D., 1920.

[SEAL.]

M. H. COULSTON,
Acting Commissioner of Patents.

Cl. 250—6.

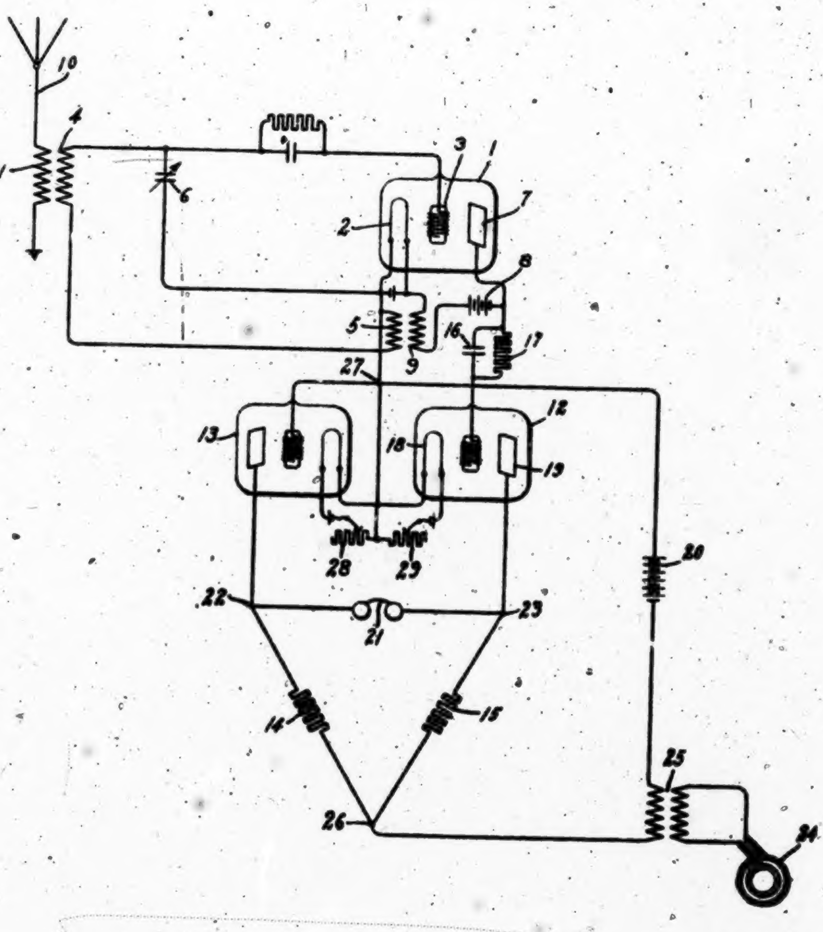
DEFENDANT'S EXHIBIT No. 312.

E. F. W. ALEXANDERSON.

RADIO RECEIVING SYSTEM.

APPLICATION FILED JUNE 5, 1919.

1,373,931. **Patented Apr. 5, 1921.**


10
4
11
6
3
1
2
7
8
5
9
16
17
27
12
13
18
19
28
29
20
22
21
23
14
15
25
26
24

Inventor:
Ernst F. W. Alexanderson
by Albert G. Davis
His Attorney

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL
ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIO-RECEIVING SYSTEM.

1,373,931. Specification of Letters Patent. Patented Apr. 5, 1921.

Application filed June 5, 1919. Serial No. 302,003.

To all whom it may concern:

Be it known that I, Ernst F. W. Alexanderson, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Radio-Receiving Systems, of which the following is a specification.

My present invention relates to radio receiving systems, and more particularly to systems for receiving continuous wave signals.

The object of my invention is to provide an efficient and sensitive system for receiving continuous wave signals which will at the same time be highly selective and which will also produce a high degree of amplification of the signals received.

In carrying my invention into effect I provide at a receiving station a means for producing sustained high frequency oscillations. This means for producing high frequency oscillations is so adjusted that it is normally inoperative. It is also so arranged that when signals of a desired frequency are received in the system the local means for producing high frequency oscillations will be set into operation to produce oscillations of the same frequency as the signaling oscillations, the production of these oscillations continuing as long as signals are being received. If the high frequency oscillations thus produced are rectified or detected, a continuous current will be produced, the duration of which will correspond to the length of the dots and dashes of the telegraphic signals received. Such a current will not produce any indication in the ordinary telephone receivers, which are customarily used for reception. I therefore provide additional means for producing a desired indication of the signals which are received.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. The invention itself both as to its organization and method of operation will be best understood by reference to the following description taken in connection with the accompanying drawing in which I have indicated diagrammatically one way in which my invention may be carried into effect.

As indicated in the drawing, my receiving system comprises an electron discharge device 1 having associated therewith a grid circuit which includes the cathode 2 of the device, the grid 3, inductances 4 and 5, and a variable condenser 6, for the purpose of tuning the circuit of frequency of the signals which are to be received. A plate circuit for this device comprises a cathode 2, an anode 7, a source of current 8 and an inductance 9. Inductances 5 and 9 are so coupled together that the system is normally on the verge of oscillating. It is well known that the operation of such a system for the production of high frequency oscillations depends upon the transfer of enough energy from the plate circuit to the grid circuit to make up for the losses in the grid circuit. If the coupling is so arranged that the amount of energy which normally would be transferred is too small to produce oscillations a slight increase in the energy in the grid circuit will cause the device to act to produce high frequency oscillations. The small amount of energy required is supplied by means of signaling oscillations received upon the antenna 10 and impressed by means of the coil 11 upon the coil 4 in the grid circuit. Since the energy supplied to the grid circuit must have a proper phase relation to the current in the plate circuit in order to cause the device to act as an oscillator, it is apparent that if the received signals are of different frequency from the frequency for which the oscillating system is tuned, this phase relation will not be suitable for the production of high frequency oscillations. Therefore, the system will not be caused to produce oscillations by signaling currents of other than the desired frequency and will be highly selective for currents of the one particular frequency for which it is tuned. The high frequency oscillations produced by the device will be of much greater magnitude than the oscillations received upon the antenna 10 by reason of the amplifying properties of the electron discharge device 1.

In order to produce an audible indication by means of the high frequency oscillations produced in the manner above described, the potential changes set up between the cathode 2 and anode 7 of the device 1 are applied to the grid circuit of an electron discharge detector 12, the plate circuit of which is included in one arm of a Wheatstone bridge, the other arms of which are made up of electron discharge device 13 and resistances 14 and 15. The grid circuit of the detector 12 includes the usual condenser 16 shunted by resistance 17, and by means of this arrangement the resistance between the cathode 19 and anode 19 of the detector 12 will be varied in accordance with the signals received. In other words, the current flowing through the detector 12 from the direct current source 20 will vary at a periodicity corresponding to the length of the individual dots and dashes making up the signals which are received. These current changes will of course produce no audible indication in the telephone receiver 21 which is connected between the terminals 22 and 23 of the bridge. The bridge is normally so balanced that no current whatever will flow through the receiver 21. When the signals are received the resistance of the detector 12 which forms one arm of the bridge is varied in the manner described and current will be caused to flow through the receiver 21. In order that an audible indication may be given in the receiver I provide a source of current of audible frequency 24, which is impressed by means of the transformer 25 between the two terminals 26 and 27 of the bridge. When the bridge is unbalanced in the manner described current of this audible frequency will flow through the receiver 21 and give the desired indication of the signals which are being received.

I have indicated a second electron discharge device 13 as forming the arm of the bridge opposite the detector 12 because of the fact that the provision of this device renders the bridge more easily balanced. The desired balancing may be conveniently effected by a variation of the resistances 28 and 29 through which heating current for devices 12 and 13 is supplied.

It will be apparent to one skilled in the art that my invention is by no means limited to the precise circuit arrangement shown, but that many modifications in the connections used as well as in the apparatus employed may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is—

1. The combination in a radio receiving system of normally inoperative means for generating high frequency oscillations at a receiving station, means for receiving continuous high frequency signaling waves and means actuated by received high frequency signaling waves for setting into operation said means for producing high frequency oscillations at the receiving station and thereby producing high frequency oscillations of the same frequency as the received waves.

2. The combination in a radio receiving system of means for receiving continuous wave signals and controlling thereby the generation of a current which changes at a frequency below audibility, a source of current of audible frequency, a receiver and means actuated by the current changes below audibility for causing current from said audible frequency source to actuate said receiver.

3. The combination in a radio receiving system, of normally inoperative means for producing high frequency oscillations at the receiving station, means for receiving continuous high frequency signaling waves and means actuated by received high frequency signaling waves for setting into operation said means for producing high frequency oscillations at the receiving station and thereby producing high frequency oscillations of the same frequency as the received waves, means for producing by the high frequency oscillations locally produced a current which changes at a frequency below audibility and means actuated by said current of a frequency below audibility for producing a desired indication of signals.

4. The combination in a radio receiving system of normally inoperative means for producing high frequency oscillations at the receiving station, means for receiving continuous high frequency signaling waves and means actuated by received high frequency signaling waves for setting into operation said means for producing high frequency oscillations at the receiving station and thereby producing high frequency oscillations of the same frequency as the received waves, means for producing by the high frequency oscillations locally produced a current which changes at a frequency below audibility, a source of current of audible frequency, a receiver, and means actuated by the current changes below audibility for causing current from said audible frequency source to actuate said receiver.

5. The method of receiving and detecting continuous wave radio telegraphic signals which consists in utilizing the received signals for causing the generation at the receiving station of high frequency oscillations of the same frequency as the received signals, producing by means of the locally generated high frequency oscillations a current which varies at a frequency below audibility and utilizing said low fre-

1288

quency current to cause a local source of audio frequency current to produce an audible indication.

6. The method of receiving and detecting continuous wave radio telegraphic signals which consists in utilizing received signals to produce a current which varies at a frequency below audibility and utilizing the current thus produced to cause a local source of audio frequency current to produce an audible indication.

In witness whereof, I have hereunto set my hand this 3rd day of June, 1919.

ERNST F. W. ALEXANDERSON.

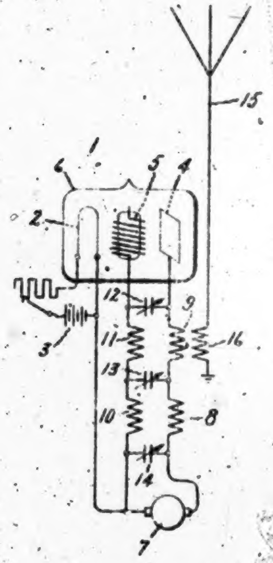
DEFENDANT'S EXHIBIT No. 313.

J. H. PAYNE, Jr.

METHOD OF AND MEANS FOR PRODUCING ALTERNATING CURRENTS.

APPLICATION FILED SEPT. 14, 1916.

1,400,235. Patented Dec. 13, 1921.


15
1
6
5
4
2
12
9
3
11
16
13
10
8
14
7

Inventor:
John.H.Payne.Jr.
by Albert G. Davis
His Attorney.

UNITED STATES PATENT OFFICE.

JOHN H. PAYNE, JR., OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AND MEANS FOR PRODUCING ALTERNATING CURRENTS.

1,400,235. Specification of Letters Patent. Patented Dec. 13, 1921.

Application filed September 14, 1916. Serial No. 120,070.

To all whom it may concern:

Be it known that I, JOHN H. PAYNE, Jr., a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Methods of and Means for Producing Alternating Currents of which the following is a specification.

My present invention relates to the production of continuous alternating currents by the use of electron discharge devices comprising a cathode capable of emitting electrons, an anode, and a discharge controlling member or grid, all inclosed in a highly evacuated receptacle.

The object of my invention is to produce radio frequency oscillations by means of such a device and to break up these oscillations into groups having a definite or audible frequency. A further object of my invention is to simultaneously produce by means of a single device oscillations of a plurality of frequencies.

The features of my invention which I consider novel are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have illustrated one of the circuit arrangements whereby my invention may be carried into effect.

As indicated in the drawing an electron discharge device 1, comprises a cathode 2, supplied by current from the battery 3 for heating to incandescence, an anode 4 and a discharge controlling member or grid 5 inclosed in an evacuated receptacle 6. An external circuit between cathode 2 and anode 4 comprises a source of direct current 7 and inductances 8 and 9. This circuit for convenience of description I designate the plate circuit. A second circuit between the cathode and grid 5 includes inductances 10 and 11. This circuit for convenience of description I designate the grid circuit.

It is well known that in an organization of this kind if the grid and plate circuits are properly coupled together continuous alternating currents may be produced. I designate such an arrangement a "self excited electron discharge device"; that is, one capable of producing alternating currents of itself in contra distinction to the usual arrangement in which alternating currents are produced only when an alternating exciting current is supplied from another source. In the present case the coupling between the grid and the plate circuits is provided by condensers 12, 13 and 14. The inductances 9 and 11 and the capacities 12 and 13 are preferably so chosen that radio frequency oscillations will be set up in the circuit which includes these inductances and capacities. The frequency of these oscillations may be varied by varying the capacity of condenser 12, which is preferably of smaller capacity than condenser 13. Inductances 8 and 10 and condensers 13 and 14 are so proportioned that the circuit including these inductances and capacities will be resonant to a different and preferably an audible frequency and the frequency of the alternating currents generated in this circuit may be varied by varying the capacity of condenser 14. Because of the complexity of the current and voltage conditions in the circuits which are organized in this way it is difficult to state precisely the manner in which it operates. I have found, however, that by coupling an antenna 15 to the inductance 9 by means of the coil 16 high frequency oscillations will be produced in the antenna 15 and these high frequency oscillations will be broken up into groups having a frequency equal to the frequency of the currents produced in the circuit 8, 13, 10, 14. It is also possible by varying the tuning of the two resonant circuits to produce oscillations in the two circuits which differ from each other in frequency by a small amount either at audible or radio frequencies, and by means of the currents thus produced impress upon the antenna a composite wave which is a combination of the two frequencies in any desired manner.

While I have illustrated a single form of my invention, it is by no means limited to the particular form of electron discharge devices illustrated or to the exact circuit connections shown, as many modifications therein may be made without departing from the scope of the appended claims.

For example, more than two resonant circuits may be utilized and oscillations of as many frequencies as desired may simultaneously be produced by a single electron discharge device. By coupling the utilization circuits to the different resonant circuits oscillations of any one of the different frequencies may be employed for any desired purpose. Some of these oscillations may be of radio frequency, some of audio frequency, or all may be of audio frequency, or all may be of radio frequency.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The method of operating a radiating system comprising a self-excited electron discharge device which consists in causing said device to produce two separate currents, one of radio frequency and one of audio frequency, causing the two currents to interact to produce radio frequency currents having an audible group frequency equal to that of the audio frequency currents produced and utilizing the currents thus produced for effecting a useful radiation of energy.

2. Means for producing radio frequency currents having a definite group frequency comprising an electron discharge device having plate and grid circuits, two circuits which include separate inductances in both grid and plate circuits and which are resonant to two different frequencies associated therewith in such a way that alternating currents will be produced in said resonant circuits, an electrostatic coupling between said resonant circuits, and a utilization circuit operatively related to said plate circuit.

3. Means for producing radio frequency currents having an audible group frequency comprising a self-excited electron discharge device having plate and grid circuits, two circuits directly associated with both plate and grid circuits in such a way that alternating currents will be produced therein, one of said circuits being resonant to a radio frequency and the other to an audible frequency equal to the group frequency desired, and a utilization circuit operatively related to said plate circuit.

4. Means for producing radio frequency currents having an audible group frequency comprising an electron discharge device having an anode, a cathode and a grid inclosed in an evacuated receptacle, a circuit connecting the cathode and anode which includes a direct current source of energy, a second circuit connecting the cathode and grid, a plurality of condensers coupling the two circuits in such a way as to form therewith two coupled circuits which are resonant to two different frequencies.

5. Means for producing radio frequency currents having an audible group frequency comprising an electron discharge device having an anode, a cathode and a grid inclosed in an evacuated receptacle, a circuit connecting the cathode and anode which includes a source of energy and a pluralty of inductances, a circuit connecting the cathode and grid which also includes a plurality of inductances and a plurality of condensers connected in multiple between the two circuits, said inductances and condensers being so proportioned and arranged as to form two coupled circuits, one of which is resonant to audible frequencies and the other of which is resonant to radio frequencies.

6. The combination with an electron discharge device comprising an anode, a cathode and a grid inclosed in an evacuated receptacle of a resonant circuit associated with the device in such a way that radio frequency currents will be produced in said circuit, a second circuit resonant to audio frequencies and associated with the first circuit in such a way that the radio frequency currents in the first circuit will be broken up into groups of audible frequency corresponding to the frequency of the second circuit, and a utilization circuit operatively related to said first circuit and adapted to receive energy therefrom.

7. Means for producing alternating currents of a plurality of frequencies comprising a self-excited electron discharge device, a single plate circuit and a single grid circuit for said device, a plurality of circuits which are resonant to the different frequencies desired directly associated with said plate circuit and said grid circuit in such a way that alternating currents will be produced in said resonant circuits, and a utilization circuit operatively related to said plate circuit.

8. Means for producing a plurality of alternating currents of different frequencies comprising a self-excited electron discharge device, a single plate circuit and a single grid circuit for said device, a plurality of circuits which are resonant to the different frequencies desired, directly associated with both plate and grid circuits in such a way that alternating currents will be produced in said resonant circuits, and means whereby the currents thus produced may be caused to interact one upon another.

9. Means for producing alternating currents of a plurality of different frequencies comprising an electron discharge device, a plate circuit for said device, a grid circuit for said device, and a plurality of resonant circuits each of which is formed in part by a portion of the grid circuit and in part by a portion of the plate circuit, and so associated with those circuits that alternating currents of different frequencies will be produced in said resonant circuits.

10. The method of operating a radiating system having a self-excited electron discharge device with plate and grid circuits

associated therewith, which consists in causing said device to generate two separate currents, one of radio frequency and one of audio frequency, causing the two currents to interact to produce in the plate circuit radio frequency currents having an audible group frequency equal to the frequency of the audio frequency current generated and impressing the current thus produced upon the radiating system.

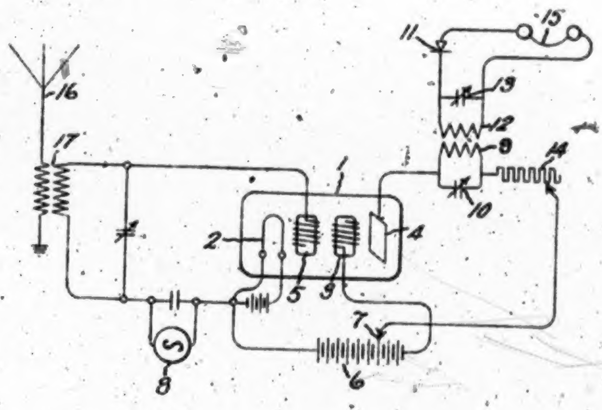
In witness whereof, I have hereunto set my hand this 12th day of September, 1916.

JOHN H. PAYNE, Jr.

DEFENDANT'S EXHIBIT No. 314.

B. BRADBURY.
SIGNAL RECEIVING SYSTEM.
APPLICATION FILED MAR. 23, 1921.

1,430,883. Patented Oct. 3, 1922.


11
15
16
13
12
17
9
14
1
10
2
4
5
3
7
8
6

Inventor:
Burke Bradbury,
by Albert G. Davis
His Attorney.

Patented Oct. 3, 1922 **1,430,883**

UNITED STATES PATENT OFFICE.

BURKE BRADBURY, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

SIGNAL-RECEIVING SYSTEM.

Application filed March 23, 1921. Serial No. 454,828.

To all whom it may concern:

Be it known that I, Burke Bradbury, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Signal-Receiving Systems, of which the following is a specification.

My present invention relates to signal receiving systems, and more particularly to signaling systems employing continuous radio frequency currents. The object of my invention is to provide a simple and efficient means for producing an audible indication of signals transmitted by means of radio frequency continuous currents.

In carrying out my invention, I provide at a receiving station a source of audio frequency current which is associated with an electron discharge device and a detector in such a way that when no signaling currents are impressed upon the system there will be no appreciable flow of audio frequency current in the detector circuit. When, however, a radio frequency signaling current is impressed upon the system this signaling current is modulated by means of the audio frequency source and the modulated radio frequency signaling current is transmitted to the detector circuit where it is rectified and the rectified current is used to produce the desired audible indication.

The novel features which I believe to be characteristic of my invention are set forth with particularly in the appended claims. My invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have illustrated diagrammatically one way in which my invention may be carried into effect.

As indicated in the drawing, my receiving apparatus comprises an electron discharge device 1 having an electron emitting cathode 2, an anode 3, a third electrode 4 in the form of a plate, and a discharge controlling member or grid 5 interposed between the cathode and other electrodes. By means of the battery 6, a constant positive potential is impressed upon the anode 3 and the third electrode 4 is connected to a point 7 in this battery so that a smaller positive potential is impressed upon the third electrode 4. The potentials of the battery 6 and the point 7 are preferably so chosen that a negative resistance will be produced in the circuit between cathode and third electrode 4. A source of audio frequency current 8 which is connected in the circuit between the cathode and discharge controlling member impresses upon that circuit at all times an audio frequency current. The circuit between cathode and third electrode, contains an inductance 9 and a variable capacity 10 which are tuned to the frequency of the signals which it is desired to receive. An auxiliary circuit containing a detector 11 is coupled by means of the inductance 12 to inductance 9 and this circuit may also be tuned by means of a variable capacity 13 to the frequency of the signals to be received. A resistance 14 is preferably included in the circuit between cathode and third electrode and this resistance is adjusted to a value slightly greater than the critical value at which the circuit becomes self-oscillating so that when no signaling currents are being received no current of signaling frequency will be produced in the circuit.

When no signals are being received no appreciable amount of audio frequency current will be produced in the detector circuit and in the telephone receivers 15 because of the fact that the detector circuit and the circuit with which it is associated are both tuned to the radio frequency of the signal and the coupling between 9 and 12 is too loose to permit the transfer of any appreciable amount of audio frequency current. When signals are received upon the antenna 16 and impressed upon the circuit between cathode and discharge controlling grid by means of the coupling transformer 17, the potential of the grid 5 will vary at a radio frequency corresponding to the frequency of the signaling current, this radio frequency being modulated in accordance with the audio frequency source 8. A modulated current of radio signaling frequency will then be produced in the circuit 9, 10 and this moduated radio frequency current will be transferred to the detector circuit by means of the coupling 9, 12, and when rectified in that circuit by the action of the detector 11, will produce an audio frequency current in the telephone receivers 15.

While I have shown and described the preferred embodiment of my invention, it will be apparent that my invention is by no means limited to the particular circuit arrangement shown but that many variations in the connections employed as well as in the form of apparatus used may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, means for continuously impressing audio frequency currents upon said circuit and a detector circuit loosely coupled to the circuit between cathode and third electrode, the circuit between cathode and third electrode and the detector circuit being resonant to the signaling frequency and the positive resistance of the circuit between cathode and third electrode being of a value greater than the critical value at which oscillations will be generated in the circuit.

2. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, means for continuously impressing audio frequency currents upon said circuit and a detector circuit loosely coupled to the circuit between cathode and third electrode, the circuit between cathode and third electrode and the detector circuit being resonant to the signaling frequency.

3. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, means for modulating the signaling current at an audio frequency, and a detector circuit loosely coupled to the circuit between cathode and third electrode, the circuit between cathode and third electrode and the detector circuit being resonant to the signaling frequency.

4. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, and a detector circuit loosely coupled to the circuit between cathode and third electrode, the circuit between cathode and third electrode being resonant to the signaling frequency.

5. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits, connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, means for modulating the signaling current at an audio frequency, and a detector circuit loosely coupled to the circuit between cathode and third electrode, the circuit between cathode and third electrode being resonant to the signaling frequency.

6. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, means for continuously impressing audio frequency currents upon said circuit, and a detector circuit loosely coupled to the circuit between cathode and third electrode, the circuit between cathode and third electrode being resonant to the signaling frequency, and the resistance of the cir-

cuit between cathode and third electrode being of a value greater than the critical value at which oscillations will be generated in the circuit.

7. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, means for modulating the signaling current at an audio frequency, and a detector circuit loosely coupled to the circuit between cathode and third electrode, the circuit between cathode and third electrode and the detector circuit being resonant to the signaling frequency, and the resistance of the circuit between cathode and third electrode being of a value greater than the critical value at which oscillations will be generated in the circuit.

8. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, and means associated with the circuit between cathode and third electrode for producing an audible indication of the modulated high frequency current flowing therein, the circuit between cathode and third electrode being resonant to the signaling frequency.

9. The combination in a signal receiving system of an electron discharge device having an electron emitting cathode, an anode, a third electrode and a discharge controlling member, electric circuits connecting said cathode with each of the other electrodes, sources of potential applied to said circuits in such a way as to produce a negative resistance in the circuit between cathode and third electrode, means for impressing signaling currents of radio frequency upon the circuit between cathode and discharge controlling member, means for modulating the signaling current at an audio frequency, and means associated with the circuit between cathode and third electrode for producing an audible indication of the modulated high frequency current flowing therein, the circuit between cathode and third electrode being resonant to the signaling frequency.

In witness whereof, I have hereunto set my hand this 22nd day of March, 1921.

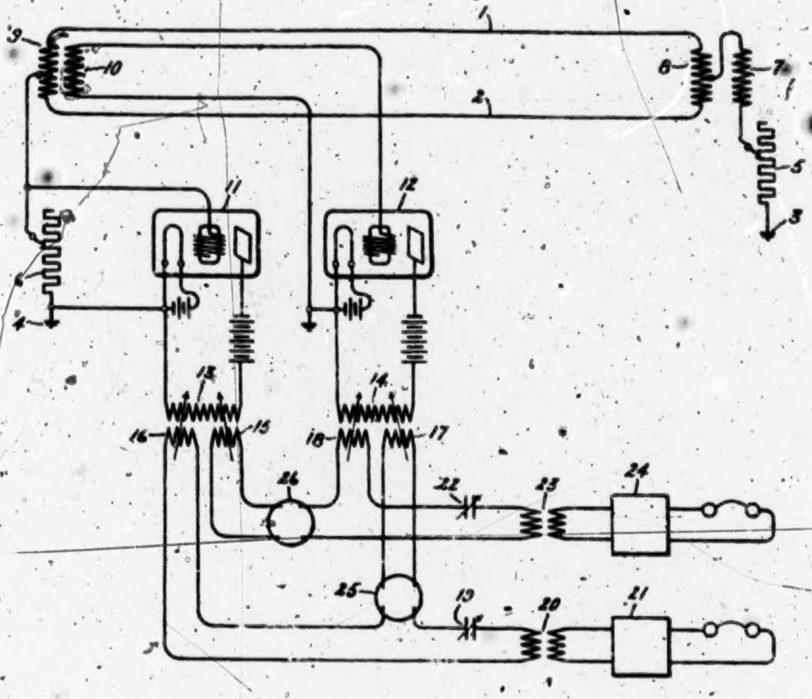
BURKE BRADBURY.

DEFENDANT'S EXHIBIT No. 315.

H. H. BEVERAGE.
RADIORECEIVING SYSTEM.
APPLICATION FILED MAY 3, 1921.

1,434,984.

Patented Nov. 7, 1922.


1
9
10
2
8
7
5
3
11
12
6
4
13
14
16
15
18
17
26
22
23
24
25
19
20
21

Inventor:
Harold H. Beverage,
by Albert G. Davis
His Attorney

Patented Nov. 7, 1922. **1,434,984**

UNITED STATES PATENT OFFICE.

HAROLD H. BEVERAGE, OF RIVERHEAD, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIORECEIVING SYSTEM.

Application filed May 3, 1921. Serial No. 466,475.

To all whom it may concern:

Be it known that I, Harold H. Beverage, a citizen of the United States, residing at Riverhead, in the county of Suffolk, State of New York, have invented certain new and useful Improvements in Radioreceiving Systems, of which the following is a specification.

My present invention relates to radio receiving systems, and more particularly to a system which permits of the reception of signals coming from more than one direction upon a single antenna.

In my prior application, Serial No. 372,933, filed April 10, 1920, issued June 7, 1921, as Patent No. 1,381,089, I have described and claimed a form of horizontal receiving antenna which is especially adapted for the efficient reception of signals from any desired direction. I have pointed out in that application, but have not claimed a method of operation whereby it is possible to employ the same antenna for simultaneously receiving signals from two different directions.

One of the objects of my present invention is to provide a method of and means for accomplishing the result mentioned; a more specific object of my invention is to provide apparatus whereby the desired reception from two different directions may be accomplished at a single receiving station.

I have pointed out in the above mentioned application that with a long horizontal receiving antenna extending in the general direction of transmission of signaling waves to be received, signaling currents produced in the antenna by waves coming from one particular transmitting station will be strongest at the ends of the antenna farthest from the transmitting station while currents produced by waves coming from the opposite direction will be a minimum at that point. This permits of the reception of waves coming from opposite directions by connecting the receiving apparatus at opposite ends of the antenna. It will in general however, be desirable to accomplish the desired reception from the two directions at the same point. In order to accomplish this result I may locate the receiving apparatus at either end of the antenna and utilize the antenna as a transmission line for conveying signaling currents from the opposite end of the antenna to the receiving station. One receiving set will then be operated by means of the currents flowing in the ground connection of the antenna at the receiving station and the other set of receiving apparatus will be operated by means of the currents transmitted over the antenna as a transmission line.

The novel features which I believe to be characteristic of my invention are set forth in the appended claims. The invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have indicated diagrammatically one way in which my invention may be carried into effect.

As indicated in the drawing, I provide a long horizontal receiving antenna made up of two conductors 1 and 2, which are grounded at the ends 3 and 4. If this antenna is constructed with distributed constants of such value that the current wave therein travels at the same velocity or substantially the same velocity as the ether wave, the current wave in the antenna will gradually build up and become a maximum at the end farthest from the transmitting station. Currents produced at the end 3 by ether waves traveling from that end toward the end 4 will have substantially zero value at the end 3 and will increase to a maximum value at the end 4. In the same way currents produced by ether waves traveling from the end 4 toward the end 3, will have a minimum value at the end 4 and a maximum value at the end 3. In order to prevent reflection of the current waves flowing in the antenna from the ends, the ground connections are made through resistances 5 and 6 having a value substantially equal to the surge impedance of the antenna.

While the receiving antenna should preferably have such constants that the current wave travels therein at the same velocity as the ether wave this is not essential for successful results in carrying out my invention. If the velocity of the current wave in the antenna differs somewhat from that of the ether wave then for a certain distance the waves will add and a point will finally be reached where one wave will be so far in advance of the other that the two will be in phase opposition. Interference will then occur and the current wave will start to decrease. In any case, the antenna should be constructed with such constants that the length at which the current wave becomes maximum will be at least as great as a half wave length of the signaling waves to be received.

In the present case I have indicated the receiving station as being located at the end 4 of the antenna. In order to be able to receive at this point currents produced by waves traveling from the end 4 toward the end 3, the antenna conductors may be employed as a transmission line. In order to accomplish this the currents in the antenna conductors flowing toward the end 3 are caused to flow to ground through the primary winding 7 of the transformer, the secondary 8 of which has its terminals connected to conductors 1 and 2 respectively. As a result the signaling currents flowing to ground at 3 produce currents flowing in opposite directions in the conductors 1 and 2. In other words, the conductors 1 and 2 form the two sides of a transmission line which is completed by means of the primary 9 of the transformer at the end 4 of the antenna. The mid-point of the winding 9 being connected to ground at 4 and the mid point of the secondary 8 being connected to ground at point 3 substantially no current will be produced at the ground connection 4 by means of the signaling currents conveyed over the transmission line.

The signaling currents produced by waves coming from the two different directions which are caused to flow in the ground connection at 4 and in the secondary winding 10, are impressed upon the input circuits of the two electron discharge amplifiers 11 and 12 of the usual three-electrode type. The output circuits of these amplifiers include coupling coils 13, 14, which are coupled by variable couplings to coils 15, 16, and 17, 18, respectively. Current produced in coil 16 is caused to flow in the resonant circuit connected thereto which is tuned by means of capacity 19 to the frequency of the signaling waves which are to be received and which travel from the end 3 toward the end 4. Currents flowing in this resonant circuit are impressed by means of coupling 20 upon the receiving apparatus 21, which may be of any desired form. Currents produced in the coil 18 are impressed upon a resonant circuit tuned by means of the variable condenser 22 to the frequency of the waves to be received which are traveling from the end 4 toward the end 3 of the antenna, and the currents produced in this resonant circuit are impressed by means of the coupling 23 upon the second receiving set 24. The waves to be received in set 24 may be of the same frequency or a different frequency from those received in set 21.

While a long horizontal antenna such as that employed has decided unidirectional properties, mathematical analysis indicates and experience shows that at the end farthest from the transmitting station small currents will under some conditions be produced by waves coming from the opposite direction even though the end nearest the transmitting station is grounded through a resistance approximately equal to the surge impedance of the antenna so that no reflection occurs. In some cases, also, it may happen that while the antenna is adjusted so that the receiving apparatus is not affected by disturbing waves coming from a direction exactly opposite to that of the desired signal, it is affected by disturbances coming from some other direction, for instance, 160° from the transmitting station and that it is more important to limit the effect of the disturbing waves coming from this direction than those coming from the direction 180° from the transmitting station. In order to eliminate the effect of the undesired waves mentioned, in the receiving set 21, a current component is impressed by means of the coil 17 upon a phase rotator 25 by means of which the phase of this component is adjusted so as to be opposite in phase to the undesired component of the current flowing in the resonant circuit associated with the receiving set 21. This neutralizing component is impressed upon the resonant circuit from the phase rotator 25 and the intensity of this neutralizing component is adjusted to secure the desired neutralization by means of the variable coupling between coils 14 and 17. In the same way undesired currents are neutralized in the receiving set 24 by means of the current component produced by means of the coil 15 and phase rotator 26.

While I have described the preferred embodiment of my invention, it will be apparent that my invention is by no means limited to the precise arrangement shown and that modifications therein may be made without departing from the scope of my invention as set forth in the appended claims. While in general it will be desirable that the receiving antenna be located so that the two sets of signals to be received come from directions 180° apart, or approximately so, the apparatus which I have shown may be successfully employed for receiving signals coming from two directions at an angle much less than 180°.

I have indicated the receiving station as being located at one end of the antenna, but this is not essential in carrying out my invention as the receiving station may be located at any desired point and connected with the desired points in the antenna in such a way that the desired signaling currents may be impressed upon the receiving apparatus in the general manner indicated. While I have indicated the points at which the signaling currents are selected as being located at the two ends of the antenna, and while in general these points will be the most suitable, the selection of these particular points is not essential to the carrying out of my invention as in some cases it may happen that the signaling currents will be stronger or will have a more favorable stray ratio at some other point along the length of the antenna than the end. When I speak, therefore, of the point where the signaling currents received from a desired station are strongest, it will be understood that I mean either the point where they are of the greatest amplitude, or where the stray ratio is most favorable for desired reception.

While I have shown only a single receiving set for receiving waves coming from each direction the system which I have shown and described may equally well be employed for receiving simultaneously a plurality of signals coming from either direction or from both directions.

What I claim as new and desire to secure by Letters Patent of the United States is:—

1. A receiving system for radio signals comprising a horizontal receiving antenna which is grounded at both ends and has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at substantially the same velocity as that at which the desired signaling waves travel along its length in the ether, and means associated with said antenna for selectively receiving signals coming from opposite directions.

2. A receiving system for radio signals comprising a horizontal receiving antenna which is grounded at both ends and has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at substantially the same velocity as that at which the desired signaling waves travel along its length in the ether, and means associated with said antenna at one point along its length for receiving signals coming from different directions.

3. A receiving system for radio signals comprising a horizontal receiving antenna which is grounded at both ends and has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at substantially the same velocity as that at which the desired signaling waves travel along its length in the ether, and means associated with said antenna at one end thereof for selectively receiving signals coming from different directions.

4. A receiving system for radio signals comprising a horizontal receiving antenna which is grounded at both ends and has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at substantially the same velocity as that at which the desired signaling waves travel along its length in the ether, and means associated with said antenna at one end thereof for selectively and simultaneously receiving signals coming from opposite directions.

5. A receiving system for radio signals comprising a horizontal receiving antenna, means for utilizing said antenna as a transmission line for conveying signaling currents from a selected point in said antenna where signaling currents received on the antenna from a desired station are strongest, to a distant receiving station located along the length of said antenna, and means associated with said antenna at the receiving station for selectively and simultaneously receiving both the signaling currents thus transmitted, and signaling currents received on the antenna from a direction different from that of the desired station.

6. A receiving system for radio signals comprising a horizontal receiving antenna, means for utilizing said antenna as a transmission line for conveying signaling currents from the end of said antenna where signaling currents received on the antenna from a desired station are strongest to a distant receiving station located along the length of said antenna, and means associated with said antenna at the receiving station for selectively and simultaneously receiving both the signaling currents thus transmitted and signaling currents received on the antenna from a station located in a different direction from the receiving station than that of the first station.

7. A receiving system for radio signals comprising a long horizontal receiving antenna, ground connections at both ends of said antenna, means for utilizing said antenna as a transmission line for conveying signaling currents from a selected point in said antenna where signaling currents received on the antenna from a desired station are strongest to a distant receiving station located along the length of said antenna, a pair of receiving sets, a pair of electron discharge devices having input and output circuits, means for impressing the signaling currents thus transmitted upon the input circuit of one of said electron discharge devices, means for impressing currents from one of the ground connections of said antenna upon the input circuit of the second electron discharge device, and means for impressing currents from both of the output circuits of said electron discharge devices upon both of the receiving sets.

8. A receiving system for radio signals comprising a long horizontal receiving antenna, ground connections at both ends of said antenna, means for utilizing said an-

tenna as a transmission line for conveying signaling currents from a selected point in said antenna where signaling currents received on the antenna from a desired station are strongest to a distant receiving station located along the length of said antenna, a pair of receiving sets, a pair of electron discharge devices having input and output circuits, means for impressing the signaling currents thus transmitted upon the input circuit of one of said electron discharge devices, means for impressing currents from one of the ground connections of said antenna upon the input circuit of the second electron discharge device, means for impressing currents from both of the output circuits of said electron discharge devices upon both of the receiving sets, and means for regulating the phase and intensity of the currents thus impressed upon the receiving sets.

9. A receiving system for radio signals comprising a horizontal receiving antenna which is grounded at both ends, a transmission line for carrying signaling currents from a selected point in said antenna to a receiving station located at a distant point along the length of said antenna, two receiving sets at the receiving station, means for impressing upon one receiving set currents conveyed over said transmission lines, means for impressing upon the second receiving set currents flowing in the ground connection at one end of said antenna, means for impressing upon the first receiving set from the ground connection currents of equal magnitude and opposite phase to those impressed thereon from the transmission line which are produced by waves coming from a different direction than that of the desired signaling waves to be received by that set and means for impressing upon the second receiving set from the transmission line currents of equal magnitude and opposite phase to those impressed thereon from the ground connection which are produced by waves coming from a different direction than that of the desired signaling waves to be received by the second set.

10. A receiving system for radio signals comprising a horizontal receiving antenna which is grounded at both ends and which has distributed constants of such values that electric waves produced therein by desired signaling waves will be propagated along its length at such a velocity that increments of current produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave and means associated with said antenna for selectively receiving signals coming from opposite directions.

11. The method of operating a radio receiving system comprising a horizontal receiving antenna which is grounded at both ends and two receiving sets, which consists in impressing upon one of said receiving sets currents produced in said antenna by signaling waves coming from one direction and impressing upon the other receiving set currents produced in said antenna by signaling waves coming from a different direction.

12. The method of operating a radio receiving system comprising a horizontal receiving antenna which is grounded at both ends and two receiving sets which consists in impressing upon one of said receiving sets desired signaling currents produced in one of said ground connections and impressing upon the other receiving set desired signaling currents produced in the other ground connection.

13. The method of operating a radio receiving system comprising a horizontal receiving antenna which is grounded at both ends and two receiving sets which consists in impressing upon one of said receiving sets desired signaling currents produced in one of said ground connections impressing upon the other receiving set desired signaling currents produced in the other ground connection, and neutralizing the effect in the first receiving set of undesired currents therein by impressing thereon currents of equal intensity and opposite phase derived from the second ground connection.

14. The method of operating a radio receiving system comprising a horizontal receiving antenna which is grounded at both ends and two receiving sets which consists in impressing upon one of said receiving sets desired signaling currents produced in one of said ground connections, impressing upon the other receiving set desired signaling currents produced in the other ground connection, and neutralizing the effect in the first receiving set of undesired currents therein by impressing thereon currents of equal intensity and opposite phase derived from the second ground connection, and neutralizing the effect in the second receiving set of undesired currents therein by impressing thereon currents of equal intensity and opposite phase derived from the first ground connection.

15. The method of operating a radio receiving system comprising a horizontal receiving antenna which is grounded at both ends and two receiving sets which consists in impressing upon one of said receiving sets currents produced in said antenna at a selected point by signaling waves coming from one direction and impressing upon the other receiving set currents produced in said antenna at another selected point by signaling waves coming from a different direction.

16. The method of operating a radio receiving system comprising a horizontal receiving antenna which is grounded at both ends and two receiving sets which consists in impressing upon one of said receiving sets desired signaling currents produced in said antenna at a selected point, impressing upon the second receiving set desired signaling currents produced in said antenna at a second selected point and neutralizing the effect in the first receiving set of undesired currents therein by impressing thereon currents of equal intensity and opposite phase derived from the antenna at the second selected point.

17. The method of operating a radio receiving system comprising a horizontal receiving antenna which is grounded at both ends and two receiving sets which consists in impressing upon one of said receiving sets desired signaling currents produced in said antenna at a selected point, impressing upon the second receiving set desired signaling currents produced in said antenna at a second selected point and neutralizing the effect in the first receiving set of undesired currents therein by impressing thereon currents of equal intensity and opposite phase derived from the antenna at the second selected point, and neutralizing the effect in the second receiving set of undesired currents therein by impressing thereon currents of equal intensity and opposite phase derived from the antenna at the first selected point.

In witness whereof I have hereunto set my hand this twenty ninth day of April 1921.

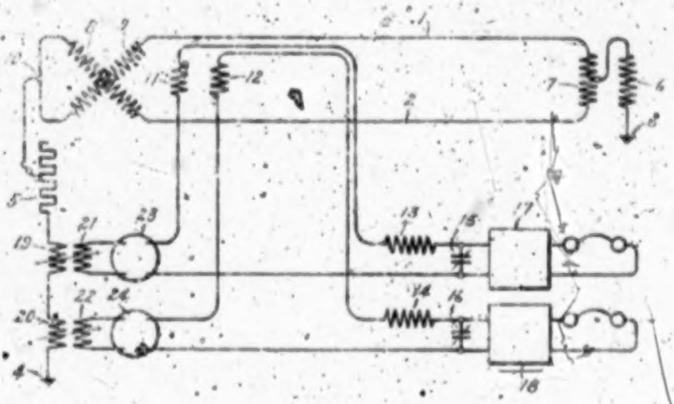
HAROLD H. BEVERAGE.

DEFENDANT'S EXHIBIT No. 316.

H. H. BEVERAGE.
RADIO RECEIVING SYSTEM.
APPLICATION FILED MAY 3, 1921.

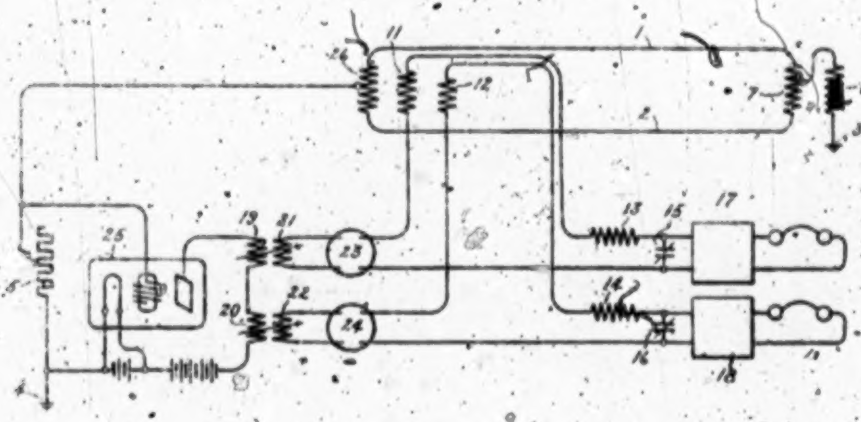
434,985. Patented Nov. 7, 1922.
2 SHEETS—SHEET 1.

Fig. 1



1
2
4
5
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Fig. 2



26
11
1
12
7
2
6
3
13
21
17
25
5
23
15
14
20
22
24
16
18
4

Inventor
Harold H. Beverage.
by Albert G. Davis
His Attorney

1304

H. H. BEVERAGE.
RADIORECEIVING SYSTEM.
APPLICATION FILED MAY 3, 1921.

1,434,985. Patented Nov. 7, 1922.

2 SHEETS—SHEET 2.

Fig 3.

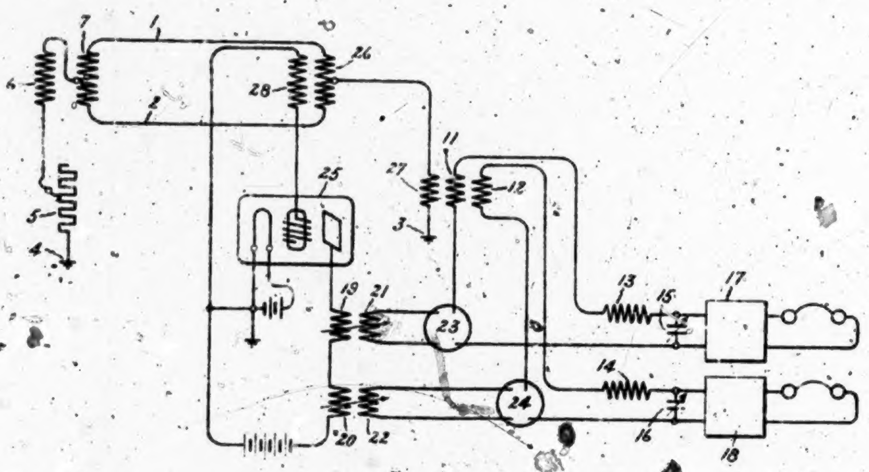
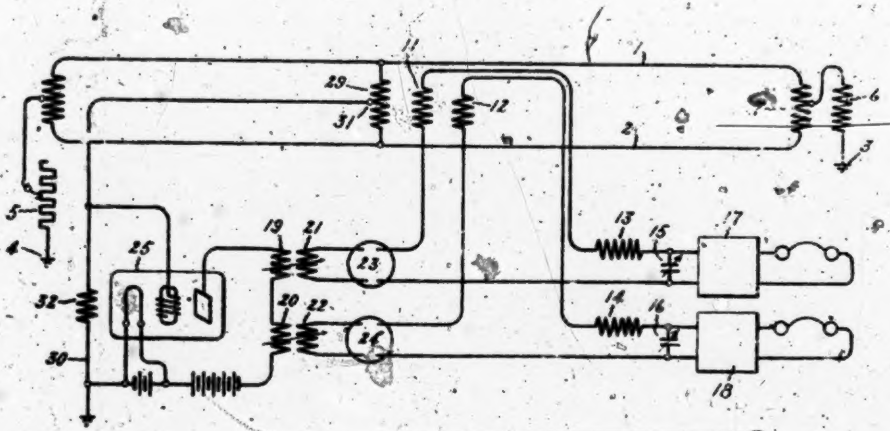

1
2
6
7
26
28
5
4
27
11
12
3
25
19
21
23
13
15
17
14
24
16
18
20
22

Fig 4.


1
2
29
31
11
12
6
3
5
4
25
19
21
23
13
15
17
32
20
22
24
14
16
18
30

Inventor
Harold H. Beverage,
by Albert G. Davis
His Attorney

Patented Nov. 7, 1922. 1,434,985

UNITED STATES PATENT OFFICE.

HAROLD H. BEVERAGE, OF RIVERHEAD, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIORECEIVING SYSTEM.

Application filed May 3, 1921. Serial No. 466,476.

To all whom it may concern:

Be it known that I, Harold H. Beverage, a citizen of the United States, residing at Riverhead, in the county of Suffolk, State of New York, have invented certain new and useful Improvements in Radioreceiving Systems, of which the following is a specification.

My present invention relates to radio receiving system, and more particularly to a system which permits of the simultaneous reception of a plurality of signals at a single receiving station.

In my prior application, Serial No. 372,933, filed April 10, 1920, issued June 7, 1921 as Patent No. 1,381,089, I have described and claimed a form of horizontal receiving antenna which is especially adapted for the efficient reception of signals.

The object of my present invention is to provide a method of and means for utilizing an antenna of the form described in my prior application for the simultaneous reception of a plurality of signals of different wave lengths. I have pointed out in the above mentioned application that with a long receiving antenna extending in the general direction of transmission of the signaling waves to be received signaling currents produced in the antenna by waves coming from any particular transmitting station will be strongest at the end of the antenna farthest from the transmitting station, while current produced by waves coming from the opposite direction will be a minimum at that point. The antenna described is preferably aperiodic so that the strength of the signaling currents produced therein is substantially independent of the wave length.

In carrying out my invention, I utilize an antenna of this type and impress from the antenna upon a plurality of receiving circuits which are resonant to the frequencies of the different signaling waves to be received, currents produced in the antenna at a selected point. Each receiving circuit selects the particular signaling wave which it is desired to receive in that circuit, without interfering with the selection of the desired waves by any of the other receiving circuits. In order to improve the reception, I also provide means for impressing upon each receiving circuit a current selected from another point in the antenna which will be of the proper intensity and phase to neutralize in each receiving circuit disturbing currents produced therein either by interference from undesired waves or by strays.

The novel features which I believe to be characteristic of my invention are set forth in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawings in which Figs. 1 to 4, inclusive, show diagrammatically four different circuit arrangements whereby my invention may be carried into effect.

As indicated in the drawings, I provide a long horizontal receiving antenna made up of two conductors 1 and 2 which are grounded at the ends 3 and 4. If this antenna is constructed with distributed constants of such value that the current wave therein travels at the same velocity as the ether wave, the current wave in the antenna will gradually build up and become a maximum at the end farthest from the transmitting station. If the velocity of the current wave in the antenna differs somewhat from that of the ether wave, then for a certain distance the waves will add but a point will finally be reached where one wave will be so far in advance of the other that the two will be in phase opposition. Interference will then occur and the current wave will start to decrease. In any case, the antenna should preferably be constructed with such constants that the length at which the current wave becomes maximum will be at least as great as a half wave length of the signaling wave to be received. Currents produced at the end 3 by ether waves traveling from that end to the end 4 will have substantially a zero value at the end 3 and will increase to a maximum value at the end 4. In the same way currents produced by ether waves traveling from the end 4 toward the end 3 will have a minimum value at the end 4 and a maximum value at the end 3. In order to prevent reflection of the current waves flowing in the antenna from the ends, the ground connections may be made through resistances having a value substantially equal to the surge impedance of the antenna. In the present case, I have indicated such a grounding resistance 5 at the end 4 of the antenna.

A similar grounding resistance may be used at both ends of the antenna if desired.

In Figs. 1 and 2, I have indicated the receiving station as being located at the end 4 of the antenna. In order to be able to receive at this point currents produced by waves traveling from the end 4 toward the end 3 which consequently are a maximum at the end 3, the antenna conductors may be employed as a transmission line for transmitting signaling currents from the end 3 of the antenna to the receiving apparatus. In order to accomplish this the currents in the antenna conductors flowing toward the end 3 are caused to flow to ground through the primary winding 6 of a transformer, the secondary 7 of which has its terminals connected to conductors 1 and 2 respectively. As a result the signaling currents flowing to ground at 3 produce currents flowing in opposite directions in the conductors 1 and 2. In other words, the conductors 1 and 2 form the two sides of a transmission line which is completed in the arrangement shown in Fig. 1 by means of the two coils 8 and 9 of a goniometer located at the end 4 of the antenna. The point 10 between the two coils of the goniometer being connected to ground at 4 and the mid point of the secondary 7 being connected to ground at 3, substantially no current will be produced in the ground connection 4 by means of the signaling currents conveyed over the transmission line.

Two secondary coils 11 and 12 which are associated with the goniometer coils 8 and 9 are included in two resonant receiving circuits which include inductances 13 and 14 and tuning condensers 15 and 16. While for simplicity I have indicated only two receiving circuits, as many receiving circuits as desired may be employed.

The current produced in the receiving circuits may be impressed upon the two sets of receiving apparatus 17, 18, which may be of any desired form. The distributed inductance and capacity of the antenna do not remain constant, but change more or less with frequency. This may be due to lesser depth of penetration into the earth at higher frequencies. It may also happen that the antenna will be partially unbalanced to signals and strays coming from the side except when the antenna length bears a definite relation to the wave length. If, therefore, the reception of several signals is to be carried on simultaneously, and if these signals differ greatly in wave length, an adjustment of the damping resistance 5 will render the antenna perfectly unidirectional for only the wave length for which the damping resistances is adjusted. While when properly adjusted the antenna has decided unidirectional properties, mathematical analysis indicates and experience shows that at the end farthest from the transmitting station small currents will under some conditions be produced by waves coming from the opposite direction even though the ground resistance is properly adjusted to prevent reflection. For these reasons it is desirable in order to secure the best results to balance out in the receiving circuit undesired currents produced by these different factors. This balancing action is accomplished in the arrangement shown in Fig. 1 by connecting in series with the ground connection at 4 the primary windings of two intensity couplers 19 and 20, the secondary nection at 4 the primary windings of two to phase rotators 23 and 24 respectively, these phase rotators being included in the receiving circuits. The currents flowing to ground at 4 are currents built up on the antenna conductors in parallel by the ether waves traveling from the end 3 toward the end 4. By selecting currents from the ground connection at 4 and regulating the phase and intensity of the currents selected, it is possible to neutralize in the receiving circuits the effect of substantially all currents produced therein by waves coming from a different direction from that of the desired signaling waves.

It will be noted that in the arrangement shown in Fig. 1 the primaries 19 and 20 of the intensity couplers are connected in series with the damping resistance 5 thus making the damping circuit inductive. The inductive reactance can be neutralized by a series condenser for a single wave length, but for other wave lengths the damping circuit will be reactive either capacitive or inductive, and the undesired currents which will be reflected from the end 4 of the antenna and impressed upon the receiving sets will be greater than will be the case if the damping circuit were pure resistance.

In the arrangement shown in Fig. 2, this disadvantage is overcome by employing an electron discharge amplifier 25 having its input circuit connected to the resistance 5, and having the primaries 19, 20 of the intensity couplers included in the output circuit. Since the input circuit of this amplifier is pure resistance the damping circuit is also a pure resistance. In the arrangement shown in Fig. 2 also the goniometer coils 8 and 9 are replaced by a single primary winding 26 which is coupled with the individual secondary windings 11 and 12.

The arrangement shown in Fig. 3 differs from that shown in the preceding figures in that the receiving station is located at the end of the antenna farthest from the transmitting station. The desired signaling currents, therefore, which flow through the conductors 1 and 2 in parallel flow to ground through the primary winding 27 which is coupled to the individual secondaries 11 and

32. In this case, the antenna is used as a transmission line for transmitting back to the end 3 of the antenna the currents desired for neutralization purposes. These currents are impressed from the primary winding 26 upon the secondary winding 28, which is included in the input circuit of the amplifier 25. The method of operation to secure neutralization of undesired currents is the same as with the arrangements shown in the preceding figures.

In Fig. 4 I have shown an arrangement of the apparatus whereby the receiving station may be located at a point between the ends of the antenna. In this case, the desired signaling currents which travel from the end 4 of the antenna toward the end 3 are fed back over the antenna as a transmission line to a point where the receiving station is located, and caused to flow through the primary winding 29 which is connected across the two antenna conductors at that point. The currents for neutralization purposes produced by waves traveling from the end 3 toward the end 4 of the antenna are caused to flow through the ground connection at [illegible] which is made to the mid point 31 of the winding 29. A high inductance choke coil 32 is included in this ground connection and the input circuit of the amplifier 25 is connected to the terminals of this choke coil. In other respects the operation is the same as the operation of the arrangement shown in the preceding figures.

While I have shown and described the preferred embodiments of my invention, it will be apparent that it is by no means limited to the particular circuit arrangements shown as many modifications in the arrangement of the circuits, the location of the receiving apparatus, and the type of apparatus employed may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing desired signaling currents produced in said antenna at one point upon said receiving circuits, and means for impressing upon said receiving circuits undesired currents produced in said antenna at another point.

2. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits and means for impressing upon each of said receiving circuits currents produced in said antenna at two different points.

3. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, located at a point along the length of said antenna, means for impressing upon said receiving circuits currents produced in said antenna at the point where the receiving circuits are located and means for impressing upon said receiving circuits currents produced in said antenna at a different point along its length.

4. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, located at a point along the length of said antenna, means for impressing upon said receiving circuits currents produced in said antenna at the point where the receiving circuits are located and means for utilizing said antenna as a transmission line for transmitting to said receiving circuits currents produced in said antenna at a different point along its length.

5. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at a point along the length of said antenna, means for impressing upon said receiving circuits desired signaling currents produced in said antenna at a distant point and means for impressing upon said receiving circuits undesired currents produced in said antenna at the point where the receiving circuits are located.

6. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at a point along the length of said antenna, means for utilizing said antenna as a transmission line for transmitting to said receiving circuits desired signaling currents produced in said antenna at a distant point, and means for impressing upon said receiving circuits undesired currents produced in said antenna at the point where the receiving circuits are located.

7. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at one end of said antenna and means for impressing upon said receiving circuits currents produced in said antenna at the end where the receiving circuits are located and at a distant point along the length of the antenna.

8. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at one end of said antenna and means for impressing upon said receiving circuits undesired currents produced in said antenna

at the end where the receiving circuits are located, and desired signaling currents produced in said antenna at a distant point along the length of the antenna.

9. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at one end of said antenna, means for impressing upon said receiving circuits undesired currents produced in said antenna at the end where the receiving circuits are located and means for utilizing said antenna as a transmission line for transmitting to the receiving circuits desired signaling currents produced in said antenna at a distant point along the length of the antenna.

10. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing desired signaling currents received upon said antenna upon each of said receiving circuits and means for impressing upon each of said receiving circuits currents derived from said antenna and of suitable phase and intensity to neutralize therein the effect of undesired currents received upon said antenna.

11. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon said receiving circuits desired signaling currents produced in said antenna at one point and means for impressing upon said receiving circuits currents produced in said antenna at another point and of suitable phase and intensity to neutralize in the receiving circuits the effect of undesired currents received upon said antenna.

12. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at a point along the length of the antenna, means for impressing upon said receiving circuits desired signaling currents produced in said antenna at a distant point and means for impressing upon said receiving circuits currents produced in the antenna at the point where the receiving circuits are located and of suitable phase and intensity to neutralize in the receiving circuits the effect of undesired currents received upon said antenna.

13. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at one end of the antenna, means for impressing upon said receiving circuits desired signaling currents produced in said antenna at a distant point, and means for impressing upon said receiving circuits currents produced in the antenna at the end where the receiving circuits are located and of suitable phase and intensity to neutralize in the receiving circuits the effect of undesired currents received upon said antenna.

14. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits located at one end of the antenna, means for utilizing said antenna as a transmission line for transmitting to said receiving circuits desired signaling currents produced in said antenna at a distant point, and means for impressing upon said receiving circuits currents produced in the antenna at the end where the receiving circuits are located and of suitable phase and intensity to neutralize in the receiving circuits the effect of undesired currents received upon said antenna.

15. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, and means for impressing upon each of the receiving circuits currents produced in both of the ground connections.

16. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon each of the receiving circuits currents produced in the ground connection at one end and means for impressing upon each of the receiving circuits currents produced in the antenna at a point remote from said ground connection.

17. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon each of the receiving circuits currents produced in the ground connection at one end and means for utilizing said antenna as a transmission line for transmitting to each of the receiving circuits currents produced in the antenna at a point remote from said ground connection.

18. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality or resonant receiving circuits, means for impressing upon each of the receiving circuits currents produced in the ground connection at one end and means for impressing upon each of the receiving circuits currents of adjusted phase and intensity derived from the ground connection at the opposite end.

19. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for utilizing said antenna as a trans-

mission line for transmitting to each of the receiving circuits currents produced in the ground connection at one end and means for impressing upon each of the receiving circuits produced in the ground connection at the opposite end.

20. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon each of said receiving circuits desired signaling currents produced in one of said ground connections, and means for impressing upon each of said receiving circuits currents produced in the other ground connections and of suitable phase and intensity to neutralize therein the effect of undesired currents received upon said antenna.

21. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for utilizing said antenna as a transmission line for transmitting to each of said receiving circuits desired signaling currents produced in one of said ground connections, and means for impressing upon each of said receiving circuits currents produced in the other ground connection and of suitable phase and intensity to neutralize therein the effect of undesired currents received upon said antenna.

22. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, a primary winding associated with said antenna in which desired signaling currents produced at one point in said antenna are caused to flow, a plurality of secondary windings coupled to said primary winding and associated with the respective receiving circuits, and means for impressing upon each of said receiving circuits undesired currents produced in said antenna at another point.

23. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, a primary winding associated with said antenna in which desired signaling currents produced at one point in said antenna are caused to flow, a plurality of secondary windings coupled to said primary winding and associated with the respective receiving circuits, and an individual primary and secondary winding for impressing upon each of said receiving circuits undesired currents produced in said antenna at another point.

24. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, a primary winding in which desired signaling currents produced in the ground connection at one end of said antenna are caused to flow, a plurality of secondary windings coupled to said primary winding and associated with the respective receiving circuits, and means for impressing upon each of said receiving circuits undesired currents produced in the ground connection at the other end of said antenna.

25. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, a primary winding in which desired signaling currents produced in the ground connection at one end of said antenna is caused to flow, a plurality of secondary windings coupled to said primary winding and associated with the respective receiving circuits, and an individual primary and secondary winding for impressing upon each of said receiving circuits undesired currents produced in the ground connection at the other end of said antenna.

26. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, a primary winding associated with said antenna in which desired signaling currents produced at one point in said antenna are caused to flow, a plurality of secondary windings coupled to said primary winding and associated with the respective receiving circuits, an individual primary and secondary winding for impressing upon each of said receiving circuits undesired currents produced in said antenna at another point, and means for adjusting both the phase and intensity of the undesired currents thus impressed upon the receiving circuits.

27. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, a primary winding in which desired signaling currents produced in the ground connection at one end of said antenna are caused to flow, a plurality of secondary windings coupled to said primary winding and associated with the respective receiving circuits, an individual primary and secondary winding for impressing upon each of said receiving circuits undesired currents produced in the ground connection at the other end of said antenna, and means for adjusting both the phase and intensity of the undesired currents thus impressed upon the receiving circuits.

28. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon said receiving circuits desired signaling currents produced

in said antenna at one point, an electron discharge device having an input circuit associated with said antenna at another point and an output circuit having means associated therewith for impressing upon said receiving circuits currents of a desired phase and intensity.

29. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon said receiving circuits desired signaling currents produced in said antenna at one point, an electron discharge device having an input circuit associated with said antenna at another point and an output circuit which includes a plurality of primary windings, a secondary winding associated with each of said primary windings and means for impressing upon each of said receiving circuits from an individual secondary winding a current of a desired phase and intensity.

30. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon said receiving circuits desired signaling currents produced in one of the ground connections of said antenna, an electron discharge device having an input circuit upon which currents produced in the other ground connection may be impressed and an output circuit having means associated therewith for impressing upon said receiving circuits currents of a desired phase and intensity.

31. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends, a plurality of resonant receiving circuits, means for impressing upon said receiving circuits desired signaling currents produced in one of the ground connections of said antenna, an electron discharge device having an input circuit upon which currents produced in the other ground connection may be impressed, and an output circuit which includes a plurality of primary windings, a secondary winding associated with each of said primary windings, and means for impressing upon each of said receiving circuits from an individual secondary winding a current of a desired phase and intensity.

32. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at at least two points, a plurality of resonant receiving circuits, and means for impressing upon each of said receiving circuits currents produced in two different ground connections.

33. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at at least two points, a plurality of resonant receiving circuits, means for impressing upon each of said receiving circuits desired signaling currents produced in one of said ground connections, and means for impressing upon each of said receiving circuits undesired currents produced in another of said ground connections.

34. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at at least two points, a plurality of resonant receiving circuits, means for utilizing said antenna as a transmission line for transmitting to each of said receiving circuits desired signaling currents produced in one of said ground connections, and means for impressing upon each of said receiving circuits undesired currents produced in another of said ground connections.

35. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at at least two points, a plurality of resonant receiving circuits located at a point along the length of said antenna adjacent to one of said ground connections, means for impressing upon each of said receiving circuits currents produced in the adjacent ground connection and in one other ground conenction.

36. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at at least two points, a plurality of resonant receiving circuits located at a point along the length of said antenna adjacent to one of said ground connections, means for impressing upon each of said receiving circuits desired signaling currents produced in a distant ground connection, and means for impressing upon each of said receiving circuits undesired currents produced in the adjacent ground connection.

37. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at at least two points, a plurality of resonant receiving circuits located at a point along the length of said antenna adjacent to one of said ground connections, means for impressing upon each of said receiving circuits desired signaling currents produced in a distant ground connection, and an electron discharge device having an input circuit associated with the adjacent ground connection and an output circuit having means associated therewith for impressing upon each of said receiving circuits currents of a desired phase and intensity.

38. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at at least two points, a plurality of resonant receiving circuits located at a point along the length of said antenna adjacent to one of

said ground connections, means for impressing upon each of said receiving circuits desired signaling currents produced in a distant ground connection, an electron discharge device having an input circuit associated with the adjacent ground connection and an output circuit which includes a plurality of primary windings, a secondary winding associated with each of said primary windings, and means for impressing upon each of said receiving circuits from an individual secondary winding a current of a desired phase and intensity.

39. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends and which has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at such a velocity that increments of current produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave, and a plurality of receiving circuits associated therewith which are resonant to the frequencies of a plurality of signaling waves which it is desired to receive.

40. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends and which has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at such a velocity that increments of current produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave, a plurality of receiving circuits associated therewith which are resonant to the frequencies of a plurality of signaling waves which it is desired to receive, means for impressing upon said receiving circuits desired signaling currents produced in said antenna at one point and means for impressing upon said receiving circuits currents produced in said antenna at another point and of suitable phase and intensity to neutralize in the receiving circuits the effect of undesired currents received upon said antenna.

41. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends and which has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at such a velocity that increments of current produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave, a plurality of receiving circuits associated therewith which are resonant to the frequencies of a plurality of signaling waves which it is desired to receive, and means for impressing upon each of the receiving circuits currents produced in both the of the ground connections.

42. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends and which has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at such a velocity that increments of current produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave, a plurality of receiving circuits associated therewith which are resonant to the frequencies of a plurality of signaling waves which it is desired to receive, means for impressing upon each of said receiving circuits desired signaling currents produced in one of said ground connections, and means for impressing upon each of said receiving circuits currents produced in the other ground connection and of suitable phase and intensity to neutralize therein the effect of undesired currents received upon said antenna.

43. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends and which has distributed constants of such value that electric waves produced therein by desired signaling means will be propagated along its length at such a velocity that increments of current produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave, a plurality of receiving circuits associated therewith which are resonant to the frequencies of a plurality of signaling waves which it is desired to receive, a primary winding in which desired signaling currents produced in the ground connection at one end of said antenna are caused to flow, a plurality of secondary windings coupled to said primary winding and associated with the respective receiving circuits and means for impressing upon each of said receiving circuits undesired currents produced in the ground connection at the other end of said antenna.

44. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends and which has distributed constants of such value that electric waves produced therein

by desired signaling waves will be propagated along its length at such a velocity that increments of currents produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave, a plurality of receiving circuits associated therewith which are resonant to the frequencies of a plurality of signaling waves which it is desired to receive, means for impressing upon said receiving circuits desired signaling currents produced in said antenna at one point, an electron discharge device having an input circuit associated with said antenna at another point and an output circuit having means associated therewith for impressing upon said receiving circuits currents of a desired phase and intensity.

45. A receiving system for radio signals comprising an aperiodic horizontal receiving antenna which is grounded at both ends and which has distributed constants of such value that electric waves produced therein by desired signaling waves will be propagated along its length at such a velocity that increments of currents produced in the antenna at points along its length by desired signaling waves in the ether will add to the current flowing therein through a distance which is at least equal to a half wave length of the desired signaling wave, a plurality of receiving circuits associated therewith which are resonant to the frequencies of a plurality of signaling waves which it is desired to receive, and which are located at a point along the length of said antenna adjacent to one of said ground connections, means for impressing upon each of said receiving circuits desired signaling currents produced in a distant ground connection, an electron discharge device having an input circuit associated with the adjacent ground connection and an output circuit which includes a plurality of primary windings, a secondary winding associated with each of said primary windings, and means for impressing upon each of said receiving circuits from an individual secondary winding a current of a desired phase and intensity.

46. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consist in impressing upon said receiving sets currents produced in said antenna at a single selected point by a plurality of desired signaling waves of different frequencies.

47. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consists in impressing upon said receiving sets currents produced in one of the ground connections of said antenna by a plurality of desired signaling waves of different frequencies.

48. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consists in impressing upon said receiving sets currents produced in said antenna at a single selected point and neutralizing the effect in each receiving set of undersired currents therein by impressing thereon currents of equal intensity and opposite phase derived from a different selected point in said antenna.

49. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consists in impressing upon said receiving sets currents produced in one of the ground connections of said antenna by a plurality of desired signaling waves of different frequencies and neutralizing the effect in each receiving set of undesired currents therein by impressing thereon currents of equal intensity and opposite phase derived from the other ground connection.

50. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consists in impressing upon said receiving sets currents produced in said antenna at a single selected point by a plurality of desired signaling waves of different frequencies, and impressing upon each receiving set currents derived from another selected point in said antenna.

51. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consists in impressing upon said receiving sets currents produced in one of the ground connections of said antenna by a plurality of desired signaling waves of different frequencies, and impressing upon each receiving set currents derived from the other ground connections.

52. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consists in impressing upon said receiving sets currents produced in said antenna at a single selected point by a plurality of desired signaling waves of different frequencies, impressing upon each receiving set currents derived from another selected point in said antenna, and separately adjusting both the phase and intensity of the last mentioned currents.

53. The method of operating a radio receiving system comprising a horizontal aperiodic receiving antenna which is grounded at both ends and a plurality of receiving sets which consists in impressing upon said receiving sets currents produced in one of the ground connections of said antenna by a plurality of desired signaling waves of different frequencies, impressing upon each receiving set currents derived from the other ground connection, and separately adjusting both the phase and intensity of the last mentioned currents.

In witness whereof, I have hereunto set my hand this 29th day of April, 1921.

HAROLD H. BEVERAGE.

Certificate of Correction.

It is hereby certified that in Letters Patent No. 1,434,985, granted November 7, 1922, upon the application of Harold H. Beverage, of Riverhead, New York, for an improvement in "Radioreceiving Systems," errors appear in the printed specification requiring correction as follows: Page 1, line 10, for the word "system" read *systems;* page 2, strike out present line 80 and insert instead *windings 21 and 22 of which are connected;* page 4, line 118, claim 18, for the word "or" read *of;* page 5, line 5, claim 19, before the word "produced" insert the word *currents;* same page, line 16, claim 20, and page 8, line 117, claim 51, for the word "connections" read *connection;* page 8, line 3, claim 44, and line 28, claim 45, for the word "currents" read *current;* same page, line 56, claim 46, for the word "consist" read *consists;* and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

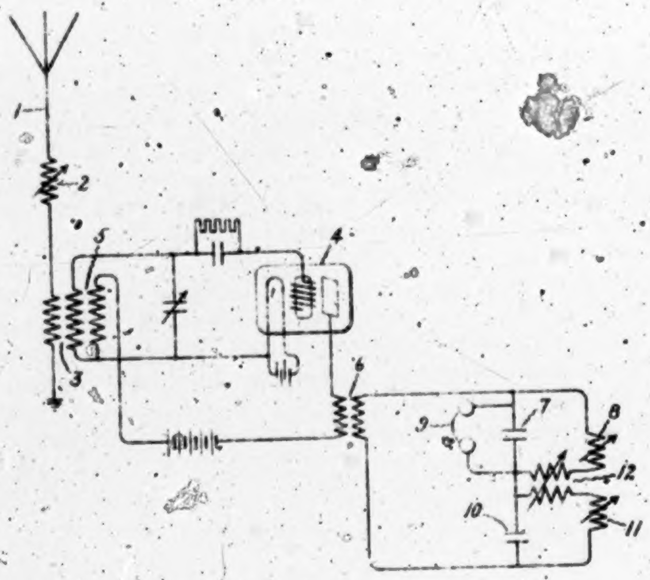
Signed and sealed this 9th day of January, A. D., 1923.

[SEAL.]

KARL FENNING,
Acting Commissioner of Patents.

Jan. 23, 1923. **DEFENDANT'S EXHIBIT No. 317.** 1,443,209

B. BRADBURY
RADIO RECEIVING SYSTEM
FILED SEPT. 15, 1920.


1
2
5
4
3
6
9
7
8
12
10
11

Inventor

Patented Jan. 23, 1923. **1,443,209**

UNITED STATES PATENT OFFICE.

BURKE BRADBURY, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIO RECEIVING SYSTEM.

Application filed September 15, 1920. Serial No. 410,520.

To all whom it may concern:

Be it known that I, BURKE BRADBURY, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Radio Receiving Systems, of which the following is a specification.

The present invention relates to radio receiving systems, particularly to systems for receiving continuous wave signals.

In some cases where it is desired to receive continuous wave signals by some method, such for example as the heterodyne method, for rendering such signals audible, it will be found difficult to tune a receiving system sharply enough to eliminate the effects in the receiver of stations of neighboring wave length which are either of higher power or located much nearer a receiving station than the one from which signals are to be received.

The object of my invention is to overcome such difficulties as the one mentioned and to provide a means for eliminating the effect in the receiver of interfering signals. The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have illustrated diagrammatically one way in which my invention may be carried into effect.

I have indicated in the drawing an antenna 1 with the usual tuning inductance 2 and a coupling transformer 3 by means of which the received signals are impressed upon the grid circuit of a detector 4 of the electron discharge type. The plate and grid circuits of the detector are coupled together at 5 in order that the detector may generate local oscillations of a frequency slightly different from that of the signals which are to be received. Coupled to the plate circuit of the detector 4 by means of the transformer 6 is a separate circuit in which are provided two frequency traps. One of these which comprises the capacity 7 and parallel inductance 8 is tuned for the frequency of the signals to be received, the usual telephone receiver 9, or any other desired form of indicator, being connected in parallel to this trap. The second trap made up of the condenser 10 and parallel inductance 11 is tuned to the frequency of the interfering signals which it is desired to suppress. This second trap offers a high impedance in the circuit to the flow of currents of the interfering frequency and thereby prevents such currents from affecting the telephone receivers 9. In case the second frequency trap does not completely prevent the interfering signals from affecting the telephone receivers a coupling 12 may be provided between the two frequency traps for the purpose of impressing upon the first frequency trap a current of the proper phase and intensity to neutralize any current of the undesired frequency which may flow in the first trap.

I have found that it is possible by the system indicated to eliminate the effect upon the receivers of signals produced from nearby stations of high power and of wave length differing only slightly from that of signals which are to be received from a distant station.

While I have indicated and described only a single way of carrying my invention into effect, it will be obvious to those skilled in the art that many modifications in the type of apparatus employed as well as in the circuit connections used may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a signal receiving system of a detector, a circuit upon which currents of audio frequency produced by said detector may be impressed, a frequency trap in said circuit which is resonant to the frequency of the signals to be received, and a second frequency trap in said circuit which is resonant to the frequency of interfering signals which it is desired to suppress.

2. The combination in a signal receiving system of a detector, a circuit upon which currents of audio frequency produced by said detector may be impressed, a frequency trap in said circuit which is resonant to the frequency of the signals to be received and a second frequency trap in said circuit which is resonant to the frequency of interfering signals which it is desired to suppress, and a coupling between said fre-

quency traps for neutralizing in the first trap currents set up therein of the undesired frequency.

3. In a system for receiving and detecting continuous wave signals, means for receiving continuous wave signals, means for producing currents of audio frequencies from the received signals, a circuit upon which the currents of audio frequencies are impressed, an indicator operatively related to said circuit in such a way as to be directly affected by currents of a desired frequency impressed upon said circuit, and means directly associated with said circuit for preventing currents of an undesired frequency impressed upon said circuit from affecting said indicator.

4. In a system for receiving and detecting continuous wave signals, means for receiving continuous wave signals, a detector, an indicator operatively related to said detector so as to be directly actuated by signaling currents of a desired frequency produced by said detector and means associated with said detector for preventing currents of an undesired frequency produced by said detector from affecting said indicator.

5. The combination in a signal receiving system of a detector, a frequency trap associated with said detector which is resonant to the audio frequency of the signals to be received and a second frequency trap associated with said detector which is resonant to the audio frequency of interfering signals which it is desired to suppress.

6. The combination in a signal receiving system of a detector, a frequency trap associated with said detector which is resonant to the frequency of the signals to be received, a second frequency trap associated with said detector which is resonant to the frequency of interfering signals which it is desired to suppress, and a coupling between said frequency traps including means for neutralizing in the first trap currents set up therein of the undesired frequency.

In witness whereof, I have hereunto set my hand this 14th day of September 1920.

BURKE BRADBURY.

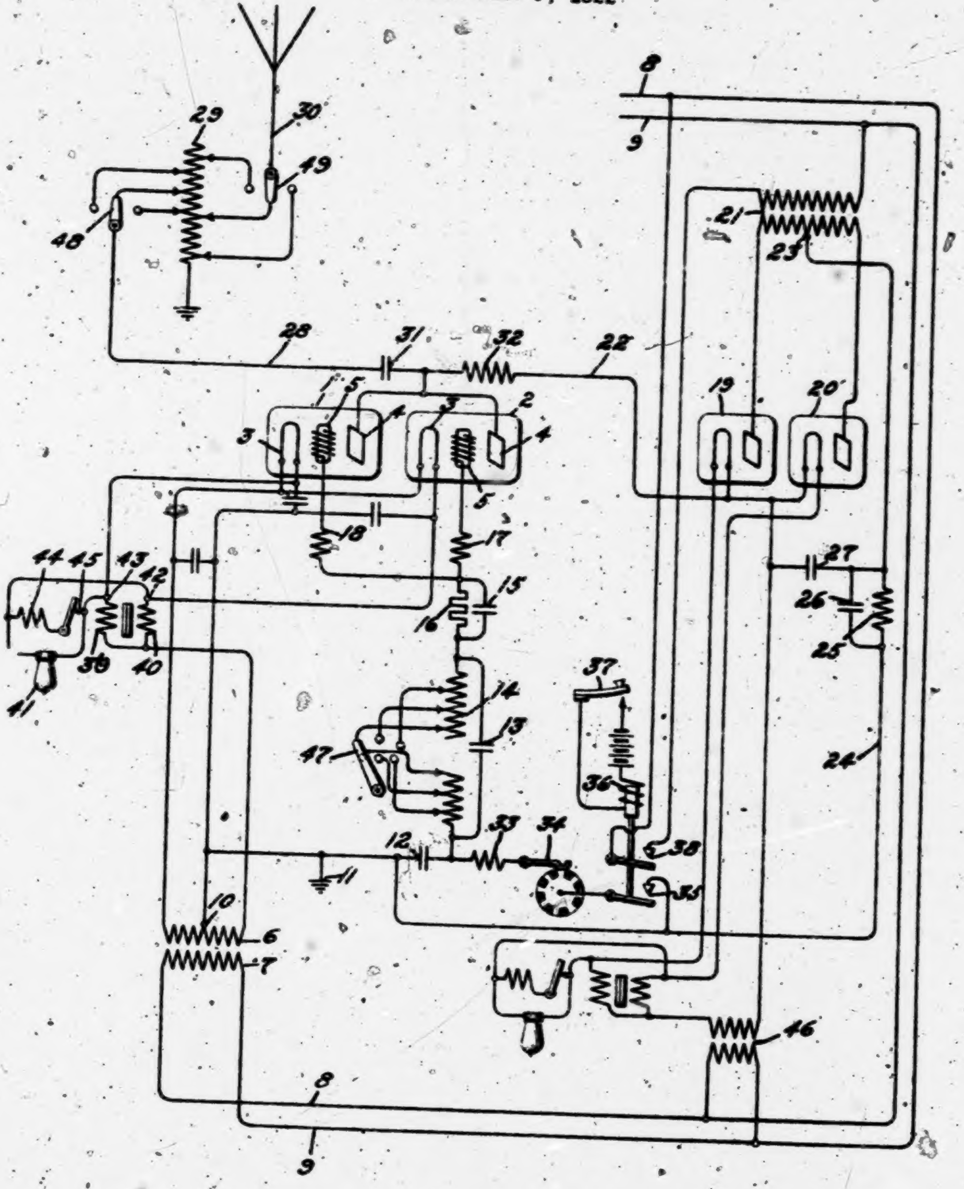
DEFENDANT'S EXHIBIT No. 318.

May 15, 1923. 1,455,099

W. R. G. BAKER

HIGH FREQUENCY SIGNALING SYSTEM

Filed Jan. 5, 1922


29
30
49
48
8
9
21
23
28
31
32
22
1
5
3
4
2
19
20
18
17
15
16
44
45
43
42
39
40
41
27
26
25
14
13
47
37
36
24
12
33
34
38
35
11
10
6
7
46
8
9

Inventor:
Walter R. G. Baker,
by Albert G. Davis
His Attorney.

Patented May 15, 1923.

1,455,099

UNITED STATES PATENT OFFICE.

WALTER R. G. BAKER, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

HIGH-FREQUENCY SIGNALING SYSTEM.

Application filed January 5, 1922. Serial No. 527,168.

To all whom it may concern:

Be it known that I, Walter R. G. Baker, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in High-Frequency Signaling Systems, of which the following is a specification.

My present invention relates to high frequency signaling systems, and more particularly to systems employing vacuum tubes as generators of high frequency oscillations.

One of the objects of my invention is to provide a simple and efficient arrangement for producing high frequency oscillations by means of vacuum tubes and supplying them to a transformer circuit. Another object of my invention is to provide a safe and reliable means for controlling the current output in accordance with signals to be transmitted.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, my invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have indicated diagrammatically one circuit organization whereby my invention may be carried into effect.

I have indicated in the drawing two electron discharge vacuum tube devices 1 and 2, which are employed for the generation of high frequency oscillations. These devices each comprise the usual filamentary cathode 3, a plate or anode 4, and a grid electrode 5. Current for heating the cathodes 3 is supplied by the secondary 6 of a transformer, the primary 7 of which is supplied by A C distribution lines 8 and 9. The midpoint 10 of the transformer secondary 6 is grounded at 11. A grid circuit for the devices 1 and 2 includes a condenser 12, a second condenser 13, which is shunted by variable inductance 14, a grid condenser 15, which is shunted by grid leak resistance 16, and two small choke coils 17 and 18, which are connected in the individual leads to the two grids. The plate or anode circuits of the devices 1 and 2 are supplied with current by means of rectifiers 19 and 20, these rectifiers serving to rectify the alternating current impressed upon the plate electrodes from transformer 21, which is supplied with current from distribution mains 8, 9. The cathodes of rectifiers 19 and 20 are connected to the anodes 4 of the electron discharge devices 1 and 2, by a conductor 22. The midpoint 23 of the secondary of transformer 21 is grounded at 11 by means of the conductor 24, a smoothing reactance 25 shunted by a condenser 26 being included in the ground connection. A shunt condenser 27 may also be employed to assist in smoothing out the rectified current.

The potential impressed upon the anodes 4 of electron discharge devices 1 and 2 in this manner is preferably high in order that a large output may be obtained with the comparatively small currents which normally flow through the usual form of electron discharge device. Under these circumstances high frequency oscillations will be produced in the oscillating grid circuit made up of inductance 14 and capacity 13 without any necessity of a feed-back coupling between the grid and plate circuits. The production of oscillations will occur by reason of the negative resistance or dynatron action of the device accompanying the emission of secondary electrons from the grid electrode 5. It has been discovered that with properly constructed tubes this dynatron action will take place even though the average potential of the grid electrode 5 is negative with respect to the cathode 3. The efficiency of the operation is in fact improved by such an arrangement. The condenser 15 shunted by resistance 16 forms a simple and efficient arrangement for maintaining the average potential of the grid electrode 5 negative with respect to the cathode.

When high frequency oscillations are produced in the grid circuit the grid potential oscillates accordingly and this produces corresponding variations in the current in the plate or output circuit. The oscillations thus set up in the plate or output circuit may in the case illustrated be supplied through the conductor 28 to a predetermined point in the inductance 29, which is associated with the antenna 30. A condenser 31 is included in series with the conductor 28 to prevent the rectified current supplied to the device from being short-circuited through inductance 29 and a radio frequency choke coil 32 is included in series with the conductor 22 to prevent the radio frequency currents produced from being short-circuited through the rectifiers 19, 20.

In order to interrupt the current supplied to the antenna 30 to produce telegraphic signals, the condenser 12 may be shunted by a circuit which includes a choke coil 33, a rotary contact maker 34 and a contact 35 of a relay 36, which is operated by means of a key 37. When the key 37 is closed and relay 36 operates to close contact 35, the condenser 12 will be shunted by a comparatively low resistance circuit whenever contact is made by the rotating contact maker 34. Whenever this shunt circuit is closed oscillations will be produced and supplied in the antenna. On the other hand when this shunt circuit is open the grids 5 of devices 1 and 2 will immediately assume so high a negative potential that production of oscillations will be interrupted. The rotating device 34, therefore, furnishes a convenient means for transmitting interrupted continuous wave signals. In case it is desired to transmit continuous wave signals the rotary device 34 may be omitted and current will be supplied to the antenna 30 as long as the key 37 is closed.

It will be apparent that by the arrangement thus far described, the load will be taken by the rectifiers 19, 20 when oscillations cease, and the apparatus will then be subjected to the full potential of the secondary of transformer 21. To overcome this difficulty a second contact 38 is provided for the relay 36, and when the key 37 is opened this contact is opened and power supplied to the rectifiers 19, 20 is interrupted simultaneously with the opening of the shunt circuit around key condenser 12.

It is desirable in the operation of transmitting equipment of the type described that an operator should be immediately informed whenever the filament of one of the electron discharge devices burns out or when the filament current becomes interrupted. I have indicated in the drawing one way in which such an indication may be given. Current is supplied to the filaments 3 of the two devices 1 and 2 in parallel, and in the individual supply conductors to the two filaments I insert two inductively related windings 39 and 40. An indicating lamp 41 is connected to the terminals 42, 43 of said windings, which are adjacent the cathodes 3. When current is being supplied to both filaments points 42 and 43 will be at the same potential and no current will flow through the lamp 41. As soon as one of the filaments is interrupted, however, a potential difference is produced between the points 42 and 43, and the lamp 41 will be illuminated. Lamp 41 may also be shunted by coil 44 through which current will pass when the lamp 41 is illuminated, and this coil may serve to operate a vibratory contact 45 which will control any desired form of audible signal.

The cathodes of the rectifiers 19 and 20 are supplied with heating current by means of a transformer 46, which is connected to the supply mains 8, 9 and an indicating device is provided to indicate a burn out of the filaments of either rectifiers 19 or 20.

Inasmuch as no coupling is provided between the grid and plate circuits of devices 1 and 2 except for the internal coupling of the circuits inside the tubes, the frequency of the oscillations produced will be principally determined by the inductance and capacity of the grid circuit, and will be substantially independent of the antenna constants. The frequency of the oscillations produced may be adjusted by varying either inductance 14 or capacity 13 in the grid circuit. I have indicated variable connections to the inductance 14 and the switch 47 whereby three different predetermined wave lengths may be obtained. A switch 48 may be provided for performing similar adjustments to the supply portion of the inductance 29 and a switch 49 for performing complementary adjustments in the antenna inductance for the various wave lengths. Switches 47, 48 and 49 are preferably so arranged that they may all be operated simultaneously thus permitting of the change of wave length from one predetermined value to another by a single movement of a switch handle.

While I have shown and described a preferred embodiment of my invention it will be understood that many modifications in the form of apparatus employed as well as in the various circuit connections, may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The combination in a high frequency current generating system of a three electrode electron discharge device having plate and grid circuits associated therewith, means for generating oscillations in said grid circuit independently of any coupling between the circuits, and a series condenser in said grid circuit which is shunted by a resistance for maintaining the average potential of the grid negative with respect to the cathode.

2. The combination in a high frequency current generating system of an electron discharge device having a cathode, an anode and a grid, an oscillating grid circuit associated therewith, means for generating oscillations in said grid circuit independently of any coupling between the grid circuit and other circuits of the device, an oscillating circuit connected between the cathode and

anode of said device and a separate circuit containing a source of potential between the cathode and anode.

3. The combination in a high frequency signaling system of an electron discharge device having a cathode, an anode and a grid, an oscillating antenna circuit connected between the cathode and anode of said device, a second circuit containing a source of potential connected between the cathode and anode of said device, an oscillating grid circuit associated with said device and means for generating oscillations in said grid circuit independently of any coupling between the circuits.

4. The combination in a high frequency signaling system of an electron discharge device having a cathode, an anode and a grid, an oscillating antenna circuit connected between the cathode and anode of said device, a second circuit containing a source of potential connected between the cathode and anode of said device, an oscillating grid circuit associated with said device, means for generating oscillations in said grid circuit independently of any coupling between the circuits, and a series condenser in said grid circuit which is shunted by a resistance for maintaining the average potential of the grid negative with respect to the cathode.

5. The combination in a high frequency signaling system of an electron discharge device having a cathode, an anode, and a grid, means for producing high frequency oscillations by said device and supplying them to a transmitting circuit comprising a source of alternating current and a rectifier for rectifying the current from said source for the operation of said electron discharge device, and means for simultaneously interrupting the supply of current to said rectifier and causing the production of oscillations to stop independently of the interruption in the power supply.

6. The combination in a high frequency signaling system of an electron discharge device having a cathode, an anode and a grid, an oscillating grid circuit associated with said device, means for producing oscillations in said grid circuit independently of any coupling between the grid circuit and other circuits of the device, a condenser in said grid circuit for preventing the production of oscillations and means for simultaneously shunting said condenser and supplying current to the device.

7. The combination in a high frequency signaling system of an electron discharge device having a cathode, an anode and a grid, an oscillating grid circuit associated with said device, means for producing oscillations in said grid circuit independently of any coupling between the grid circuit and other circuits of the device, a condenser in said grid circuit for preventing the production of oscillations, a shunt circuit for said condenser, a source of alternating current, a rectifier for rectifying the current from said source for the operation of said electron discharge device, and means for simultaneously interrupting the current supply to said rectifier and opening said shunt circuit.

8. The combination with a pair of electron discharge devices each of which has a filamentary cathode, of a transformer for supplying current to the cathodes of the two devices in parallel, two inductively related windings connected in individual current supply conductors to said cathodes and a signaling device connected to the terminals of said windings adjacent the two cathodes.

In witness whereof, I have hereunto set my hand this 3rd day of January, 1922.

WALTER R. G. BAKER.

DEFENDANT'S EXHIBIT No. 319.

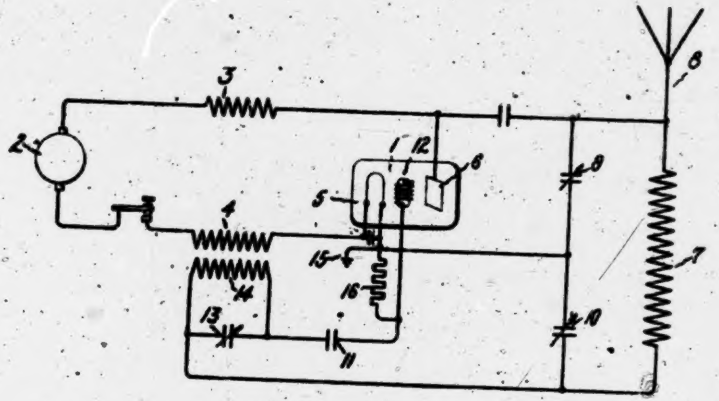
Aug. 28, 1923.

1,466,263

E. F. W. ALEXANDERSON

HIGH FREQUENCY SIGNALING SYSTEM

Filed April 10, 1922


3
2
1
12
6
8
5
4
9
15
16
7
14
13
10
11

Inventor:
Ernst F. W. Alexanderson
by Albert G. Davis
His Attorney

Patented Aug. 28, 1923. **1,466,263**

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

HIGH-FREQUENCY SIGNALING SYSTEM.

Application filed April 10, 1922. Serial No. 550,248.

To all whom it may concern:

Be it known that I, ERNST F. W. ALEXANDERSON, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in High-Frequency Signaling Systems, of which the following is a specification.

My present invention relates to high frequency signaling systems and more particularly to systems for producing interrupted continuous high frequency signaling currents.

The object of my invention is to provide a simple and efficient method and apparatus for producing interrupted continuous waves which will be particularly adapted for effective transmission of radio telegraphic signals.

In carrying my invention into effect, I employ an electron discharge device of the well known three electrode type and arrange this in such a way that it will be capable of producing oscillations of both audio and radio frequency. The apparatus is further adjusted and arranged in such a way that high frequency oscillations will be produced only during a portion of each cycle of the audio frequency oscillations. By proper adjustment of the apparatus the high frequency oscillations produced may be made of substantially constant amplitude during the period when they are being produced. High frequency oscillations produced in accordance with my invention because of the fact that they have a high decrement are more efficient for the transmission of signals than modulated high frequency oscillations such as have been produced in ways heretofore proposed for producing modulated high frequency oscillations by waves of an electron discharge device.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, my invention itself however both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have indicated diagrammatically one way of carrying my invention into effect.

I have indicated in the drawing an electron discharge device 1 of the usual three-electrode type. A supply circuit which includes a source of current 2 and inductances 3 and 4 is connected between the cathode 5 and anode 6. A high frequency oscillating circuit associated with the device 1 comprises an inductance 7 in circuit with the antenna 8 and capacities 9 and 10, this circuit being coupled by capacity 11 to the grid 12. The grid circuit also includes a low frequency oscillating circuit made up of capacity 13 and inductance 14, which is coupled to the inductance 4 in the supply circuit. The antenna 8 is grounded at 15 and the usual grid leak resistance 16 is connected between grid and cathode.

It will be apparent that with the arrangement described when so adjusted as to produce low frequency oscillations the potential of the grid varies at the audio frequency of the low frequency oscillations generated. If the device has suitable characteristics or the normal grid potential is adjusted to the proper value high frequency oscillations will be produced only during a portion of each cycle of the low frequency oscillations. This portion may by suitable adjustment be made to be all of the positive half cycle, a part only of the positive half cycle, or all of the positive half cycle and part of the negative. With the arrangement which I have described the point at which high frequency oscillations start may be made quite critical and the high frequency oscillations will quickly build up to their maximum amplitude and continue at substantially constant amplitude during the entire period during which they are produced. A high frequency wave of this type is more efficient for the transmission of signals than the usual modulated wave which builds up slowly to maximum amplitude and dies down slowly.

I am aware that it has heretofore been proposed to produce modulated high frequency oscillations by means of a single electron discharge device. In none of the systems which have been proposed for this purpose of which I am aware, however, have any means been provided for limiting the amplitude of the audio frequency oscillations in proportion to the amplitude of the radio frequency oscillations and there has been a general tendency in such systems for the audio frequency oscillations to rise in amplitude at the expense of the high frequency oscillations. In the system which I have described, however, it is apparent that the amplitude of the audio frequency oscillations will be limited by the amplitude of the radio frequency oscillations as the amplitude of the audio frequency oscillations is entirely dependent upon the amount of energy which is supplied to the tube and the greater part of this energy is converted into high frequency oscillations.

While I have shown and described the preferred embodiment of my invention it is apparent that many modifications in the circuit arrangement employed for carrying out my invention may be made without departing from the scope of my invention as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. A system for producing interrupted continuous waves comprising an electron discharge device having a cathode, an anode, and a grid, a supply circuit connecting the cathode and anode and containing a source of current, a high frequency oscillating circuit in shunt to said supply circuit and coupled by capacity to a grid circuit, and a a low frequency oscillating circuit associated with the grid circuit and inductively coupled to the supply circuit.

2. A system for producing interrupted continuous waves comprising an electron discharge device having a cathode, an anode and a grid, a supply circuit connecting the cathode and anode and containing a source of current, a radiating antenna, a high frequency oscillating circuit associated with the cathode and anode independent of said supply circuit, and with said antenna and coupled by capacity to a grid circuit and a low frequency oscillating circuit associated with the grid circuit and inductively coupled to the supply circuit.

3. The method of producing interrupted continuous waves by means of an electron discharge device which consists in generating low frequency continuous oscillations by means of said device and generating high frequency oscillations during the positive portions only of the individual cycles of the low frequency oscillations.

4. The method of producing interrupted continuous waves by means of an electron discharge device which consists in generating low frequency continuous oscillations by means of said device and generating high frequency oscillations during a portion only of each individual cycle of the low frequency oscillations.

5. The method of producing interrupted continuous waves by means of an electron discharge device which consists in generating low frequency continuous oscillations by means of said device and generating high frequency oscillations during a portion only of each individual cycle of the low frequency oscillations, and maintaining the high frequency oscillations of substantially constant amplitude during the periods when they are generated.

6. The method of operating an electron discharge oscillation generator which consists in generating both high frequency and low frequency oscillations thereby and limiting the amplitude of the low frequency oscillations by the amplitude of the high frequency oscillations.

7. The method of operating an electron discharge oscillation generator which consists in generating high frequency oscillations thereby and generating low frequency oscillations thereby which are limited in amplitude by the amplitude of the high frequency oscillations.

8. A system for producing interrupted continuous waves comprising an electron discharge device having a cathode, an anode and a grid, a supply circuit connecting the cathode and anode and containing a source of current, a high frequency oscillating circuit in shunt to said supply circuit, a grid circuit, and a low frequency oscillating circuit associated with the grid circuit and inductively coupled to the supply circuit.

9. A system for producing interrupted continuous waves comprising an electron discharge device having a cathode, an anode and a grid, a supply circuit connecting the cathode and anode and containing a source of current, a radiating antenna, a high frequency oscillating circuit associated with the cathode and anode independent of said supply circuit, and with said antenna, a grid circuit and a low frequency oscillating circuit associated with the grid circuit and inductively coupled to the supply circuit.

10. A system for producing high frequency oscillations comprising an electron discharge device having a cathode, an anode and a grid, a supply circuit connecting the cathode and anode, a high frequency oscillating circuit associated with said device in such a way that high frequency oscillations will be produced therein, and a low frequency oscillating circuit associated with said supply circuit in such a way that low frequency oscillations will be produced therein of an amplitude proportional to the energy supplied to the device.

11. A system for producing high frequency oscillations comprising an electron

discharge device having a cathode, an anode and a grid, a supply circuit connecting the cathode and anode, a high frequency oscillating circuit associated with said device in such a way that high frequency oscillations will be produced therein, and a low frequency oscillating circuit associated with said supply circuit in such a way that low frequency oscillations will be produced therein of an amplitude proportional to the amplitude of the high frequency oscillations produced.

In witness whereof, I have hereunto set my hand this 8th day of April, 1922.

ERNST F. W. ALEXANDERSON.

DEFENDANT'S EXHIBIT No. 320.

Oct. 9, 1923. **1,470,582**

O. C. TRAVER

AUTOMATIC RECLOSING CIRCUIT BREAKER SYSTEM

Filed Dec. 20, 1921

Fig. 1.

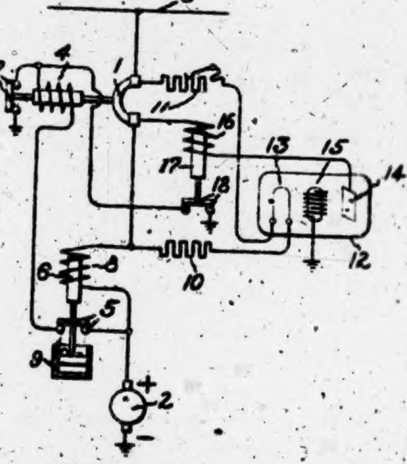

3
7
4
1
11
2
16
17
18
13
15
14
12
10
6
8
5
9
+
2
−

Fig. 2.

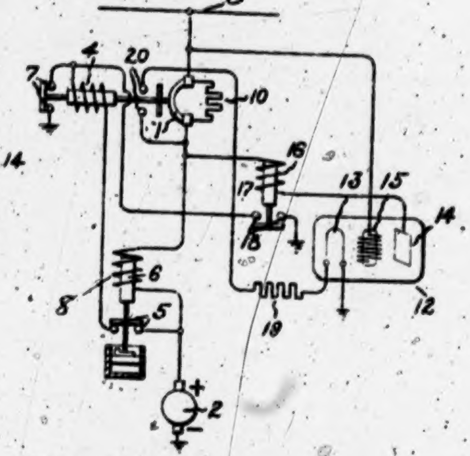

3
7
4
20
10
11
16
17
18
13
15
14
12
19
6
8
5
+
2
−

Fig. 3'

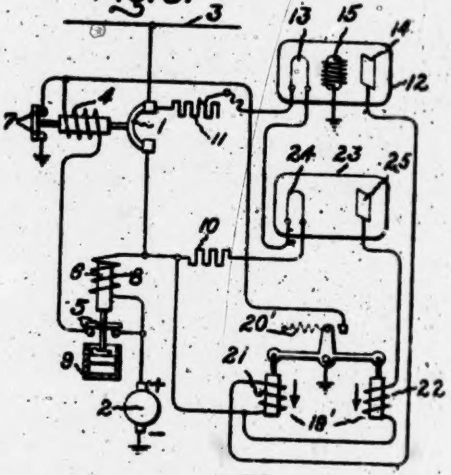

3
13
15
14
12
7
4
1
11
2
24
23
25
10
6
8
5
9
20'
21
22
19'
+
2
−

Fig. 4.

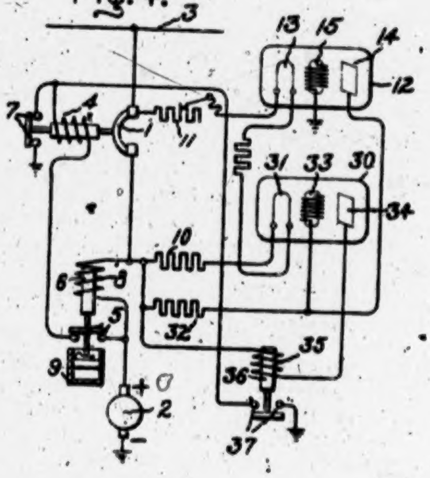
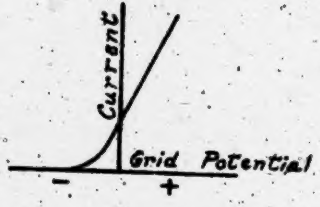

3
13
15
14
12
7
4
1
11
2
31
33
30
34
10
6
8
5
9
32
35
36
37
+
2
−

Fig. 5.



Inventor:
Oliver C. Traver,
by Albert G. Davis
His Attorney

Patented Oct. 9, 1923. **1,470,582**

UNITED STATES PATENT OFFICE.

OLIVER C. TRAVER, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

AUTOMATIC RECLOSING CIRCUIT-BREAKER SYSTEM.

Application filed December 20, 1921. Serial No. 523,755.

To all whom it may concern:

Be it known that I, Oliver C. Traver, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Automatic Reclosing Circuit-Breaker Systems, of which the following is a specification.

My invention relates to automatic reclosing circuit breaker systems, and particularly to such systems in which a circuit breaker is arranged to connect automatically a source of current to load circuit as soon as the load conditions are such that the circuit breaker can be closed without overloading the source, and has for its object the provision of a new and improved arrangement of apparatus for accomplishing this result.

In accordance with my invention, I arrange the system so that an electron discharge tube is connected to the load circuit when the circuit breaker is opened and the current through the tube is varied in accordance with the load resistance. The reclosing of the circuit breaker is governed by an electromagnetically operated device set to operate when the current through the electron discharge tube corresponds to a desired predetermined value of load resistance.

My invention will be better understood from the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

Referring to the drawing, Fig. 1 is a diagram of an automatic reclosing circuit breaker system showing one embodiment of my invention; Figs. 2, 3 and 4 show modifications of the embodiment shown in Fig. 1; and Fig. 5 shows a characteristic current curve of an electron discharge tube which may be employed.

Referring to Fig. 1, 1 represents a circuit breaker of any suitable type which is arranged to connect a source of current 2, here shown as a direct current generator, to one side of the load circuit 3, the other side of which is grounded. The circuit breaker 1 is provided with a closing coil 4 which, when energized closes and maintains the circuit breaker in its closed position. This closing coil may be connected to any suitable source of current such as the generator 2. The circuit of the closing coil 4 which is normally completed extends from the positive side of the generator 2 through the contacts 5 of the overload relay 6 and the auxiliary contacts 7 on the circuit breaker 1 to ground. The overload relay 6 is provided with a winding 8, which is connected in series with the source 2 and the load circuit 3 and is so designed that it opens the contacts 5 when the load current exceeds a predetermined value. The overload relay 6 is also provided with any suitable means, such as a dash pot 9, whereby the contacts are opened either instantly or after a predetermined interval when an overload occurs on the load circuit, but are not closed until a predetermined interval after the winding 8 is deenergized. 10 represents a current limiting impedance, such as a resistor, which is arranged to be connected in series with the source 2 and the load circuit 3 when the circuit breaker is open so as to limit the current supplied to the load circuit to a very small value.

When the circuit breaker is opened, the circuit of the closing coil 4 is controlled by means of an electron discharge tube 12 which is so arranged as to effect the energization of the coil 4 when the load resistance exceeds a predetermined value.

In the particular embodiment of my invention shown in this figure, the electron discharge tube 12 comprises a cathode 13 of filamentary form connected in series with the resistor 10, an anode 14 connected to any suitable source of potential, such as the source 2 so that it has a positive charge relative to the cathode 13 and a grid 15 interposed between the cathode and the anode and connected to the load circuit so that it has a negative charge relative to the cathode. It is evident, however, that the cathode could be heated from a separate source and a tap connection made to the load circuit or limiting resistance to establish the necessary potential of the filament. A coil 16 of a relay 17 is connected in series with the cathode 13 and anode 14. The relay 17 is arranged to close its contacts 18 and thereby complete the circuit of the closing coil 4 when the current through the tube drops below a predetermined value.

The operation of the arrangement shown in Fig. 1 is as follows:—Under normal operating conditions the circuit breaker 1 is held in its closed position by the energization of the closing coil 4. The circuit breaker 1 in its closed position short circuits the resistor 10 and the filament 13 so that no current flows through these devices and consequently the relay 17 is deenergized.

When an overload or short circuit occurs on the load circuit 3, overload relay 6 opens its contacts 5 and deenergizes the closing coil 4. Circuit breaker 1 then opens and the resistor 10 and filament 13 are connected in series with the source 2 and the load circuit 3. A small current is now supplied to the load circuit which heats the filament 13 and since the anode 14 is connected so that it has a positive charge relative to the cathode 13, a current flows through the electron discharge tube and the winding 16 of the relay 17. Relay 17 operates and opens its contacts 18 so that the closing coil 4 is not energized when the overload relay 6 closes its contacts 5 after a predetermined interval determined by the setting of the dash pot 9.

As the load resistance increases, the potential across the load circuit increases so that the grid 15 becomes more negative with respect to the cathode 13.

The amount of load resistance that is required to close the breaker may be varied in any suitable manner as by means of the adjustable resistance 11 which is connected between the filament 13 and the load circuit 3.

Referring to Fig. 5 which shows the effect the grid potential has upon the current through an electron discharge tube which is suitable for my invention it will be seen that as the grid potential becomes more negative with respect to the cathode the current through the electron discharge tube decreases. Consequently an increase in the load resistance decreases the amount of current through the tube 12 and the winding 16. When the load resistance reaches a predetermined value, the current through the tube becomes so small that the relay 17 closes its contacts 18 and completes the circuit of the closing coil 4 to close the circuit breaker 1.

In the modification of my invention shown in Fig. 2, the filament 13 of the electron discharge tube and a resistor 19 are connected in series across the terminals of the source 2 by means of the auxiliary contacts 20 on the circuit breaker when the circuit breaker is opened. It is evident, however, that the filament 13 could be heated and the desired potential impressed thereon in any other well known manner. The grid 15 in this case is connected to the load circuit so that it becomes more positive relative to the cathode as the load resistance increases. Otherwise, this modification is the same as the embodiment shown in Fig. 1, except that the relay 17 is arranged to close its contacts 18 when the current through the tube 12 is above a predetermined value instead of when it is below a predetermined value.

The operation of this modification of my invention is as follows: When a short circuit or overload occurs on the load circuit 3, the overload relay opens its contacts 5 and interrupts the circuit of the closing coil 4. Circuit breaker 1 then opens and inserts the current limiting resistor 10 in series with the source 2 and the load circuit 3 thereby completing the circuit of the filament 13. Filament 13 heats up and current flows through the tube 12 and the coil 16 of the relay 17. With a short circuit or an overload connected to the load circuit, not enough current flows through the tube 12 to operate the relay 17. As the load resistance increases, the potential drop across the load circuit increases so that the grid 15, which is connected to the positive side of the load circuit, becomes more positive with respect to the cathode 13. Consequently, the current through the relay 17 increases with the load resistance and when the load resistance reaches a predetermined value, the current through the winding 16 is sufficient to operate the relay and close its contacts 18 thereby completing the circuit of the closing coil 4. Circuit breaker 1 then closes and by closing its auxiliary contacts 7 completes a holding circuit for the coil 4. The opening of the auxiliary contacts 20 on the circuit breaker opens the circuit of the tube 12 so that the relay 17 becomes deenergized.

In the arrangement shown in Fig. 1, it is evident that if the filament of a tube burns out or the circuit thereof is interrupted in any way, the coil 16 of the relay 17 becomes deenergized and the closing coil 4 is energized to reclose the circuit breaker irrespective of the load resistance. In order to overcome this undesirable feature I prefer to use the modification shown in Fig. 3. In this modification the control relay 19′ is constructed as a balanced relay which is normally held in its open position by a spring 20′. The current that flows through the tube 12 flows through a coil 21 which also tends to keep the control relay 19′ in its open position. The control relay 19′ is arranged to be moved into its reclosing position by a solenoid 22 which is connected in series with an electron discharge tube 23, the filament of which is shown as being connected in series with the filament 13 of the tube 12. The tube 23 is of the type known in the art as the kenotron and consists of a cathode 24 and an anode 25. The anode is connected to the source 2 so that it is more positive than the cathode 24.

The operation of this modification of my invention is as follows: When an overload or short circuit occurs on the load circuit the circuit breaker 1 opens and inserts the resistor 10 and the filaments 13 and 24 in series with the load circuit. The filaments 13 and 24 become heated and a current flows through each of the tubes. So long as the short circuit or overload is connected to the load circuit the spring 20′ and the solenoid 21 are sufficient to maintain the control relay in its open position. As the load resistance increases the potential across the load circuit increases so that the grid 15 becomes more negative with respect to the cathode 13. Consequently, an increase in the load resistance decreases the amount of current through the tube 12 and the solenoid 21. The current through the tube 23, however, remains substantially constant since the percentage change in the total resistance connected to the generator 2 produced by the load resistance increasing from zero to its normal full load value is very small and consequently the temperature of the filament 24, which controls the current through the tube 23, remains substantially constant. When the load resistance reaches a predetermined value the current through the solenoid 21 decreases sufficiently to allow the solenoid 22 to overcome the opposing forces exerted by the spring 20′ and the solenoid 21. Control relay 19′ then moves into its closed position and completes the circuit of the closing coil 4 to reclose the circuit breaker. As soon as the circuit breaker closes, the holding circuit of the closing coil 4 is completed through the auxiliary contacts 7, and the resistor 10 and filaments 13 and 24 are short circuited. Solenoids 21 and 22 then become deenergized and the spring 20′ moves the control relay 19′ into its open position.

It will be noted that if either one of the filaments should burn out or the circuit thereof become broken in any way both of the solenoids 21 and 22 would be deenergized since the filaments are connected in series. Consequently, the spring 20′ would maintain the control relay 19′ in its open position and prevent the circuit breaker from being closed.

In the modification of Fig. 1 shown in Fig. 4, a second electron discharge tube 30 is used in conjunction with the tube 12 to control the reclosing of the circuit breaker. The filament 31 of the electron discharge tube 30 is shown as being connected in series with the filament 13. It may be desirable in some cases to connect the filaments so that the filament 31 is more positive than the filament 13. As above stated the filaments could be heated in any other suitable way and connections made to the load circuit or current limiting resistor so as to establish the necessary potentials. The grid 15 of the tube 12 is connected to the negative side of the load circuit, which in this case is grounded and the anode 14 is connected to a suitable source of potential, such as the generator 2 so that it has a positive potential relative to the cathode 13. An impedance 32 such as a resistor is connected in series with the cathode 13 and anode 14 and the grid 33 of the electron discharge tube 30 is connected to a tap on this impedance. The anode 34 of the tube 30 is also connected to a suitable source of potential such as the generator 2 so that it has a positive potential relative to the cathode 31. The coil 35 of a relay 36 is connected in series with anode 34 and cathode 31 of the tube 30 and this relay is arranged to close its contacts 37 and complete the circuit of the closing coil 4 to close the circuit breaker 1 when the current through the tube 34 exceeds a predetermined value.

The operation of this modification is as follows: Under normal conditions the circuit breaker 1 is held in its closed position by the energization of the closing coil 4, the circuit of which is completed through the overload relay contacts 5 and the circuit breaker auxiliary contacts 7. The circuit breaker in its closed position short circuits the resistor 10 and the filaments 13 and 31 so that no current flows through these devices and consequently the relay 36 is deenergized and the contacts 37 are opened. When an overload or short circuit occurs on the load circuit, overload relay 6 opens its contacts 5 and deenergizes the closing coil 4. Circuit breaker 1 then opens so that the resistor 10 and the filaments 13 and 31 are connected in series with the source 2 and the load circuit 3. The small current which is now supplied to the load circuit heats the filaments 13 and 31. Since the anodes 14 and 34 are connected so that they are positive relative to the cathodes 13 and 31, respectively, currents flow through both of these tubes. The current that flows through the tube 12 also flows through the impedance 32 and the current that flows through the tube 30 flows through the coil 35 of the relay 36, but is not sufficient to operate this relay when the load resistance is below a predetermined value. As the load resistance increases the potential across the load circuit increases so that the grid 15 becomes more negative with respect to the cathode 13. Consequently, the current that flows through the tube 12 and the impedance 32 decreases and this has the effect of increasing the potential of the tap on the impedance 32 to which the grid 33 of the tube 30 is connected. This increase in potential of the grid 33 in turn increases the current through the tube 30 and the coil 35 of the relay 36. It is evident, therefore, that with this arrangement of tubes a cumulative action is obtained so that a very small change in the load resistance produces a very large change in the current through the coil 35. When the load resistance reaches a predetermined value the current through the tube 30 is sufficient to operate the relay 36 which closes its contacts 37 and completes the circuit of the closing coil 4 to close the circuit breaker 1. The circuit breaker in its closed position completes a holding circuit for the coil 4 through the auxiliary contacts 7 so that the coil remains energized after the relay 35 opens its contacts due to the filaments 13 and 31 being short circuited by the main contacts of the circuit breaker.

It will be observed that if either filament should burn out while the circuit breaker is open the relay 36 would remain deenergized and consequently there is no danger of a premature closing of the circuit breaker due to the burning out of a filament. Furthermore, this arrangement has the advantage that the current through the tube 30 can be limited to a safe operating value in case the load resistance should suddenly increase to a very large value before the circuit breaker closes. By constructing the tube 12 so that the current through it decreases to zero when the load resistance reaches the predetermined value at which the circuit breaker closes, it is evident that if the load resistance should increase above this predetermined value it would not increase the potential of the grid 33 of the tube 34. Consequently, the current through the tube 30 is limited by the zero current of the tube 12. In this way large currents through the tube 30, due to large increases in the load resistance, are prevented.

While I have shown and described several embodiments of my invention, I do not desire to be limited to the exact arrangements shown and described but seek to cover in the appended claims all those modifications that fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, a circuit breaker for connecting said source to said load circuit, and closing means for said circuit breaker, of an electron discharge tube arranged to control the operation of said closing means in accordance with the load resistance when said circuit breaker is open.

2. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, and a circuit breaker for connecting said source to said load circuit, of an electron discharge tube having a cathode and an anode connected to said source so that the anode is more positive than said cathode and a grid connected to said load circuit so that the potential difference between the grid and cathode varies with the load resistance, and closing means for said circuit breaker arranged to be controlled by the current through said tube.

3. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, a circuit breaker for connecting said source to said load circuit, and a closing coil for said circuit breaker, arranged to close said breaker upon the energization thereof, of an impedance arranged to be connected in series with said load circuit and said source when said circuit breaker is open, an electron discharge tube having a cathode and an anode connected to said impedance so that the anode is more positive than the cathode and a grid connected to the load circuit so that the grid becomes more negative with respect to the cathode as the load resistance increases, and a relay arranged to be operated to effect the energization of said closing coil when the current through said tube drops below a predetermined value.

4. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, a circuit breaker for connecting said source to said load circuit, a closing coil for said circuit breaker arranged when energized to close and maintain said breaker in its closed position, a normally closed circuit for said closing coil, and means arranged to be operated by an overload on said load circuit to open said normally closed circuit and to prevent the reclosing of said normally closed circuit for a predetermined interval after the occurrence of the overload, of an impedance arranged to be connected in series with said load circuit and said source when said circuit breaker is open, an electron discharge tube having a cathode connected in series with said impedance, an anode connected to said impedance so that the anode is more positive than said cathode and a grid connected to the load circuit so that the grid becomes more negative with respect to the cathode as the load resistance increases, and a relay controlled by the current through said tube arranged to complete a circuit for said closing coil when the current through said tube drops below a predetermined value.

5. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, and a circuit breaker for connecting said source to said load circuit, of an electron discharge tube arranged to be connected to said load circuit when said circuit breaker is open so that the current through said tube varies in accordance with the load resistance, and closing means for said circuit breaker arranged to be operated by the current through said tube to close said breaker only when the load resistance is above a predetermined value.

6. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, and a circuit breaker for connecting said source to said load circuit, of an electron discharge tube comprising a cathode and an anode arranged to be connected to said load circuit when said circuit breaker is open so that the current through said tube decreases as the load resistance increases, a heating circuit for said cathode, closing means for said circuit breaker arranged to be operated when the current through said tube drops below a predetermined value, and means for preventing the operation of said closing means when the heating circuit of the cathode of said tube is open.

7. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, a circuit breaker for connecting said source to said load circuit, and closing means for said circuit breaker, of a plurality of electron discharge tubes, each having a cathode and an anode, arranged to control jointly the operation of said closing means in accordance with the load resistance, and a series heating circuit for the cathodes of said electron discharge tubes.

8. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, and a circuit breaker for connecting said source to said load circuit, of an electron discharge tube arranged to be connected to said load circuit when said circuit breaker is open so that the current through said tube varies in accordance with the load resistance, a second electron discharge tube arranged to be connected to said first mentioned tube so that current through said second tube varies in accordance with the current through said first tube, and closing means for said circuit breaker arranged to be controlled by the current through said second tube so as to close said circuit breaker when the load resistance is above a predetermined value.

9. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, and a circuit breaker for connecting said source to said load circuit, of an electron discharge tube arranged to be connected to said load circuit when said circuit is open so that the current through said tube varies inversely with the load resistance, a second electron discharge tube connected to said first mentioned tube so that the current through said second tube is controlled by the current through said first mentioned tube, and closing means for said circuit breaker arranged to be controlled by the circuit through said second mentioned tube so as to close said circuit breaker when the load resistance is above a predetermined value.

10. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, and a circuit breaker for connecting said source to said load circuit, of an impedance arranged to be connected in series with said load circuit and said source when said circuit breaker is open, an electron discharge tube having a cathode and an anode connected to said source so that the anode is more positive than said cathode and a grid connected to said load circuit so that the potential difference between said grid and cathode varies with the load resistance, a second impedance connected in series with the cathode and anode of said electron discharge tube, a second electron discharge tube having a cathode and an anode connected to said second impedance so that the anode is more positive than said cathode and a grid connected to said second impedance so that potential of said grid becomes more positive with respect to cathode of said second tube as the current through said first tube decreases, and closing means for said circuit breaker arranged to close said circuit breaker when the current through said second tube exceeds a predetermined value.

11. In an automatic reclosing circuit breaker system, the combination with a load circuit, a source of current, and a circuit breaker for connecting said source to said load circuit, of an impedance arranged to be connected in series with said load circuit and said source when said circuit breaker is open, an electron discharge tube having a cathode and an anode connected to said impedance and load circuit so that the anode is more positive than said cathode and a grid connected to said load circuit so that the potential difference between said grid and cathode varies with the load resistance, a second impedance connected in series with the cathode and anode of said electron discharge tube, a second electron discharge tube having a cathode and an anode connected to said second impedance so that the anode is more positive than said cathode and a grid connected to said second impedance so that potential of said grid becomes more positive with respect to cathode of said second tube as the current through said first tube decreases, a closing coil for said circuit breaker arranged to close said circuit breaker upon the energization thereof, and a relay connected in series with the cathode and anode of said second electron discharge tube and arranged to complete a circuit for said closing coil to close said circuit breaker when the current through said second tube exceeds a predetermined value.

In witness whereof, I have hereunto set my hand this 19th day of December, 1921.

OLIVER C. TRAVER.

DEFENDANT'S EXHIBIT No. 321.

April 22, 1924. **1,491,372**

E. F. W. ALEXANDERSON

RADIO RECEIVING SYSTEM

Filed Oct. 28, 1921

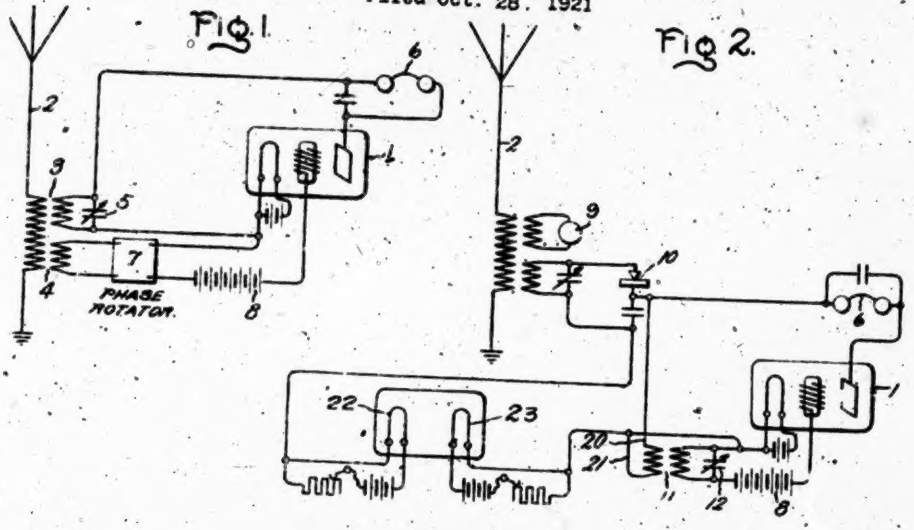


Fig. 1.
2
3
5
6
1
7
PHASE ROTATOR.
4
8
Fig. 2.
2
9
10
6
1
22
23
20
21
11
12
8

Fig. 3.

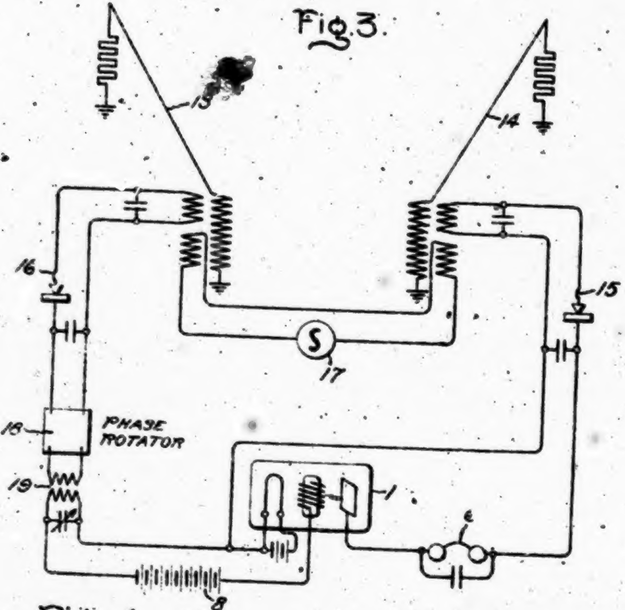
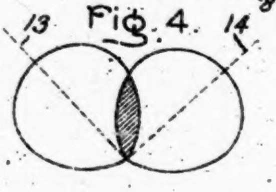

13
14
16
15
S
17
18
PHASE ROTATOR
19
1
6
8

Fig. 4.



Inventor:
Ernst F. W. Alexanderson,

by Albert G. Davis
His Attorney

Patented Apr. 22, 1924. **1,491,372**

UNITED STATES PATENT OFFICE.

ERNST F. W. ALEXANDERSON, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

RADIO RECEIVING SYSTEM.

Application filed October 28, 1921. Serial No. 511,127.

To all whom it may concern:

Be it known that I, Ernst F. W. Alexanderson, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Radio Receiving Systems, of which the following is a specification.

My present invention relates to systems for receiving high frequency radio signals, and more particularly to systems of this nature having a high degree of selectivity.

Selectivity in radio reception in the past has only taken into account the frequency of the signaling wave and the direction of wave motion. By means of these two factors it is possible to eliminate to a large extent interference from undesired stations of different wave length, or stations having approximately the same wave length, which are located in a different direction from the receiving station than the station from which signals are to be received. By means of these selective features it is also possible to eliminate to a large extent the effect of static disturbances, particularly those which are traveling in a different direction than the direction of the signaling wave. Another factor which, however, has not been employed for increasing selectivity and eliminating static disturbances is the phase of the signaling wave. While some static disturbances which may be of substantially the same frequency as the signaling wave may also be substantially in phase therewith, the probabilities are that the greater percentage of static disturbances are out of phase with the signaling wave. If, therefore, a receiving apparatus is constructed which is capable of discriminating between waves differing in phase and of selecting only currents which are in phase with the signaling current a much higher degree of selectivity and freedom from static disturbances may be obtained.

The object of my invention is to provide a simple and efficient radio apparatus which will have the property of discriminating between currents differing in phase.

If a receiver is to respond only to impulses in phase with the signal, the phase used as reference must be established by integration over as long a period as possible. Any wave that has not a constancy of phase and amplitude or the duration of which is short in comparison with that of the signaling wave, will not register in such a way as to form a definite phase. If a wave train is not in phase with the signal, it should not produce any indication. A receiver of the desired type, therefore, should have two elements: an integrating element which establishes the average phase of the signal, and a direct acting element which records impulses in so far as such impulses are in phase with current established by the integrating element.

Assume, for example, that a synchronous motor is driven by the audio frequency current of the signal. Assume further, that the motor drives a flywheel, and that the indicating device registers the torque transmitted by the motor to the flywheel. The flywheel would maintain an integrated phase but the torque reactions would register instantaneously. If disturbing currents are introduced into the driving system which are 90° out of phase with the integrating phase, they would produce no torque on the motor.

Any electrical equivalent of a mechanical device of this sort may be produced by means of a sharply tuned circuit, particularly of audio frequency, which acts as a flywheel. This circuit may form either the grid or plate circuit of a three-electrode electron discharge device, and the current to be detected may be simultaneously impressed upon both the grid and plate circuits of the device. If the two currents are in phase, current will be allowed to flow in the plate circuit and the device may be so adjusted that if the currents are 90° or more out of phase, no current will flow in the plate circuit. Since the current in the flywheel circuit will be maintained in substantially constant phase, currents in the other circuit which are out of phase will therefore produce no indication.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims; my invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof will best be understood by reference to the following description taken in connection with the accompanying drawing, in which Fig. 1 shows diagrammatically one way in which my invention may be carried into effect with radio frequency tuning; Fig. 2 shows a system in which audio frequency tuning is employed to secure the integrating effect; Fig. 3 shows a receiving system in which two antennæ having different directive properties are employed and the principle of phase selection is utilized for securing sharper directivity; and Fig. 4 is a receiving diagram of the arrangement illustrated in Fig. 3.

As indicated in the drawing, I preferably employ in my receiving apparatus an electron discharge device 1 of the usual three-electrode type having grid and plate circuits associated therewith. Signaling current received upon the antenna 2 is impressed, in the arrangement shown in Fig. 1, upon both the grid and plate circuits by means of the coupling transformers 3 and 4. The plate circuit is sharply tuned by means of a condenser 5 and the indicator 6 is associated with the plate circuit for the purpose of giving the desired indication of the received signals. Signaling current from the secondary of transformer 4 is supplied to the grid circuit of the device 1 through a phase rotator 7 for the purpose of so adjusting the phase of the signaling current in the grid circuit that it will be in phase with the current in the plate circuit. If the electron discharge device which is employed has sharp characteristics and the normal signal intensity is just sufficient to bring both grid and plate circuits up to the point where the tube becomes conductive when the plate and grid circuits are in phase, then it is obvious that the signaling current will readily pass through the tube, whereas any disturbances which are not in phase with the signaling current will not pass through unless they are of equal or greater strength than the signal. A phase selector of this simple form may be useful in connection with the operation of the recording device because it will give a clean cut record when the disturbances are of a moderate intensity. When, however, atmospheric disturbances are several times the intensity of the signal the flywheel effect which may be obtained in this manner will be insufficient to prevent the atmospheric disturbances from producing currents which are in phase in both the plate and grid circuits.

The grid of the device 1 is preferably given a negative bias by means of the battery 8 as by this means the phase selectivity will be greatly increased. The combination of the effects of the two currents in this manner apparently follows an entirely different law than the usual vectorial combination. For example, if two currents of unlike phase are combined vectorially they will give a resultant current unless they are 180° apart in phase. I find on the other hand, that with the combination described, the resultant current may be reduced to a zero value when the phase displacement between the two currents is 90°, or even less.

In the arrangement shown in Fig. 2 of the drawing, the signaling currents received upon the antenna 2, if of continuous wave form, are combined with currents from a local source 9 to produce beats and the beat current is rectified by means of a rectifying detector 10. The currents thus produced are preferably of audio frequency and are impressed directly upon the plate circuit of device 1 and are impressed upon the grid circuit of device 1 through a coupling transformer 11. The grid circuit in this case is sharply tuned by means of condenser 12 to give a flywheel effect. With this combination it is apparent that only currents which are substantially in phase with currents in a grid or flywheel circuit will flow through the plate circuit and the indicator 6. The signaling current will give a clear indication in the indicator 6 as long as it is applied to the plate circuit. The flywheel circuit will have a tendency to continue oscillating after the signaling current has been cut off. This swinging of the flywheel circuit will not produce any sound in the receiver, however, because no voltage will be applied to the plate. By means of this arrangement successful operation may be obtained with disturbing impulses much stronger than the signal because the disturbances will be of indiscriminate phase and will not have the same accumulative effect in the flywheel circuit as the signal which is of constant phase and frequency. When no signal is being received the flywheel circuit will be comparatively inactive, no current will pass through the indicator and it will not be until the static disturbances have reached an intensity many times that of the signal that they will affect the flywheel circuit sufficiently to allow current to flow through the indicator.

The principle of phase selection outlined above may be used to advantage in combining signals received from two stations of different geographical location or different directive characteristics. In Fig. 3 I have indicated a receiving system in which two directive receiving antennæ 13 and 14 are employed which extend in directions approximately 90° from each other. The receiving diagrams of these two antennæ overlap only to a slight extent, as indicated in the diagram of Fig. 4, the extent of overlapping being shown by the shaded area of the diagram. If the currents received from the two antennæ were combined vectorially in the ordinary way, three diagrams would result which would have substantially the same shape as the original diagrams. It will be possible, however, by the arrangement shown in Fig. 4 to combine the two currents by means of phase selection in such a way that waves will be received only from the directions indicated by the shaded area of the diagram.

In the arrangement shown in Fig. 3, the two antennæ are connected to separate detectors 15 and 16, but both of the detectors are controlled by the same local heterodyne source 17 or its equivalent. Current from detector 15 is passed through the plate circuit of the device 1 while the current from the detector 16 is passed through the phase rotator 18 and supplied to the grid circuit of device 1.

If a wave is received from a direction which is not within the overlapping range of the two receiving diagrams, it will act only upon one of the detectors. It will, therefore, affect only the plate circuit or the grid circuit of the phase selector, and neither of these actions will produce any sound in the telephone receiver 6. Upon the other hand, if a signal is received from a direction which is within the range of the overlapping of the directivity diagrams, the signal will act upon both detectors. The phase rotator 18 is so adjusted that signals from the desired direction will produce impulses which are in phase in the grid and plate circuits, and under these circumstances the signals will produce a sound in the telephone receiver. It is apparent that by the means described much sharper directivity may be obtained than with a simple directive antenna. The arrangement described is, of course, not entirely immune to the effects produced by impulses received from the non-overlapping parts of the receiving diagram. If two disturbing impulses are received simultaneously one by one antenna and the other by the other antenna, these two disturbances will act simultaneously upon the grid circuit and the plate circuit of the phase selector. They will, however, produce no effects in the telephone unless they are in phase. Inasmuch as atmospheric disturbances are of indiscriminate phase, it is obvious that the greater part of these simultaneous disturbances will be eliminated. There may, however, be a residual of disturbances which occur simultaneously from different directions and which are in phase, as well as disturbances which come from the same direction as the signaling wave. The effect of these disturbances may be largely overcome by introducing a flywheel tuning 19 in the grid circuit of the system shown in Fig. 3.

The form of my invention shown in Fig. 3 is described and claimed in my application Serial No. 638,362, which is a continuation in part of the present application.

Current limiting devices may to advantage be employed in order to limit the current which can be supplied to the flywheel circuit at any time to a value substantially equal to the signaling current. Any desired form of current limiting device may be used. For example, an electron discharge device having two filamentary electrodes 22, 23, with means for adjusting the heating currents thereof to such a value that the current flowing between the electrodes cannot exceed a predetermined desired value may be inserted in series with the conductors 20, 21 of Fig. 2. The use of such a device will prevent shocking of the flywheel circuit by disturbances of large intensity and thereby causing the phase of the current therein to vary. While the use of such devices may also limit the signal at the time a severe static disturbance occurs, their use in this connection will not be objectionable because of the fact that the flywheel effect will carry the current over the period when the current limiting device comes into action. Such devices, however, should not be employed in the circuit in which there is no flywheel effect, as they would tend to limit the signaling current to such an extent as to greatly reduce the signal strength whenever a severe disturbance occurs.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a signal receiving system of a detector, two circuits associated with said detector upon which received signaling current may be impressed, means associated with one of these circuits for integrating the phase of the signaling current flowing therein, an indicator associated with one of said circuits and means associated with the other circuit for causing said indicator to respond only to currents which are in phase with the signaling current.

2. The combination in a signal receiving system of a detector, two circuits associated with said detector upon which received signaling currents may be impressed, means associated with one of these circuits for maintaining substantially constant the phase of the current therein, an indicator associated with one of said circuits and means associated with the other circuit for causing said indicator to respond only to currents which are in phase with the current in the indicator circuit.

3. The combination in a signal receiving system of a detector, two circuits associated with said detector upon which received signaling currents may be impressed, one of said circuits comprising a low decrement tuning to the signal frequency, an indicator associated with one of said circuits, and means associated with the second circuit for causing said indicator to respond only to currents which are in phase with the current in the second circuit.

4. The combination in a signal receiving system of a detector for producing an audio frequency current from the received high

frequency current, two separate circuits associated with said detector to which the audio frequency currents may be supplied, means associated with one of said circuits for integrating the phase of the signaling current, an indicator associated with one of said circuits and means associated with the other circuit for causing said indicator to respond only to currents which are in phase with the signaling current.

5. The combination in a signal receiving system of a detector for producing an audio frequency current from the received high frequency current, two separate circuits associated with said detector to which the audio frequency currents may be supplied, means associated with one of said circuits for maintaining substantially constant the phase of the current therein, an indicator associated with one of said circuits, and means associated with the second circuit for causing said indicator to respond only to currents which are in phase with the currents in the second circuit.

6. The combination in a signal receiving system of a detector for producing an audio frequency current from the received high frequency current, two separate circuits associated with said detector to which the audio frequency currents may be supplied, one of said circuits comprising a low decrement tuning to the audio frequency signal current, an indicator associated with one of said circuits, and means associated with the second circuit for causing said indicator to respond only to currents which are in phase with the current in the second circuit.

7. The combination in a signal receiving system of detecting means for producing audio frequency currents from the received high frequency currents, two separate circuits to which the audio frequency currents are supplied, an indicator associated with one of said circuits, and means controlled by the current in the second circuit for causing said indicator to respond only to currents having a predetermined phase relation to the current in the second circuit.

8. The combination in a signal receiving system of an electron discharge device having plate and grid circuits associated therewith, means for supplying signaling currents to both of said circuits, means associated with one of said circuits for integrating the phase of the signaling current flowing therein, an indicator associated with the plate circuit, and means associated with the grid circuit for causing said indicator to respond only to currents in the grid circuit which are substantially in phase with the current in the plate circuit.

9. The combination in a signal receiving system of an electron discharge device having plate and grid circuits associated therewith, means for supplying signaling currents to both of said circuits, one of said circuits comprising a low decrement tuning to the signal frequency, an indicator associated with the plate circuit, and means associated with the grid circuit for causing said indicator to respond only to currents in the grid circuit which bear a predetermined phase relation to the signal current in the plate circuit.

10. The combination in a signal receiving system of an electron discharge device having plate and grid circuits associated therewith, means for supplying audio frequency signaling currents to both of said circuits, one of said circuits comprising a low decrement tuning to the signal frequency, an indicator associated with the plate circuit and means associated with the grid circuit for causing said indicator to respond only to currents in the grid circuit which bear a predetermined phase relation to the signal current in the plate circuit.

11. The combination in a signal receiving system of an electron discharge device having plate and grid circuits associated therewith, means for supplying signaling currents to both of said circuits, one of said circuits comprising a low decrement tuning to the signal frequency, an indicator associated with the plate circuit, means associated with the grid circuit for causing said indicator to respond only to currents in the grid circuit which bear a predetermined phase relation to the signal current in the plate circuit, and means for adjusting the phase of the current supplied to one of said circuits.

12. The method of selective reception of radio signals which consists in supplying received signaling currents to two circuits, integrating the phase of the signaling current flowing in one of said circuits and controlling the response in an indicator in one of said circuits by means of current flowing in the other circuit in such a way that the indicator will respond only to signaling currents which are in phase with the current of integrated phase.

13. The method of selective reception of radio signals which consists in producing an audio frequency current from received signaling currents, impressing the audio frequency currents upon two different circuits, integrating the phase of the current in one of said circuits, and controlling the response of an indicator in one of said circuits by means of the current in the other circuit in such a way that it will respond only to currents of the same phase as the current of integrated phase.

14. The method of selective reception of radio signals which consists in producing audio frequency currents from received signaling currents, impressing these audio frequency currents upon two different circuits,

integrating the phase of the current in one of said circuits, limiting the current which may be supplied to said circuit to a value substantially equal to the maximum signal current, and controlling the response of an indicator in the second circuit in such a way that the indicator will respond only to currents in the second circuit, which are in phase with the current of integrated phase in the first circuit.

In witness whereof, I have hereunto set my hand this 22nd day of October, 1921.

ERNST F. W. ALEXANDERSON.

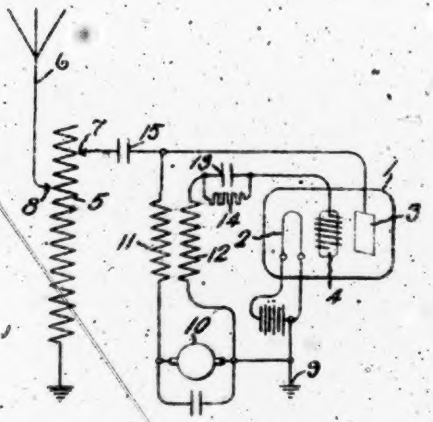
DEFENDANT'S EXHIBIT No. 322.

June 30, 1925 1,544,202

W. C. WHITE

SYSTEM FOR PRODUCING OSCILLATIONS

Filed Jan. 20, 1921


6
7
15
13
1
3
8
5
14
2
11
12
4
10
9

Inventor
William C.White
by Albert G Davis
His Attorney.

Patented June 30, 1925. **1,544,202**

UNITED STATES PATENT OFFICE.

WILLIAM C. WHITE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

SYSTEM FOR PRODUCING OSCILLATIONS.

Application filed January 20, 1921. Serial No. 438,560.

To all whom it may concern:

Be it known that I, William C. White, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Systems for Producing Oscillations, of which the following is a specification.

My present invention relates to the production of electrical oscillations, and more particularly to the production of such oscillations in a radio transmitting system.

The first object of my invention is to provide a simple and efficient system for producing high frequency oscillations which will be particularly adapted for operation over a wide range of frequencies and which will require a minimum number of adjustments for securing the most efficient operation over the same range of frequencies.

In many of the oscillating systems employing electron discharge devices for producing and transmitting by radio high frequency oscillations, which have previously been employed, it has been customary to employ the transmitting antenna as the oscillating circuit and to derive the energy necessary for exciting the grid to maintain oscillations directly or indirectly from the antenna system. In the operation of such systems three adjustments have been necessary to obtain good efficiency in operation, namely:—

(1) Adjustment of antenna inductance for desired wave length;

(2) Adjustment of the ratio of transformation between the antenna and the electron discharge device;

(3) Adjustment of grid coil and of coupling between antenna and grid circuit to vary the phase and voltage of the energy supplied to the grid to maintain oscillations.

Because of the fact that these adjustments are more or less dependent upon one another a more or less "cut and try" process is necessary in order to secure the desired output and operating efficiency. For example, the third adjustment depends upon the first two because of the fact that the grid excitation is dependent upon antenna current and any adjustment which changes the antenna current will necessitate a change in the third adjustment to secure the best results.

A second object of my invention is to provide a system in which the third adjustment mentioned will be unnecessary over a wide range of frequencies.

In attaining the objects of my invention I provide a coupling to the grid circuit from the portion of the plate circuit which supplies energy to the oscillating system. When the system is operating at rated output, the current voltage relations in this portion of the plate circuit are the same regardless of the frequency generated or the constants of the antenna as these conditions are fixed by the second adjustment. No readjustment of the coupling to the grid circuit with change in antenna constants is necessary therefore to obtain the desired phase relation and voltage of the energy supplied to the grid circuit, once it has been adjusted to one antenna system.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims; the invention itself, however, both as to its organization and method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have illustrated diagrammatically one way in which my invention may be carried into effect.

I have indicated in the drawing an electron discharge device having the usual filamentary cathode 2, anode 3, and grid 4. The anode 3 is connected to an inductance 5, a portion of which is in circuit with the antenna 6, variable connections 7 and 8 being provided for varying the coupling between the electron discharge device and the antenna, and for varying the amount of inductance, and hence the tuning of the antenna. The cathode 2 of the device may be grounded at 9 so that the antenna circuit is coupled to a shunt circuit between the cathode and anode and forms the oscillating circuit of the system. Energy for the operation of the system is supplied by means of a source 10, which is connected in a circuit between cathode and anode, which is separate from the antenna circuit and the shunt circuit between cathode and anode. This circuit contains inductance 11, which is closely coupled to inductance 12 in the circuit between cathode and grid. This grid circuit may also include the usual grid condenser 13 and the grid leak 14. A stopping condenser 15 is inserted in the connection between anode and antenna in order to prevent short-circuiting of the source 10.

In the operation of the system the tuning of the antenna may be accomplished in any desired way as by varying the connection 8 and the coupling between the device and the antenna may be adjusted by varying the connection 7. A system of this sort will ordinarily be operated at a certain rated output and by making the two adjustments described this rated output may be obtained for the wave lengths desired. Since the circuit by means of which energy is supplied to the grid system is independent of the oscillating circuit the current voltage relations in this circuit will be substantially constant irrespective of the constants of the antenna. The energy supplied to the grid circuit for maintaining oscillations is dependent upon the variations of voltage on the plate and when the plate to antenna ratio is correctly made will therefore remain substantially constant over a wide range of wave lengths and the phase of the energy thus supplied will also be substantially constant. As a result no change in the coupling between the plate circuit and the grid circuit will be required in order to secure the desired results.

While I have illustrated and described only one embodiment of my invention it will be obvious that my invention is by no means limited to the particular embodiment indicated, but that many modifications in the circuit connections employed may be made without departing from the scope of my invention as set forth in the appended claims.

While I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination in a system for producing electrical oscillations of an electron discharge device having a cathode, an anode and a grid, an oscillating circuit coupled to a shunt circuit between cathode and anode, a second circuit connected between cathode and anode containing a source of energy, a circuit between cathode and grid and a coupling between the second circuit between cathode and anode and the circuit between cathode and grid, the frequency of the oscillations produced being determined principally by the constants of said oscillating circuit.

2. The combination in a system for producing electrical oscillations of an electron discharge device having a cathode, an anode and a grid, an oscillating circuit coupled to a shunt circuit between cathode and anode, a second circuit connected between cathode and anode containing a source of energy and an inductance, a circuit between cathode and grid and a coupling between the inductance in the second circuit between cathode and anode and the circuit between cathode and grid, the frequency of the oscillations produced being determined principally by the constants of said oscillating circuit.

3. The combination in a system for producing electrical oscillations of an electron discharge device having a cathode an anode and a grid, an oscillating circuit coupled to a shunt circuit between cathode and anode, a second circuit connected between cathode and anode containing a source of energy and an inductance and a circuit between cathode and grid containing an inductance which is coupled to the inductance in the second circuit between cathode and anode, the frequency of the oscillations produced being determined principally by the constants of said oscillating circuit.

4. The combination in a system for producing electrical oscillations of an electron discharge device having a cathode, an anode and a grid, an oscillating antenna associated with a shunt circuit between the cathode and anode, a separate circuit between cathode and anode containing a source of energy a grid circuit and means for supplying to the grid circuit from the separate circuit between cathode and anode energy for maintaining oscillations in the system, the energy thus supplied being independent of the constants of the antenna and the frequency of the currents generated and the frequency of the currents generated being determined principally by the constants of the antenna.

5. The combination in a system for producing electrical oscillations of an electron discharge device having a cathode, an anode and grid, an oscillating antenna associated with a shunt circuit between the cathode and an anode, a separate circuit between cathode and anode containing a source of energy and an inductance, a grid circuit and means for supplying to the grid circuit from the inductance in the separate circuit between cathode and anode energy for maintaining oscillations in the system the frequency of which are determined principally by the antenna constants, the energy thus supplied being independent of the constants of the antenna and the frequency of the currents generated.

6. The combination in a system for producing electrical oscillations of an electron discharge device having a cathode, an anode and a grid, an oscillating antenna associated with the cathode and anode, a separate circuit between cathode and anode containing

a source of energy, a grid circuit, said circuits being closely coupled in order to supply to the grid circuit from the separate circuit between cathode and anode energy for maintaining oscillations in the system the frequency of which are determined principally by the antenna constants, the energy thus supplied being independent of the constants of the antenna and the frequency of the currents generated.

In witness whereof, I have hereunto set my hand this 18th day of January 1921.

WILLIAM C. WHITE.

DEFENDANT'S EXHIBIT No. 323.

July 21, 1925. 1,547,153

A. W. HULL

AMPLIFIER

Filed Oct. 13, 1921

Fig.1

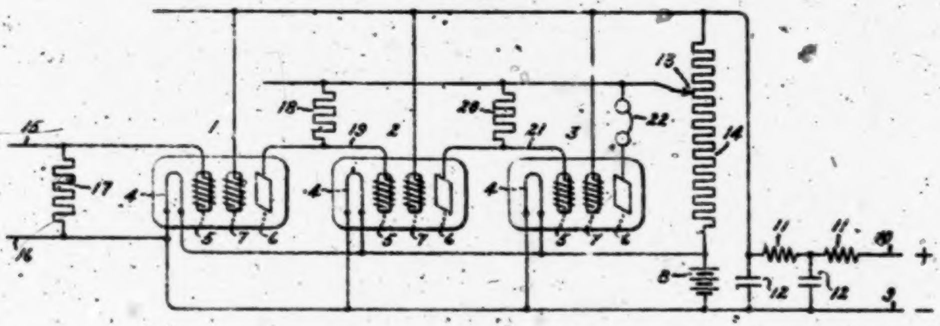

15
16
17
18
19
20
21
22
13
14
1
2
3
4
5
7
6
8
11
10
12
9
+
−

Fig.2

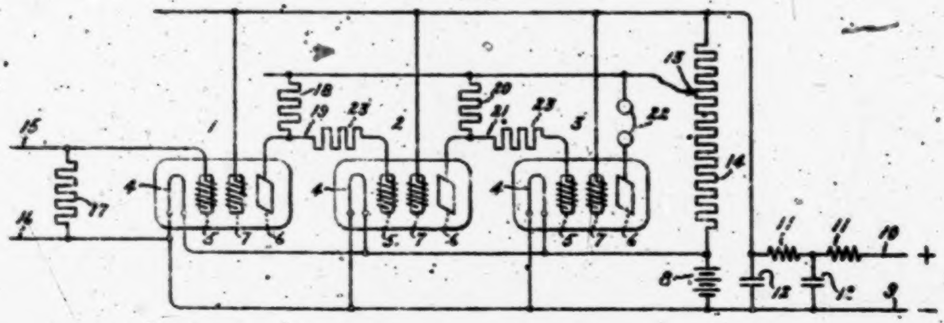
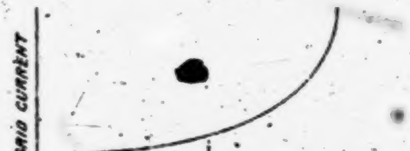

15
16
17
18
19
23
20
21
22
13
14
1
2
3
4
5
7
6
8
11
10
12
9
+
−

Fig.3.



Inventor:
Albert W. Hull,
by Albert G. Davis
His Attorney.

Patented July 21, 1925. 1,547,153

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

AMPLIFIER.

Application filed October 13, 1921. Serial No. 507,478.

To all whom it may concern:

Be it known that I, Albert W. Hull, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Amplifiers, of which the following is a specification.

My present invention relates to amplifiers, and more particularly to amplifiers of the multi-stage type employing a plurality of electron discharge devices connected in cascade.

One of the objects of my invention is to provide a simple and efficient circuit connection for connecting a plurality of electron discharge amplifiers in cascade.

Another object of my invention is to provide a multi-stage amplifier capable of giving a high degree of amplification for each stage and at the same time capable of operating with substantially the same efficiency for all frequencies.

In connecting electron discharge amplifiers in cascade in the past it has not been customary to operate the grids of the amplifiers at the same potential as the anodes of the preceding amplifiers of the series, the connection between stages having been made either by inductive or capacity coupling, or where a direct resistance connection has been made between stages it usually has been found necessary to employ a battery in the connection between the anode and the grid of the next succeeding amplifier of the series. In some cases where a direct connection has been made without a battery it has been necessary to employ separate filament and plate batteries for the different amplifiers.

A further object of my invention is to provide means whereby a direct conductive connection may be made from the anode of one amplifier to the grid of the next so that both electrodes will always be at the same potential and at the same time a common filament battery and a common plate battery may be employed for all of the amplifiers of the series.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 illustrates diagrammatically one way whereby my invention may be carried into effect; Fig. 2 shows a modification and Fig. 3 is a characteristic curve showing the relation between grid voltage and grid current under one condition of operation.

I have indicated in the drawing a cascade connection of three electron discharge amplifiers, 1, 2 and 3, each having the usual electron emitting cathode 4, a discharge controlling grid 5 and an anode or plate electrode 6. In addition to these three electrodes these amplifiers may have an additional grid electrode 7 interposed between the grid 5 and anode 6. Current for heating the cathode of all of the amplifiers may be supplied by a common source 8. Current for the plate circuits of all of the amplifiers may be derived from a source connected to the supply mains 9 and 10 through filtering inductances 11 and capacities 12. The potential applied to the plate circuits of the amplifiers may if desired be varied by means of the variable connection 13 to the potentiometer 14. In most cases, however, the potentiometer may be omitted.

The currents to be amplified are impressed from conductors 15 and 16 upon the resistance 17, which is included in the grid circuit of amplifier 1. The amplified current in the plate circuit of amplifier 1 flows through the resistance 18 and corresponding amplified potential variations are produced upon the anode of amplifier 1. These potential variations of the anode of amplifier 1 are impressed upon the grid of amplifier 2 by means of the direct conductive electrical connection 19. Similarly, the amplified potential variations of the anode of amplifier 2 produced by the amplified current flowing through resistance 20 in the plate circuit are impressed by means of the direct conductive electrical connection 21 upon the grid of amplifier 3.

I have indicated in the plate circuit of amplifier 3 a telephone receiver 22 for giving an indication of the amplified current flowing in the plate circuit of amplifier 3 in case the current to be amplified is an audio frequency current. In case the current to be amplified is a radio frequency current, the plate circuit of amplifier 3 may be connected in any desired way with a detector. It will be understood that as many amplifiers as desired may be connected in cascade and that any form of indicating apparatus desired may be associated with the plate circuit of the last amplifier of the series.

In the operation of multi-stage amplifiers in the past it has not been found feasible to operate the grid of one amplifier at the same potential as the plate of the preceding amplifier unless separate plate batteries were employed for the different amplifiers. This difficulty has been due to the fact that it has not been practical to operate the grid of the amplifier at a positive potential near that of the plate. Consequently where common plate batteries have been employed it has been found necessary to connect the plate of one amplifier to the grid of the next either by capacity or inductive coupling, or to insert a biasing battery in the grid circuit of the second amplifier. These disadvantages may, in accordance with my invention, be overcome in several ways to permit of the use of common plate and filament batteries for all of the amplifiers. If the resistance 18 is made of greater value than resistance 20, the drop of potential through resistance 18 will be greater than that through resistance 20, and the anode potential of amplifier 1 will be less than that of amplifier 2. Hence the grid of amplifier 2 may be connected to the anode of amplifier 1 and the positive potential of the grid amplifier 2 will always be less than the potential of the anode. Similarly the resistance of the plate circuit of amplifier 3 may be made less than that of 20 so that the plate potential of amplifier 3 will always be greater than the grid potential. By progressively decreasing the resistance in the plate circuits of the amplifiers in this way several more stages of amplifiers than those indicated may be operated in cascade for a common plate battery with the plate potential of each amplifier always higher than the grid potential.

One of the factors which has prevented the successful operation of amplifiers in cascade with the grid operating at about the same potential as the plate, has been the tendency of the grid to receive current from the plate due to the emission of secondary or impact electrons from the plate which flow to the grid preventing the grid from becoming more positive. This tendency may be overcome and the grids operated normally at about the same potential as the plate by making the plate in such a way that it will not emit any appreciable number of secondary electrons. This may be accomplished in several ways, as for example, by making the plate with a black or rough surface or by forming relatively deep and narrow corrugations on its surface. By constructing the plate in such a manner any impact electrons emitted will have difficulty in escaping from the plate and reaching the grid.

By the use of the extra grid electrode 7, other operating advantages may be secured. In the drawing I have indicated the electrodes 7 of all of the amplifiers as connected directly to the positive terminal of the source which supplies current to the plate circuits. It will be apparent that by this connection the potential of electrodes 7 will be fixed at a positive value which is always higher than that of the anodes 6, whether the potentiometer 14 is used or omitted. If this potential and the potentials of the anodes are properly chosen advantage may be taken of secondary or impact emission from the anode to produce a high positive resistance or a negative resistance in the plate circuits in accordance with the well known dynatron action, as described in my Patent 1,387,984 of August 16, 1921. The negative resistance may be proportioned to neutralize the positive resistance in the plate circuit and the positive resistance of the grid circuit of the next succeeding amplifier, and thus greatly increase the degree of amplification per stage which may be obtained. A great increase in amplification over that obtainable without the electrode 7 may be obtained however without the resistances being actually negative provided they are increased from their normal low values to very high positive values. If desired, the connections to the grid 5 and 7 may be reversed, the grid 5 being maintained at the constant positive potential and the grid 7 serving as a control grid. In this way the grid 7 may be made to have a negative or very high positive resistance.

The capacity effect between grid and anode of a three-electrode device also greatly reduces the possible amplification of the device when radio frequencies are employed and causes a tendency for the device to produce undesired high frequency oscillations. Both of these difficulties may also be reduced by the use of the extra electrode 7, which serves as a screen between grid and anode either when maintained at a higher potential than the anode, as indicated in the drawing, or at approximately the same potential, or at a lower potential than the anode, as set forth more fully and claimed in my copending application, Serial No. 431,746, filed December 18, 1920.

In case the resistance of the grid circuits of the amplifiers becomes negative or of a higher positive value by reason of the emission of impact electrons from the grids, it may be desirable to insert positive resistances 23 in the connections 19 and 21, as indicated in Fig. 2. In this case the grids will operate at a lower potential than the anodes. This would reduce the amplification if the grids had normal positive resistance characteristics, but if the grids have negative or approximately infinite resistance characteristics over the operating range the amplification will not be reduced. Under these circumstances it would be possible to operate as many three-electrode amplifiers as desired in cascade with the grid of each amplifier operating at a lower potential than the anode.

The characteristic curve of Fig. 3 represents a grid current characteristic of very high positive resistance between the points *a* and *b*. If such a grid is connected by a high resistance 23 to an anode at a higher potential any postential variations produced on the anode will be impressed upon the grid with only slight diminution. For example, if the potential changes of the anode are such that the grid potential tends to increase from *a* to *b*, the current through the resistance 23 will increase by only a small amount much less than the relative increase of potential, and the increased drop of potential through resistance 23 will be correspondingly small.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

2. Means for amplifying electric currents comprising a plurality of electron dischage devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing currents to be amplified between the cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, a high ohmic resistance in a circuit between the cathode and anode of said device which includes said source of potential, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

3. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and one of the grids of one of said devices, a source of potentianl connected between the cathode and anode of said device, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and means for directly impressing between the cathode and one of the grids of a second device potential variations produced between the cathode and anode of the first device.

4. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing currents to be amplified between the cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, a high ohmic resistance in a circuit between the cathode and anode of said device which includes said source of potential, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and means for directly impressing between the cathode and one of the grids of a second device potential variations produced between the cathode and anode of the first device.

5. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and the grid of said device which is nearest the cathode, a source of potential connected between the cathode and anode of said device, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

6. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing currents to be amplified between the cathode and the grid of said device which is nearest the cathode, a source of potential connected between the cathode and anode of said device, a high ohmic resistance in a circuit between the cathode and anode of said device which includes said source of potential, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

7. Means for amplifying electric currents comprising a plurality of electron discharge

devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and the grid of said device which is nearest the cathode, a source of potential connected between the cathode and anode of said device, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and means for directly impressing between the cathode and one of the grids of a second device potential variations produced between the cathode and anode of the first device.

8. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing currents to be amplified between cathode and the grid of said device which is nearest the cathode, a source of potential connected between the cathode and anode of said device, a high ohmic resistance in a circuit between the cathode and anode of said device which includes said source of potential, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, and means for directly impressing between the cathode and one of the grids of a second device potential variations produced between the cathode and anode of the first device.

9. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid being so chosen that the device has a negative resistance in the circuit between cathode and anode, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

10. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing currents to be amplified between cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, a high ohmic resistance in a circuit between the cathode and anode of said device which includes said source of potential, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid being so chosen that the device has a negative resistance in the circuit between cathode and anode, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

11. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid being so chosen that the device has a negative resistance in the circuit between cathode and anode, and means for directly impressing between the cathode and one of the grids of a second device potential variations produced between the cathode and anode of the first device.

12. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing currents to be amplified between the cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, a high ohmic resistance in a circuit between the cathode and anode of said device which includes said source of potential, means for impressing upon the second grid of said device a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid being so chosen that the device has a negative resistance in the circuit between cathode and anode, and means for directly impressing between the cathode and one of the grids of a second device potential variations produced between the cathode and anode of the first device.

13. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the

anodes, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

14. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, high ohmic resistances in each of the plate circuits except the last of the series, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

15. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade, each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, and means for impressing potential variations produced upon the anode of each amplifier except the last directly upon the grid of the next succeeding amplifier of the series.

16. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade, each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, high ohmic resistances in each of the plate circuits except the last of the series, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, and means for impressing potential variations produced upon the anode of each amplifier except the last directly upon the grid of the next succeeding amplifier of the series.

17. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

18. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, high ohmic resistances in each of the plate circuits except the last of the series, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

19. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, and means for impressing potential variations produced upon the anode of each amplifier except the last directly upon the grid of the next succeeding amplifier of the series.

20. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, high ohmic resistances in each of the plate circuits except the last of the series, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential

than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, and means for impressing potential variations produced upon the anode of each amplifier except the last directly upon the grid of the next succeeding amplifier of the series.

21. Means for amplifying electric currents comprising a plurality of electron discharge devices connected in cascade, each having a cathode, an anode and a controlling grid, grid and plate circuits associated with each of said devices, a common source of potential for the plate circuits of all of said devices, separate connections from said source to each device, means for impressing the currents to be amplified upon the grid circuit of the first device, and means for maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

22. Means for amplifying electric currents comprising a plurality of electron discharge devices connected in cascade, each having a cathode, an anode and a controlling grid, grid and plate circuits associated with each of said devices, a common source of potential for the plate circuits of all of said devices, separate resistances in the plate circuit of each device, means for impressing the currents to be amplified upon the grid circuit of the first device, and means for maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

23. Means for amplifying electric currents comprising a plurality of electron discharge devices connected in cascade, each having a cathode, an anode and a controlling grid, grid and plate circuits associated with each of said devices, a common source of potential for the plate circuits of all of said devices, separate resistances in the plate circuit of each device, the values of said resistances progressively decreasing from the first to the last of the series, means for impressing the currents to be amplified upon the grid circuit of the first device, and means for maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

24. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and one of the grids of one of said devices, a source of potential connected between the cathode and anode of said device, means for impressing a constant positive potential upon the second grid of said device, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

25. Means for amplifying electric currents comprising a plurality of electron discharge devices each having a cathode, an anode and a pair of grid electrodes interposed between cathode and anode, means for impressing the currents to be amplified between the cathode and the grid of said device which is nearest the cathode, a source of potential connected between the cathode and anode of said device, means for impressing a constant positive potential upon the second grid of said device, and a direct conductive electrical connection between the anode of the first device and one of the grids of a second device.

26. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing a constant positive potential upon the second grid of each of said amplifiers, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

27. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing a constant positive potential upon the second grid of each of said amplifiers, and means for normally maintaining the first grid of each succeeding device at the same potential as the anode of the preceding device.

28. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, a common source of potential for the plate circuits of all of said devices, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing a constant positive potential upon the second grid of each of said amplifiers, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

29. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, a common source of potential for the plate circuits of all of said devices, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing a constant positive potential upon the second grid of each of said amplifiers, and means for normally maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

30. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, a common source of potential for the plate circuits of all of said devices, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

31. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, a common source of potential for the plate circuits of all of said devices, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

32. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, a common source of potential for the plate circuits of all of said devices, and means for normally maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

33. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, the potentials impressed upon the anode and second grid of each amplifier being of such values as to produce a sufficient emission of impact electrons from the anode to substantially change the resistance characteristics of the plate circuit, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

34. Means for ampifying electric currents comprising a plurality of electron discharge devices connected in cascade, each having a cathode, an anode and a controlling grid, grid and plate circuits associated with each of said devices, a common source of potential for the pate circuits of all of said devices, means for impressing currents to be ampified upon the grid circuit of the first device and means for impressing upon the grid of each succeeding device potential variations produced upon the anode of the preceding device, the potentials of the anode and grid of each of the succeeding devices being of such values as to produce a sufficient emission of impact electrons from the grid to substantially change the resistance characteristic of the grid circuit.

In witness whereof, I have hereunto set my hand this 10th day of October, 1921.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 324.

FISH, RICHARDSON, HERRICK & NEAVE
84 State Street, Boston. 5 Nassau Street, New York.

Frederick P. Fish
W. K. Richardson
Robert F. Herrick
Charles Neave
Guy Cunningham
Alex D. Salinger
Jeremiah Smith, Jr.
J. Lewis Stackpole
William G. McKnight
Malcolm Donald
W. W. Farley
Harrison F. Lyman
Clarence D. Kerr

Albert M. Lyon
Phillips Ketchum

Telephones
Boston
6740 Main
New York
5485 Rector

* * * * * * * * * * * *
Rec'd 10/10
Ack. 10/10
Ans. ....
Filed Ex. 7
* * * * * * * * * * * *

New York October 10, 1913.

H. B. Thayer, Esq.,
15 Dey Street,
New York City.

Dear Mr. Thayer:

I enclose herewith a memorandum with reference to Cooper-Hewitt matters.

I will be obliged to you if you will let me have your views and instructions, particularly as to the matters referred to near the end of this memorandum.

I am sending copies of this letter and of its enclosure to Mr. Carty and Mr. Lockwood.

Very truly yours,
CHARLES NEAVE.

COOPER-HEWITT MATTERS.

Neave's Memorandum of October 9, 1913.

Some days ago I happened to meet Mr. C. A. Terry at lunch at the Railroad Club, and he said that he and Mr. Hewitt had been trying to get out a list of the foreign patents that might come within the scope of the

29. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, a common source of potential for the plate circuits of all of said devices, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing a constant positive potential upon the second grid of each of said amplifiers, and means for normally maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

30. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, a common source of potential for the plate circuits of all of said devices, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

31. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, a common source of potential for the plate circuits of all of said devices, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

32. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, a common source of potential for the plate circuits of all of said devices, and means for normally maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

33. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, the potentials impressed upon the anode and second grid of each amplifier being of such values as to produce a sufficient emission of impact electrons from the anode to substantially change the resistance characteristics of the plate circuit, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

34. Means for ampifying electric currents comprising a plurality of electron discharge devices connected in cascade, each having a cathode, an anode and a controlling grid, grid and plate circuits associated with each of said devices, a common source of potential for the pate circuits of all of said devices, means for impressing currents to be ampified upon the grid circuit of the first device and means for impressing upon the grid of each succeeding device potential variations produced upon the anode of the preceding device, the potentials of the anode and grid of each of the succeeding devices being of such values as to produce a sufficient emission of impact electrons from the grid to substantially change the resistance characteristic of the grid circuit.

In witness whereof, I have hereunto set my hand this 10th day of October, 1921.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 324.

FISH, RICHARDSON, HERRICK & NEAVE
84 State Street, Boston. 5 Nassau Street, New York.

Frederick P. Fish
W. K. Richardson
Robert F. Herrick
Charles Neave
Guy Cunningham
Alex D. Salinger
Jeremiah Smith, Jr.
J. Lewis Stackpole
William G. McKnight
Malcolm Donald
W. W. Farley
Harrison F. Lyman
Clarence D. Kerr

Albert M. Lyon
Phillips Ketchum

Telephones
Boston
6740 Main
New York
5485 Rector

Rec'd 10/10
Ack. 10/10
Ans. ....
Filed Ex. 7

New York October 10, 1913.

H. B. Thayer, Esq.,
15 Dey Street,
New York City.

Dear Mr. Thayer:

I enclose herewith a memorandum with reference to Cooper-Hewitt matters.

I will be obliged to you if you will let me have your views and instructions, particularly as to the matters referred to near the end of this memorandum.

I am sending copies of this letter and of its enclosure to Mr. Carty and Mr. Lockwood.

Very truly yours,
CHARLES NEAVE.

COOPER-HEWITT MATTERS.

Neave's Memorandum of October 9, 1913.

Some days ago I happened to meet Mr. C. A. Terry at lunch at the Railroad Club, and he said that he and Mr. Hewitt had been trying to get out a list of the foreign patents that might come within the scope of the

29. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, a common source of potential for the plate circuits of all of said devices, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing a constant positive potential upon the second grid of each of said amplifiers, and means for normally maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

30. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, a common source of potential for the plate circuits of all of said devices, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

31. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, a common source of potential for the plate circuits of all of said devices, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

32. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anode, the potentials impressed upon the anode and second grid of each amplifier being so chosen that each amplifier has a negative resistance in the plate circuit, a common source of potential for the plate circuits of all of said devices, and means for normally maintaining the grid of each succeeding device at the same potential as the anode of the preceding device.

33. The combination in an amplifying system of a plurality of electron discharge amplifiers connected in cascade each of which has a cathode, an anode and two grids and plate and grid circuits connected between said cathode and said anode and one of said grids respectively, means for impressing currents to be amplified upon the grid circuit of the first of said amplifiers, means for impressing upon the second grid of each of said amplifiers a higher positive potential than that impressed upon the anodes, the potentials impressed upon the anode and second grid of each amplifier being of such values as to produce a sufficient emission of impact electrons from the anode to substantially change the resistance characteristics of the plate circuit, and a direct conductive electrical connection between the anode of each amplifier of the series except the last and the first grid of the succeeding amplifier.

34. Means for ampifying electric currents comprising a plurality of electron discharge devices connected in cascade, each having a cathode, an anode and a controlling grid, grid and plate circuits associated with each of said devices, a common source of potential for the pate circuits of all of said devices, means for impressing currents to be ampified upon the grid circuit of the first device and means for impressing upon the grid of each succeeding device potential variations produced upon the anode of the preceding device, the potentials of the anode and grid of each of the succeeding devices being of such values as to produce a sufficient emission of impact electrons from the grid to substantially change the resistance characteristic of the grid circuit.

In witness whereof, I have hereunto set my hand this 10th day of October, 1921.

ALBERT W. HULL.

DEFENDANT'S EXHIBIT No. 324.

FISH, RICHARDSON, HERRICK & NEAVE
84 State Street, Boston. 5 Nassau Street, New York.

Frederick P. Fish
W. K. Richardson
Robert F. Herrick
Charles Neave
Guy Cunningham
Alex D. Salinger
Jeremiah Smith, Jr.
J. Lewis Stackpole
William G. McKnight
Malcolm Donald
W. W. Farley
Harrison F. Lyman
Clarence D. Kerr

Albert M. Lyon
Phillips Ketchum

Telephones
Boston
6740 Main
New York
5485 Rector

Rec'd 10/10
Ack. 10/10
Ans. ....
Filed Ex. ....

New York October 10, 1913.

H. B. Thayer, Esq.,
15 Dey Street,
New York City.

Dear Mr. Thayer:

I enclose herewith a memorandum with reference to Cooper-Hewitt matters.

I will be obliged to you ~~if~~ you will let me have your views and instructions, particularly as to the matters referred to near the end of this memorandum.

I am sending copies of this letter and of its enclosure to Mr. Carty and Mr. Lockwood.

Very truly yours,

CHARLES NEAVE.

COOPER-HEWITT MATTERS.

Neave's Memorandum of October 9, 1913.

Some days ago I happened to meet Mr. C. A. Terry at lunch at the Railroad Club, and he said that he and Mr. Hewitt had been trying to get out a list of the foreign patents that might come within the scope of the

option contract between Mr. Hewitt and the A. T. & T. Co., but they found it very difficult to determine what patents do and what do not come within the scope of that contract because they could not tell whether the ideas covered by some of the patents were likely to be developed along lines that would be useful in the A. T. & T. work. He said that they had about come to the conclusion to include in the list to be submitted to the A. T. & T. Co. all of Mr. Hewitt's foreign patents.

He further said that this brought up for definite consideration the question as to whether or not the A. T. & T. desired to take a license on all of the Hewitt patents for the validity of them would thereby be admitted, and it seemed to Mr. Terry and Mr. Hewitt that it might well be the case that devices embodying some of the Hewitt patents could not properly be expected to pay a royalty of $30. He said that they had been puzzling a good deal over this phase of the matter, and have not yet been able to come to any conclusion even in their own minds.

I reported this conversation to Mr. Thayer and Mr. Carty, and on October 6th Mr. Carty told me that he did not know whether Mr. Hewitt considered that his patents issued or to be issued cover such devices as the audion and that he did not know what Mr. Hewitt had meant in saying, in conversation with him, that it might be desirable to get Messrs. Gifford and Bull working on his patents. I told Mr. Carty and Mr. Thayer that I would try to find out what Mr. Hewitt's views were in this connection and what the reference to Gifford and Bull meant.

On the afternoon of October 7th I had a talk with Mr. Hewitt and Mr. Terry. I will try and give the substance of our conversation, though this will not be in the exact order in which the topics arose.

Mr. Hewitt said that he had made exhaustive studies of exactly the actions which take place in the passage of current between two electrodes in a sealed tube, and had ascertained and measured the resistances occurring at the electrodes and in the space between them. He said he had established beyond any question that the greatest resistance to such flow of current was at the negative electrode, and this he had termed the negative electrode resistance in various of his patents and writings. He said that the mercury arc which he commonly uses in his device, and the incandescent filament used in the audion are both employed for identically the same purpose which is to create a condition reducing the negative electrode resistance. He said that the mercury arc was the most efficient for this purpose, and he had found that it reduced the negative electrode resistance to such a point that only three volts were required to break down or overcome this resistance. He has found that the incandescent filament is not nearly so effective for this purpose, and has ascertained by measurements that in the audion twenty-six volts are required to overcome the negative electrode resistance. He emphasized these points, not only for the purpose of indicating that the mercury arc devices are more efficient than the audion, but also for the purpose of showing that the mercury arc and the incandescent filament were used to accomplish only the same purpose and as a basis for urging or proving that while his patents showed only the mercury arc he was not limited to that, but that his patents covered the same results produced by other means.

He said he had made careful studies of the audion in both the magnetic and non-magnetic form, and that there was no doubt in his mind that the magnetic form was much the more effective.

He said that if the A. T. & T. exercised the present option he would certainly consider that under that contract he was entitled to royalties, on every vapor device which the A. T. & T. Co. made use of for the purpose specified in the contract, and that by the term "vapor device" he did not mean to limit himself to a mercury vapor but to include such devices as the audion, and he said specifically that he would expect royalties on the audion if the A. T. & T. Co. used that.

I told him that I understood the fact to be that the audion was not covered by any of his issued patents, but that he considered that he had pending applications that would cover it. He said I was in error in the first part of this statement, for he certainly considered that his patents 781,001 and 781,002, which are respectively for an apparatus and a process, covered the audion. These are the patents which Mr. Lockwood and I have already considered and we do not agree with his view. It is true that the claims of those patents are broad enough to cover the audion or almost anything else, if we disregard the specifications of the patents and the arrangement and mode of operation set forth in those specifications. I consider, however, that they cannot be construed so broadly. I asked him what applications he had that would cover such a device as the audion, and he said he knew he had some, but could not put his hand on them because there were so many applications. He finally showed me one application that does have a claim expressed so vaguely that it might be considered to cover the audion, but I called his attention to the fact that that claim was in an application which was not filed until many years after the audion patent issued. He said that this to which I called his attention illustrated what he wanted Gifford and Bull for; he explained that his applications were in a very confused condition, that the claim to which I have just referred ought really to have been in one of his cases filed many years previously, and that if the A. T. & T. exercised the option he felt that some counsel in whom both parties had confidence, such as Gifford and Bull, should be given the work of carefully studying all of the pending applications, re-arranging the claims, etc., so as to get some order out of the existing chaos. In this connection I received this morning a letter from Mr. Terry, reading as follows:

> "Dr. Hewitt calls my attention to the two following claims which have been allowed in an application of his filed March 28, 1903, and which is a division of an application filed March 23, 1901, viz:
>
> '1. The method of starting an electric gas or vapor apparatus in which there is an initial negative electrode reluctance, which consists in breaking down said reluctance locally and thereby leaving the current free to traverse the entire gas or vapor path.'
>
> '2. The method of starting a gas or vapor electric apparatus having the quality of opposing an initial negative electrode reluctance to the passage of current, which consists in providing a path through the gas or vapor by locally breaking down the said reluctance.'
>
> I would be glad to have you read these claims, having in mind the audion."

Of course we cannot know what the words in these claims mean unless we study the application in which they appear and according to Mr. Hewitt we would not know even then, for we would have to push our researches further, and find out what relation this application has to his many others, and this is the work that he had in mind that Gifford and Bull should do.

Mr. Hewitt further said at our interview that he did not believe that either his mercury arc devices or such devices as the audion would continue long to be used, for both of them had the serious disadvantage of requiring a constant expenditure of current, such current being necessary to maintain the arc or to maintain the incandescence of a filament. He says that he has found that both the arc and the incandescent filament can be omitted if the electrodes are made of the proper materials, and if the proper gas is used in the enclosed tube. He says that working along this line he has developed a device in which forty volts are required to overcome the negative electrode resistance, and that theoretically he can improve this so that only eight volts will be required, but that even if he does not get down as far as eight volts he will have a device vastly superior to any now existing.

He further said that he felt that if the A. T. & T. exercised its option the contract should be drawn on broad lines, and should include not only repeaters, amplifiers, etc., but vapor tubes used for any and every purpose in telephony other than for rectifiers and other purposes with reference to which he has already parted with rights to the Westinghouse and General Companies. He said that, for instance, he had developed a device which could be inserted in the middle of a two hundred mile telephone line with the result that just as good transmission could be obtained over that line as though it was only one hundred miles long, and that this device was not a repeater or amplifier. He said, in response to a question from me, that he had never tried any of his devices on telephone lines, and that he had never had at his disposal even an artificial line, but that he had been obliged to content himself with working out the problems theoretically. He said that if a contract was made with the telephone company he would expect to communicate to its engineers the accumulated results of the vast investigations which he had made, so that their work in this direction would be lightened, and progress hastened, and the engineers could the more rapidly experiment with and develop the devices for practical telephonic work.

Mr. Hewitt and Mr. Terry then spoke again as to the difficulty in fixing a fair royalty. Mr. Hewitt said that he believed that there would be some devices that could not properly pay $30, though on considering the matter he also felt that there were many devices which should probably pay much more than $30, but that he could not bring that up as he had concluded himself on that point by agreeing to $30, which he now regards as the fixed maximum. As illustrating his idea of devices which should not bear $30 royalty, he said that the telephone transmitter was very much out of date and he believed that by the use of some of his devices every carbon transmitter would be displaced so that millions of his devices would be put in use by the A. T. & T. He said he recognized that in such a case $30 was too much royalty for each instance. I asked him what suggestions he had to make as to the proper method of dealing with this question in the contract, and he said he did not know what would be proper, but that he had put it up to Mr. Terry to devise something that would be fair. Mr. Terry said that he had been considering whether the proper royalty could be determined by arbitration from time to time, but that he saw many objections to this as there would be no fixed basis for the decision of the arbitrators. Mr. Hewitt then said that his mind had been reverting to the idea of a lump sum which might be paid by the A. T. & T. in commutation of royalties, but that he had not yet been able to fix in his own mind what would be a proper figure for this.

Mr. Hewitt said that he felt that his patents and his patents to issue on his applications would cover the audion broadly, but that he did not mean by that to assert that the DeForest patents were not valid for the specific forms there covered.

This morning I had an interview with Mr. Lockwood, and gave him the information set forth above.

I think that both of us feel that it will be useful to the telephone engineers to have the benefit of the results of Mr. Hewitt's years of study of vapor devices, even though those studies are on theoretical lines only, and even though we believe that many of them are along lines which will prove to be impractical in telephone work. I regard Mr. Hewitt's knowledge of theoretical operations as being a distinct asset which would be obtained if the contract is made, and I think Mr. Lockwood agrees with me in this.

It seemed to Mr. Lockwood and me that there are three lines along which the contract might advantageously be modified before acceptance, namely:

(1) That a total sum should be fixed upon the payment of which all royalties should cease;

(2) That a yearly maximum should be fixed as well as the minimum now existing;

(3) That there should be a sliding scale of royalties, based on the number of devices put into use under the contract. For instance, each of the first five hundred devices should bear $30 royalty, each of the next five hundred devices $25 royalty, and so on, at a decreasing rate.

This it seems to me would follow the lines of Mr. Hewitt's suggestions that the things that went into use in enormous quantities should bear but a small royalty.

Apparently many of the views that Mr. Hewitt explained to me are views that he obtained from Mr. Carty and Mr. Lockwood, but it is clear to me that it is to our advantage that Mr. Hewitt should continue to think that they are suggestions of his own. With this same idea in mind, and knowing that Mr. Hewitt and Mr. Terry are considering some fair modification of the contract, I suggested to Mr. Lockwood that we should not now go to them with any definite suggestions, but that as I am in the habit of seeing Mr. Terry on various matters quite frequently, I should, at these interviews, bring up this question of the Hewitt royalties, and see along what lines his mind was working, and make such suggestions as might seem adapted toward getting his mind working along the lines above suggested, if these meet with the approval of Mr. Thayer and Mr. Carty. That is, I think our efforts should be to have suggestions acceptable to us come from Mr. Hewitt, instead of making suggestions ourselves which, because they were made by us, might naturally be opposed by Hr. Hewitt.

If this course is approved I will proceed along these lines which I understand meet with Mr. Lockwood's approval.

DEFENDANT'S EXHIBIT No. 325.

Received
Feb. 12, 1915
Patent Dept.

Recorded 3/10/15
Job 3307
File R-11
W. E. Audion.

Vacuum Tube Repeater D-987.

10
February 8, 1915—EHC—604

MR. D. C. TANNER (2):

From time to time, we have kept you advised as to the form which the vacuum tube repeater itself was taking. We have also advised you as to the method of manufacturing the filament, which in service, is heated to incandescence and used as the cathode. There is one matter, however, upon which I believe, we have not laid any particular emphasis and I think perhaps it should be considered by your department. I refer to the processes of manufacture which we are employing more particularly in the evacuation of the bulb and I am handing you, herewith a brief statement by Mr. Arnold covering this ground. While it has seemed to us improbable that we are doing anything which infringes existing patents or which on the other hand involves patentability, it seems to me that the time has come for you to consider what may be termed our manufacturing process.

Up to the present time no attempt has been made to determine who is responsible for the development or the adoption of the various methods employed, but I think if the need arises this can be determined from our records.

C. E. SCRIBNER.

(In lead pencil: FBJ—CES.)

Attached: Memo. Mr. H. D. Arnold to Mr. E. H. Colpitts.

Vacuum Tube Repeater
D-987—302.

Received
Feb. 12, 1915
Patent Dept.

February 8, 1915—606—HDA-GQ

Mr. E. H. Colpitts:—

The present procedure in evacuating vacuum tube repeaters is as follows:

Four tubes are sealed to the molecular pump and an oven is placed about them. The temperature is gradually raised to about 350° Centigrade when the pumps are started. After about fifteen minutes the filaments are brought to incandescence by a current about ten per cent greater than their normal running current. A potential difference is applied between filament and grid until the ensuing current heats the grid red hot. The potential difference is then applied between filament and plate and gradually increased until about 175 volts is reached without any resulting glow in the tubes. The tubes are then allowed to cool and are sealed off, numbered and run over night at normal filament current.

During the early part of the pumping process, gas is given off from the glass walls and the metal parts of the tube and there results a blue glow when a sufficient potential difference is applied between filament and plate. Our measure of a sufficiently good vacuum is that this glow shall not appear for any voltages below 175 volts.

H. D. ARNOLD.

DEFENDANT'S EXHIBIT No. 326.

Abstract of Langmuir Paper Presented on October 18, 1913, Published in "Physical Review" of November, 1913.

SILVERED QUARTZ FIBERS OF LOW RESISTANCE OBTAINED BY CATHODE SPRAY.[1]

BY HORATIO B. WILLIAMS.

LOW resistance quartz fibers suitable for use in the Einthoven galvanometer and similar instruments, are usually prepared by chemical silvering. Such deposits are rough and the amount of silver is high in proportion to the conductivity. Cannegieter has shown that smooth fibers can be produced by deposition of a cathode film, followed by electroplating. By the method here outlined, fibers of low resistance can be obtained by the cathode spray alone, thus diminishing the number of manipulations and avoiding all contact with chemical solutions. The cathode is of pure sheet silver bent to a half cylinder. The fibers are held in the discharge tube on a glass frame to which they are cemented with hot shellac. The tube is several times exhausted to .01 mm. and rinsed with dry electrolytic hydrogen. Discharge is maintained at .01 ampere with voltage from 1,200 to 1,500. Direct current is supplied by two small generators with armatures connected in series and fields separately excited. Much gas seems to be occluded during the discharge and a small stream of hydrogen is allowed to leak in steadily, maintaining the current constant. The time of discharge varies with the thickness of film desired. A fiber 140 mm. long, .002 mm. finished diameter with a resistance of 2,700 ohms was obtained by exposure for three hours. The fibers are microscopically smooth and the coating is very compact, uniform and strongly adherent. A liquid air block between the discharge tube and the other parts of the apparatus insures uniform success, but good results can sometimes be secured without it.

DEPARTMENT OF PHYSIOLOGY,
COLUMBIA UNIVERSITY, NEW YORK.

THE EFFECT OF SPACE CHARGE AND RESIDUAL GASES ON THE THERMIONIC CURRENT IN HIGH VACUUM.[1]

BY IRVING LANGMUIR.

THE mutual repulsion of electrons (space charge) in a space devoid of positive ions limits the current that flows from a hot cathode to a cold anode. For parallel plane electrodes of infinite extent, separated by the distance x, and with a potential difference v between them, the maximum current (per unit area) that can flow if no positive ions are present is

$$i = \frac{\sqrt{2}}{9\pi}\sqrt{\frac{e}{m}}\,\frac{v^{\frac{3}{2}}}{x^2}.$$

---

[1] Abstract of a paper presented at the New York meeting of the Physical Society, October 18, 1913.

For the analogous case of an infinitely long hot wire placed concentrically within a cylindrical anode of radius r, the maximum current per unit length is

$$i = \frac{2\sqrt{2}}{9}\sqrt{\frac{e}{m}}\,\frac{v^{\frac{3}{2}}}{r\beta^2},$$

when β varies from 0 to 1, according to the diameter of the wire, but for all wires less than one tenth of the diameter of the anode, β is extremely close to unity.

Experiments show that in a very high vacuum (pressure less than .0001 mm.) and with electrodes which do not give off gas the space charge limitation often prevents the thermionic currents from exceeding a few milliamperes. Pressures of gas as high as .001 mm. with voltages above 40 volts usually lead to the formation of sufficient positive ions to neutralize the effect of space charge.

The presence of low pressures of most gases (.001 mm. or less) greatly decreases the electron emission from tungsten. This effect is especially marked at lower temperatures and tends to disappear at very high temperatures. This results in an increase in the value of b of Richardson's equation produced by practically all gases except the group of inert gases.

The proper conditions for obtaining the normal thermionic current from heated metals are discussed. This electron emission is found to be a true property of the pure metal and is not due to secondary chemical effects. For tungsten the thermionic current varies with the temperature in full accordance with Richardson's equation with the following constants:

$a = 34 \times 10^6$ amps. per sq. cm.,

$b = 55{,}500.$

Pure electron currents, of even several tenths of an ampere without any perceptible positive ionization, are thus readily obtained. No disintegration of the cathode occurs under these conditions.

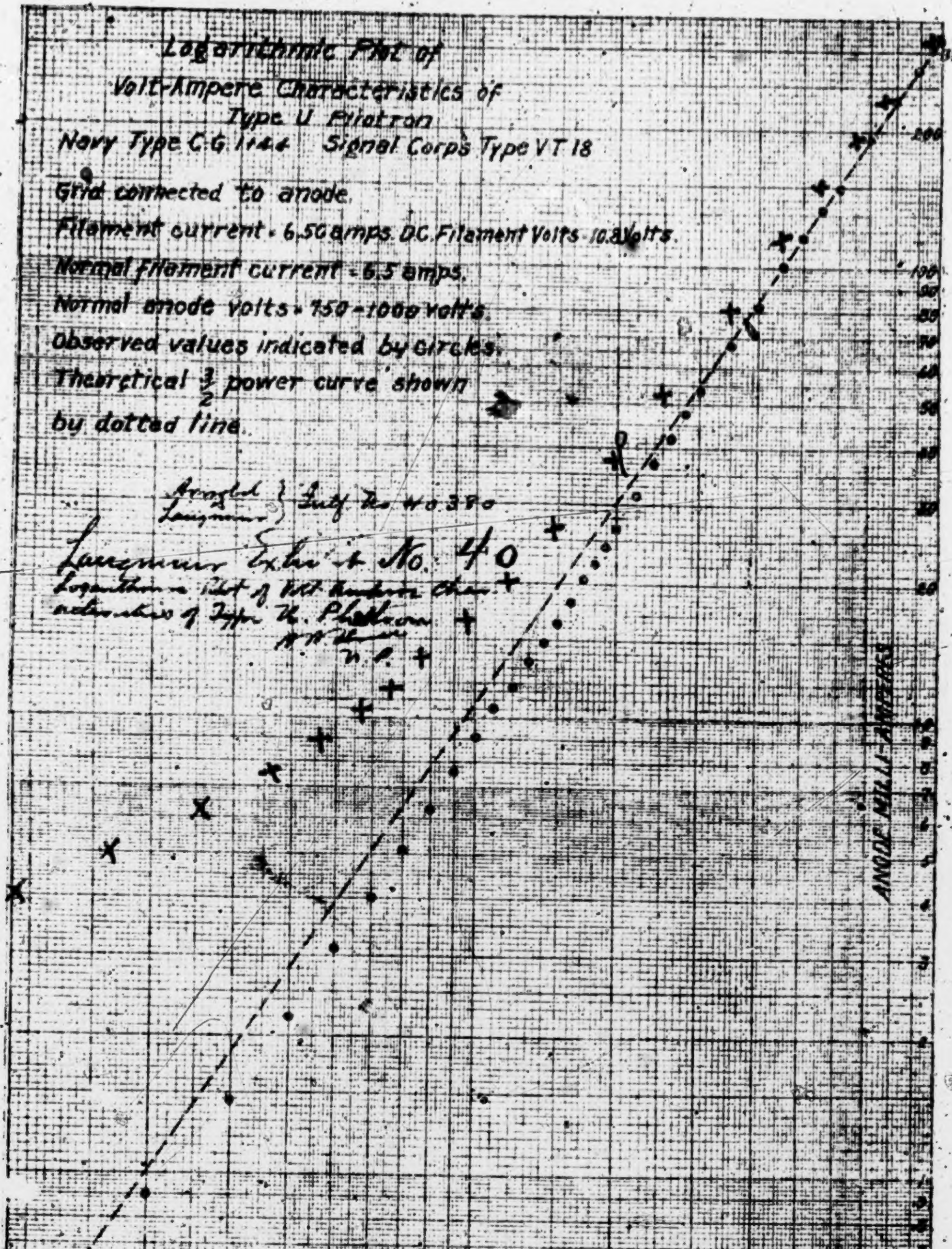
The effect of nitrogen in decreasing the thermionic current depends on the voltage of the anode. In many cases much less current is obtained at high than at lower voltages.

The following theory is in full accord with the observed phenomena: The effect of gases in changing the saturation current is due to the formation of a film of an unstable compound on the surface of the metal. The extent to which the surface is covered depends on the relative rates of formation and of destruction of the film. The film may be formed by direct reaction of the metal with the gas or be produced by the bombardment of the metal by positive ions. The film is destroyed by decomposition, volatilization, or cathodic sputtering (bombardment by positive ions).

Research Laboratory,
General Electric Co.,
Schenectady, N. Y.

DEFENDANT'S EXHIBIT No. 327.

Logarithmic Plot of Voltampere Characteristics of Type U Pliatron, (Plaintiff's Exhibit No. 60 with Additions).



DEFENDANT'S EXHIBIT No. 328.

Data Sheets Furnished to Plaintiff by Defendant's Witness Kelly.

November 1, 1926.

DESCRIPTION OF TYPE 7518-G AND TYPE 7510 VACUUM TUBES.

Type 7518-G Vacuum Tube.

General Description:

Helium filled vacuum tube number X-7408 is a sample of the laboratory type 7518-G vacuum tubes, which were designed to have approximately the characteristics of the 104-D vacuum tube. The plate and grid are of the enclosed ("wash-boiler") type and the tube was designed to have a μ of 2.00 to 2.50. A detailed description follows:

Filament:

The filament is B4 coated platinum-nickel ribbon of the following dimensions:

Length = 3-7/8" (effective)

Breadth = 0.0192"

Thickness = 0.002"

Area = 0.164 sq. in. = 1.06 cm^2.

E_A = 3.49 Volts at 1.60 amps.

Grid:

Details of the grid are shown on ES-414968. The lateral wires are formed by 23 complete turns of 0.004 inch (diam.) nickel wire wound 18.7 turns per inch. The grid is formed on a 5/8" x 1/8" mandrel. The filament grid spacing, that is the β used in our design formulae is,

$$\beta = \frac{1}{2}(0.125'' + 0.004'') = 0.0645''$$

Plate:

Details of the plate are also shown on ES-414958. It is the standard 221-D type of plate spaced on a 0.700" x 0.200" mandrel. The plate grid spacing, that is the α used in our design formulae is then,

$$\alpha = \frac{0.200}{2} - 0.0645'' = \overset{0.0355}{0.\cancel{1355}''}$$

The total plate area (both plates) is 1.63 square inches. The effective area taking the width of the grid as the effective width gives 2 x 1/2" x 1" = 1 square inch as a better approximation of the effective plate area.

Method of Measuring Gas Pressure:

A calibration curve for measuring the gas pressure tubes of this type was prepared as follows: The grid was he at a constant negative potential of 20 volts and served as t gas ion collector. With the plate at the potentials necessa to draw space current of 15, 25 and 35 milliamperes, simulta readings were made of the McLeod gauge and the ion current t the grid. The whole process was repeated for three or four tubes. The average of the results, which agreed quite well for the different tubes, are plotted on ES-419517.

Later readings of the gas pressure were obtained b reading the ion current to the grid at any one or all of the given space currents. Results of this process for vacuum tube X-7408 are [illegible] in Table I.

Type 7510 Vacuum Tube

General Description:

The laboratory type 7510 vacuum tube is an early design of the half-ampere L tube. The plate and grid are of the enclosed ("washboiler") type, and the tube was designed to have approximately the μ and R_0 of the 101-D vacuum tube. As a matter of fact the impedance of the tubes on which we ha gas data were of considerably lower impedance due to the substitution of B1 filament for the half-ampere filament. Tube number X-5928 (sent to Wilmington a few days ago) is identical in construction with the nitrogen-filled 7510 tubes for which data are being exhibited. A detailed description of this type of tube follows:

Filament:

The filament is in the form of an M of coated B1 platinum-nickel ribbon of the following dimensions:

Length = 3.0 inches

Breadth = 0.012 "

Thickness = 0.002 inches

Area = 0.54 cm^2.

E_A = 2.70 volts at 1.00 Amp.

Grid:

Details of the grid are shown on ES-419516. The lateral wires 0.008" (diam.) nickel wire wound 14 turns per inch, 13 turns in all. The grid is formed on a 3/32" x 1/2" mandrel. The grid-filament spacing, that is the β of our design formulae is

$$\beta = \frac{1}{2}(0.0937 + 0.008")$$

$$= 0.0508"$$

Plate:

A sketch of the plate is shown in ES-419515. The plate spacing is 1/4 inch, giving a plate-grid spacing, a of our formulae, of

$$a = \frac{0.250}{2} - 0.0508 = 0.0742''$$

The total plate area (both plates) is 1.35 square inches. The effective area is perhaps not more than $2 \times \frac{1}{2}'' \times 13/16'' = 0.80$ square inch approximately.

Electrical Characteristics:

The average μ for nine of these tubes made in the laboratory was 5.90, the average of the range of voltages taken being approximately $E_B = 150$ and $E_C = -12$.

The value of I_B at $E_B = 150$ volts and $E_C = 0$ under high vacuum conditions for the tubes with B1 filament is ~~18~~ 20 to ~~20~~ 24 milliamperes.

All gas data shown for this type of tube were obtained with tubes on the pump, and consequently the pressures were read directly from the McLeod guage.

Manometer Data on Helium filled
Tube X-7408 Type 718 G.
Given on Defendant's Exhibit 57.

For Initial Pressure.

$I_A = 1.60$ amperes
$E_c = -20$ volts

I_B	15	25	35 milliamperes	
E_B	87.4	105.0	118.0	
I_c	2.6	6.1	10.0 microamperes	
Pr	2.8 µ	3.1 µ	3.2 µ	3.0 Av

For Final Pressure

$I_A - 1.60$ amps
$E_c = -20$ volts

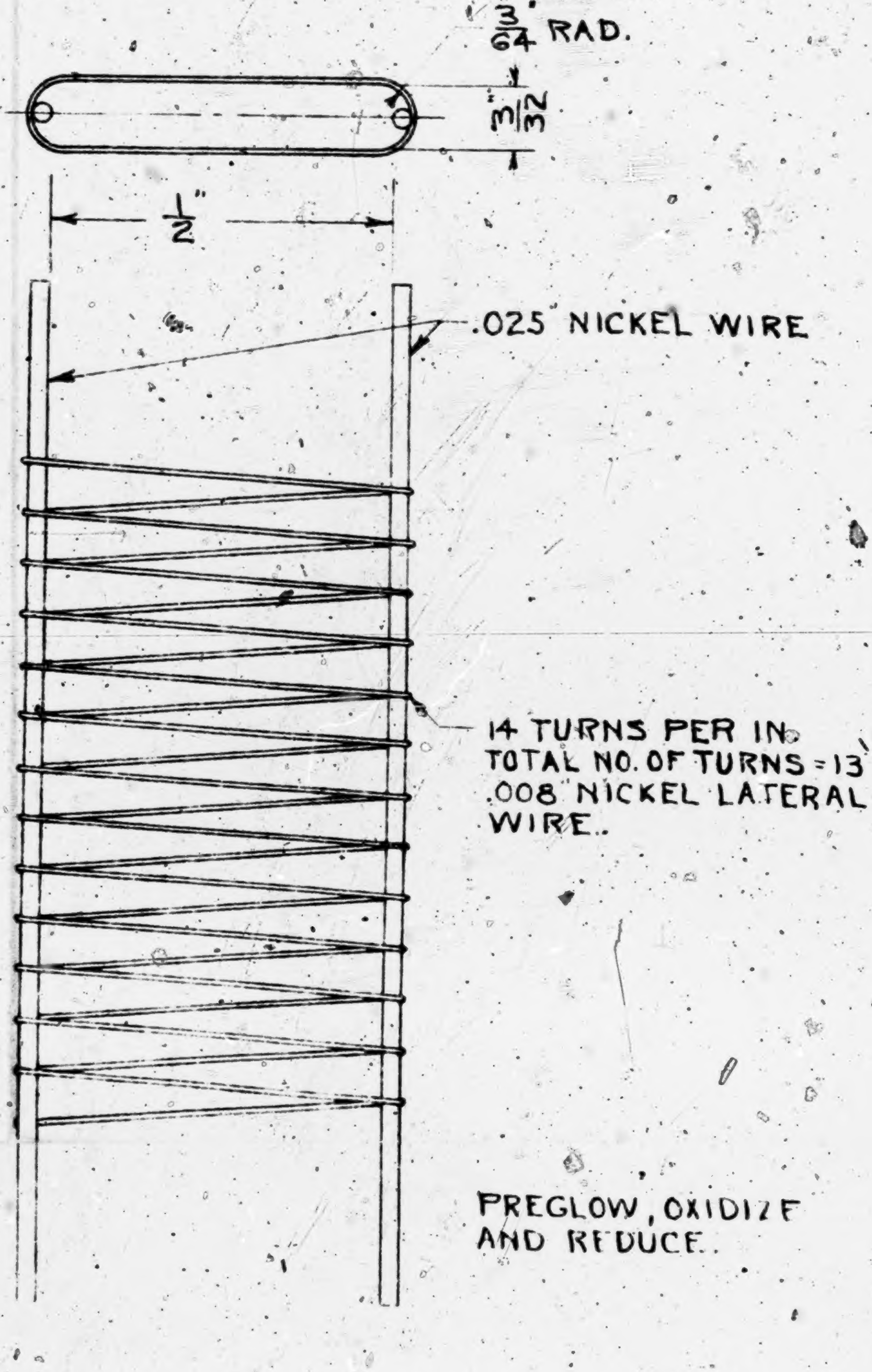
I_B	15	25	35	
E_B	88.2	106.2	120.2	
I_c	3.6	7.8	11.7	
Pr	3.8 µ	4.0 µ	3.8 µ av	3.9

1370

-ABORATORIES

Sketch No. ES419516

GRID FOR 7510 VACUUM TUBE



$\frac{3}{64}$" RAD.
$\frac{3}{32}$
$\frac{1}{2}$"
.025 NICKEL WIRE
14 TURNS PER IN.
TOTAL NO. OF TURNS = 13
.008" NICKEL LATERAL WIRE.

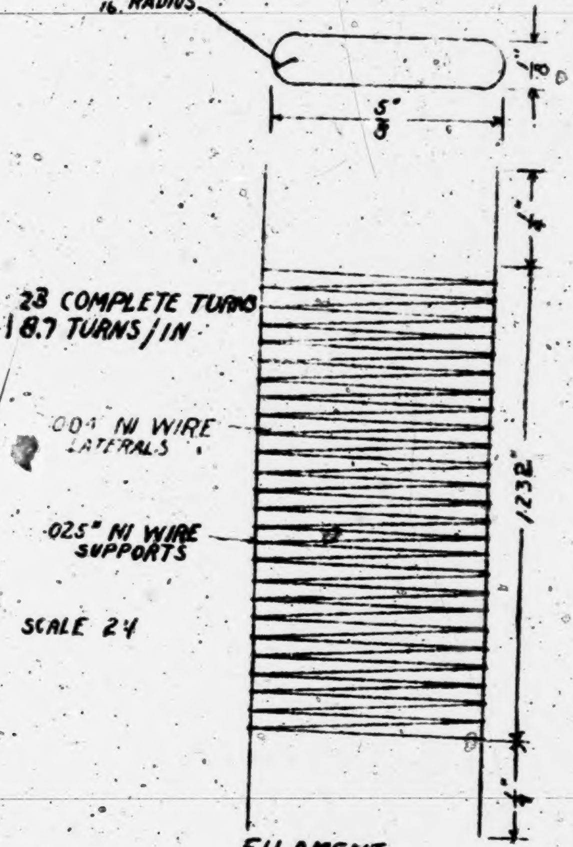
PREGLOW, OXIDIZE
AND REDUCE.

BELL TELEPHONE LABORATORIES
INCORPORATED

DATE	ISSUE	ENGINEER	DRAWN	1371
1-12-26		C.I.B.		ES-414968

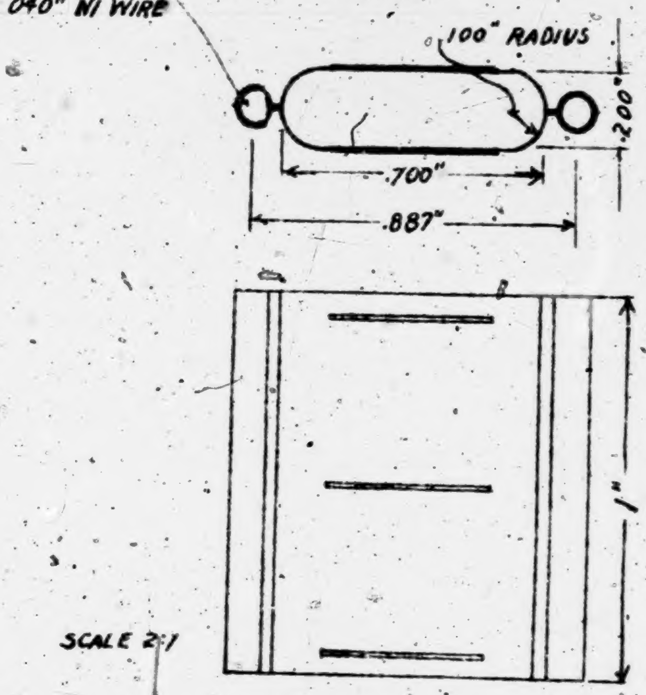
TYPE 7518G HELIUM FILLED THERMIONIC TUBE

GRID


1/16" RADIUS
1/8"
5/8"
1/4"
28 COMPLETE TURNS
18.7 TURNS/IN
.004" NI WIRE LATERALS
.025" NI WIRE SUPPORTS
1.232"
1/4"

SCALE 2:1

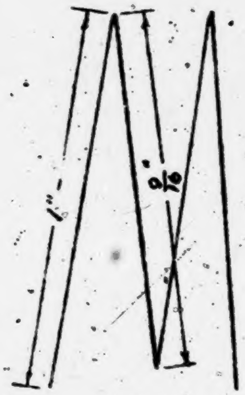
PLATE


HOLE TO FIT .040" NI WIRE
.100" RADIUS
.200"
.700"
.887"
1"

STANDARD "221D" PLATE

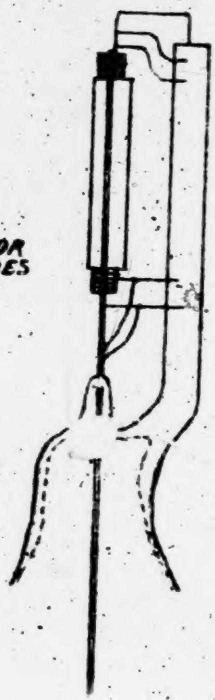
SCALE 2:1

FILAMENT.


1"
.020
3 3/8" B-4 FILAMENT (EFF. LENGTH)

SCALE 2:1

ASSEMBLY


STANDARD ARBOR FOR "101D" TUBES

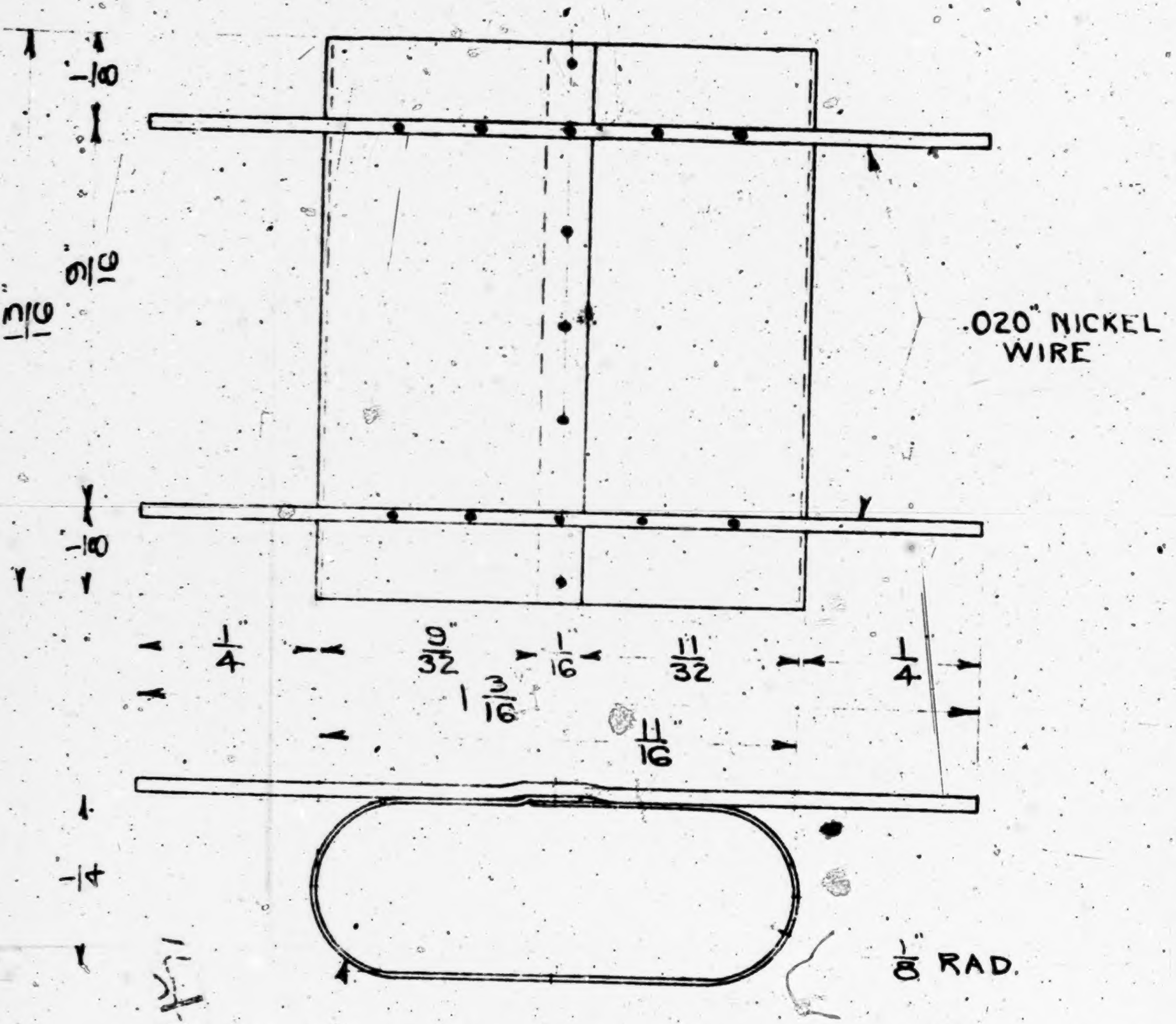
SCALE 1:1

1372

TELEPHONE LABORATORIES
INCORPORATED

Sketch No. ES 419515

PLATE FOR 7510 VACUUM TUBE

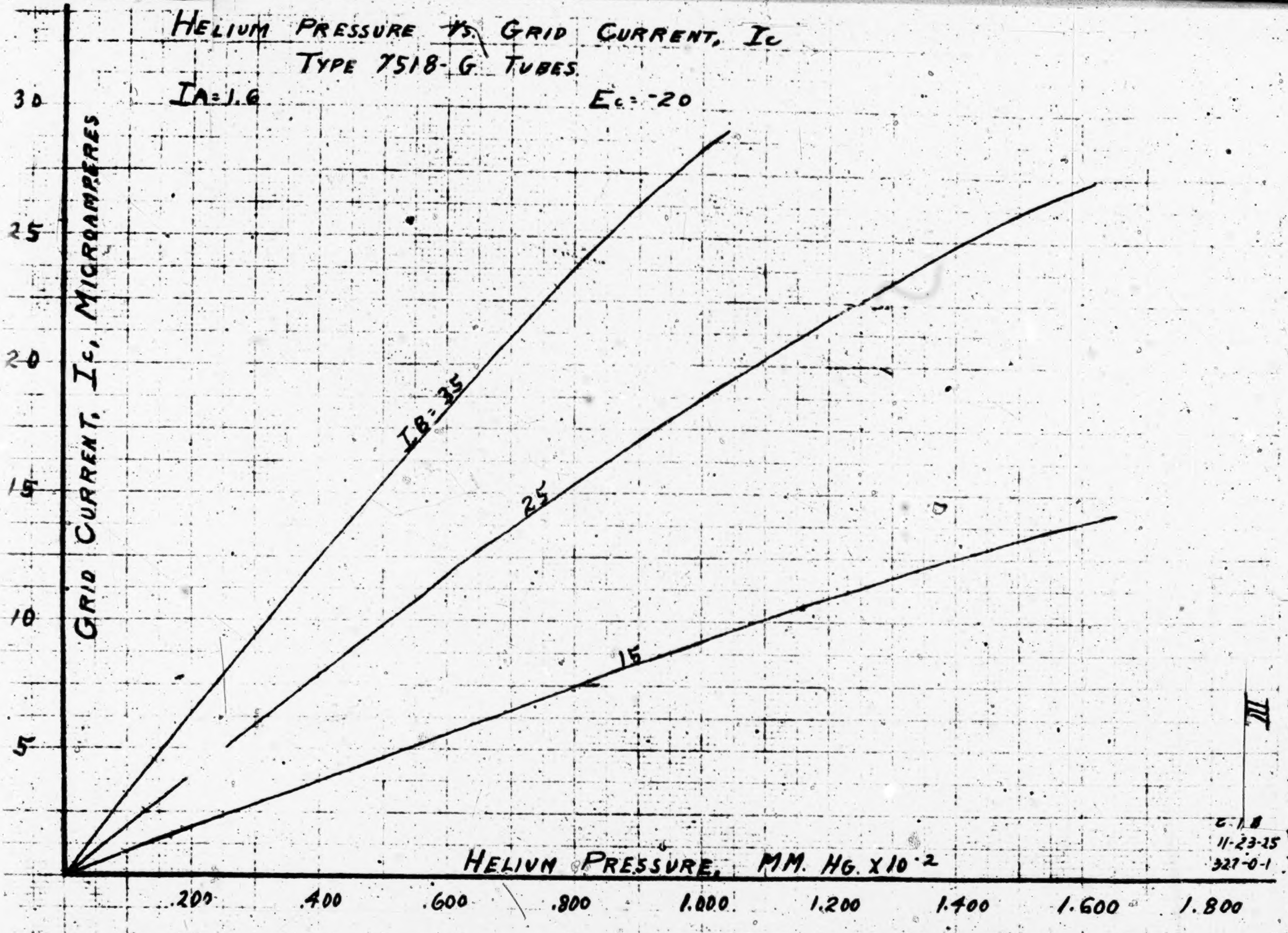


.100
3/16
5/16
.100
.020" NICKEL WIRE
1/4
9/32
1/16
11/32
1/4
1 3/16
11/16
.14
1/8" RAD.

.005" SHEET NICKEL, PREGLOWED, OXIDIZED AND REDUCED.

4195

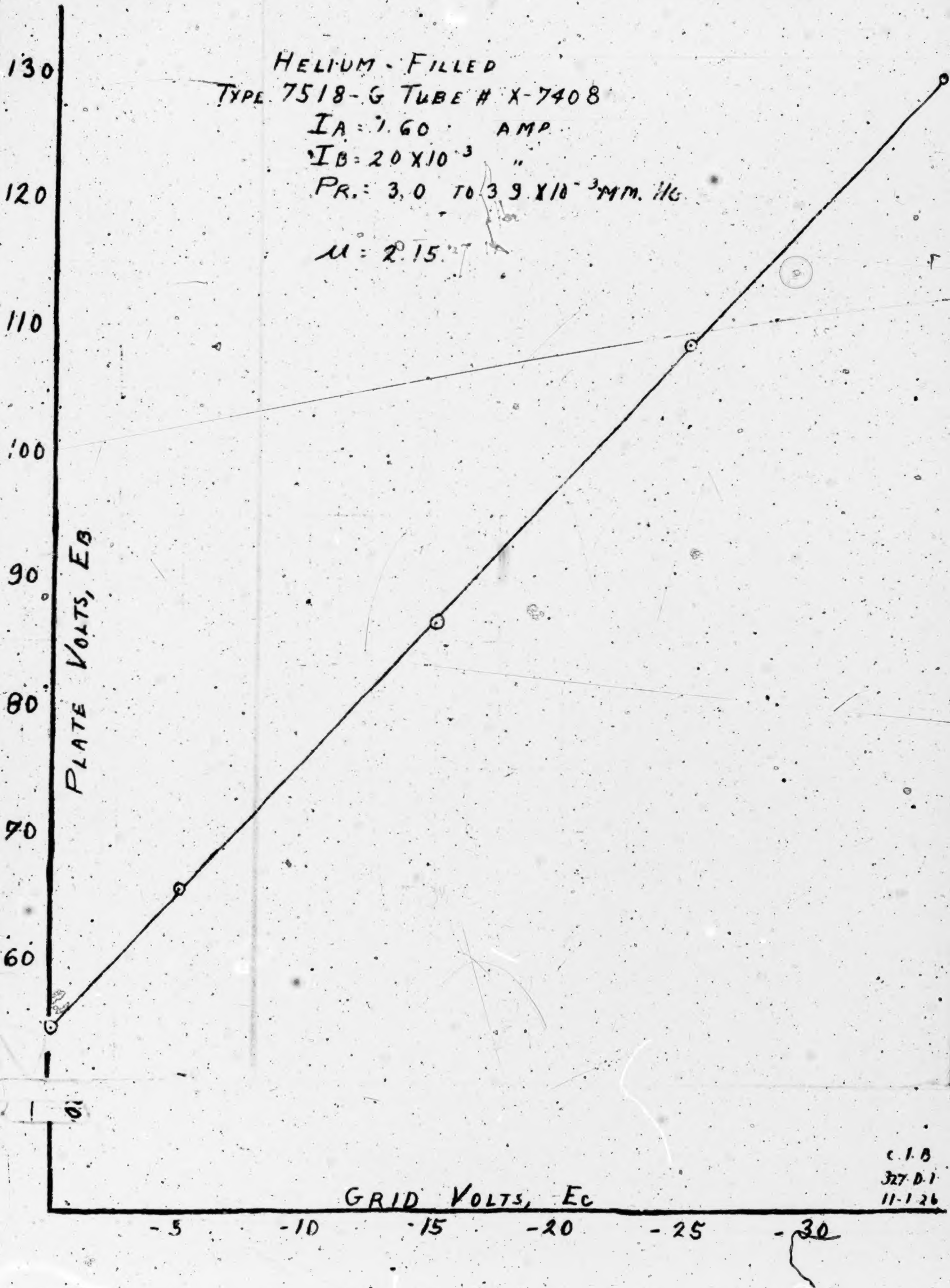
III


HELIUM PRESSURE VS. GRID CURRENT, I_c
TYPE 7518-G TUBES
$I_A=1.6$ $E_c=-20$

E.1.8
11-23-25
327-0-1

1374

Sketch No. ES 419520



HELIUM - FILLED

TYPE 7518-G TUBE # X-7408

I_A : 1.60 AMP

I_B = 20 X 10^{-3} "

PR.: 3.0 TO 3.9 X 10^{-3} MM. HG

μ = 2.15

C.I.B
327 D.1
11-1-26

DEFENDANT'S EXHIBIT No. 329.

Tube Used by Dr. Arnold in Demonstration in Court of Blue Glow.

DEFENDANT'S EXHIBIT No. 330.

DeForest Tube as Placed on Pump.

DEFENDANT'S EXHIBIT No. 331.

DeForest Tube Sealed Off From Pump.

DEFENDANT'S EXHIBIT No. 332.

DeForest Tube Prior to Volatilization of Magnesium.

DEFENDANT'S EXHIBIT No. 333.

DeForest Tube in Completed Commercial Form.

136

FILE COPY

FILED
MAR 5 1931
CHARLES ELMORE CROPLE
CLERK

65867
5 [illegible]

IN THE

Supreme Court of the United States.

DE FOREST RADIO COMPANY,
Petitioner,
vs.
GENERAL ELECTRIC COMPANY,
Respondent.
No. 630.

JOINT MOTION BY BOTH PARTIES

THOMAS G. HAIGHT,
Counsel for Petitioner.

HUBERT HOWSON,
Counsel for Respondent.

J. D. MILANS & SONS, 707 EIGHTH ST. N. W., WASHINGTON, D. C.

IN THE

Supreme Court of the United States.

DE FOREST RADIO COMPANY,
Petitioner,
vs.
GENERAL ELECTRIC COMPANY,
Respondent.
No. 630.

MOTION.

And now comes the petitioner, De Forest Radio Company, and moves the Court for an order permitting it to use as the printed record in this court the volumes of the printed record as used in this case in the United States Circuit Court of Appeals for the Third Circuit because of the following state of facts:

1. The case was originally tried in the United States District Court for the District of Delaware in the latter part of 1926 and early in 1927 and by leave of the Court and of counsel the record was printed for the use of that Court without reduction of the testimony to narrative form, in the belief that such printed volumes could and would be available for use as the printed record in the United States Circuit Court of Appeals for the Third Circuit. The record as thus printed made up six volumes of the standard size used in the United States Circuit Court of Appeals.

Of these six volumes, three are of the testimony and three are of the documentary exhibits.

2. These six volumes, with the testimony not reduced to narrative form, were accepted in the United States Circuit Court of Appeals for the Third Circuit.

3. To reduce the testimony contained in the three volumes to narrative form would not lessen the total number of volumes of record by more than one volume; that is to say, there would still remain five volumes, because the number of volumes of exhibits would necessarily remain the same.

4. There are available at the present time a sufficient number of sets of this already printed record as used in the United States Circuit Court of Appeals to supply the requirements of the rules of this Court.

5. The cost of reprinting this record, it is estimated, would be in the neighborhood of $10,000.

6. The United States District Court and the United States Circuit Court of Appeals accepted a stipulation of counsel that a printed copy of the record in the Patent Office and the Court of Appeals of the District of Columbia in the interference of Arnold vs. Langmuir might go in and be used as a physical exhibit, to avoid the necessity of reprinting that evidence.

7. For these reasons your petitioner respectfully moves this Court for an order (a) permitting the use as the printed record in this Court of the printed volumes of record in the case as used in the United States Circuit Court of Appeals, and (b) permitting printed copy of the interference record Arnold vs. Langmuir to come up as a physical exhibit.

8. The respondent General Electric Company joins in the foregoing statements and motion and asks that the motion be granted.

Respectfully,

THOMAS G. HAIGHT,
Counsel for Petitioner.

HUBERT HOWSON,
Counsel for Respondent.

March 4, 1931.

FILE COPY

Office Supreme C
FILE
JAN 8 19
CHARLES ELMORE C

IN THE

SUPREME COURT OF THE UNITED STATES

OCTOBER TERM, 1930

No. 630

DEFOREST RADIO COMPANY
Petitioner

v.

GENERAL ELECTRIC COMPANY
Respondent

Petition for a Writ of Certiorari to the Circuit Court of Appeals for the Third Circuit and Brief in Support of Petition

---

THOMAS G. HAIGHT
SAMUEL E. DARBY, JR.
Counsel for Petitioner

APPEAL PRINTING CO., 22 THAMES ST., NEW YORK CITY

INDEX

PAGE

Petition for writ of certiorari 1

I. Summary and short statement of the matter involved 2

Nature of suit and decisions below 2

Subject-matter 4

II. Reasons relied upon for granting the writ ... 9

Brief in support of petition 12

Opinions below 12

Jurisdiction 12

Statement 13

Specification of errors 13

Summary and argument 14

Argument 14

Point 1.—The case presents a sharp conflict of opinion of the Judges of the Courts below in a case of very great and far-reaching economic, industrial, and public importance, involving as it does the monopolistic control of one of the greatest industries of the country, and an article of commerce used by millions of people 14

Point 2.—The present majority decision of the Court of Appeals has reversed the dispositive findings of fact of the Trial Court, on an issue to which nearly four weeks of the trial were devoted, and which was dependent on conflicting testimony of witnesses who testified in open Court and is thus in direct conflict with the

PAGE

rules stated by this Court in Adamson *v.* Gilliland, 242 U. S. 350 16

(a) Priority of invention 17

(b) Prior use 19

Point 3.—One of the Judges of the Court of Appeals, who once adopted the opinion of the Trial Court as that of his own, and hence accepted the dispositive findings of fact of the Trial Court, on the rehearing changed his opinion without expressing any reason therefor, and concurred in an opinion which makes no reference to the subject-matter of such dispositive facts or the decision of the Trial Court with reference thereto 20

Point 4.—The present majority decision of the Court of Appeals establishes a patent monopoly for necessary articles of commerce, viz., vacuum tubes, the patents for which have expired, and from which old constructions the patented thing assertedly differs only in the degree of vacuum in the tube, thereby deciding an important question of patent law (finding patentable novelty for a mere difference in degree) in a way that is untenable and in conflict with a long line of decisions of this Court 21

Point 5.—Judge Woolley of the Court of Appeals virtually suggests, in the concluding paragraph of his dissenting opinion, that this Court review the case because of its importance to the public 24

Conclusion 25

Cases Cited.

PAGE

Adamson *v.* Gilliland, 242 U. S. 350 .... 10, 16, 18, 20

Alexander Milburn Co. *v.* Davis-Bournonville Co., 270 U. S. 290 12

Ansonia Brass and Copper Co. *v.* Electrical Supply Co., 144 U. S. 19 23

Belding Manufacturing Co. *v.* Challenge Corn Planter Co., 152 U. S. 100 23

Burt *v.* Evory, 133 U. S. 349 23

Carbice Corporation *v.* American Patents Development Corporation, *et al.*, 281 U. S. 711 12

Estey *v.* Burdett, 109 U. S. 633 23

French *v.* Carter, 137 U. S. 239 23

General Electric Company *v.* DeForest Radio Company, 23 Fed. (2) 698 12

Guiduet *v.* Brooklyn, 105 U. S. 550 23

Lord, *et al.* *v.* Radio Corporation of America, 24 Fed. (2) 565 8

Milligan and H. Glue Co. *v.* Upton, 97 U. S. 3 23

Munson *v.* New York, 24 U. S. 601 23

Pearce *v.* Mulford, 102 U. S. 112 23

Powers Kennedy Contracting Corporation and Anthony G. Fleck *v.* Concrete Mixing and Conveying Company (Supreme Court, decided December 15, 1930) 5

Slawson *v.* Grand Street, 107 U. S. 649 23

Westinghouse Electric & Manufacturing Company *v.* DeForest, 278 U. S. 562 4

White *v.* Mechanics Securities Corp., 269 U. S. 283 12

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930.

No.

DEFOREST RADIO COMPANY,
Petitioner,

v.

GENERAL ELECTRIC COMPANY,
Respondent.

PETITION FOR A WRIT OF CERTIORARI TO THE CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT.

To the Honorable, the Chief Justice and Associate Justices of the Supreme Court of the United States:

Your petitioner, DEFOREST RADIO COMPANY, respectfully prays for a writ of certiorari to the Circuit Court of Appeals for the Third Circuit, to review a judgment of that Court entered on November 11th, 1930. A transcript of the record in the case, including the proceedings in said Circuit Court of Appeals, is furnished herewith in accordance with Rule 38 of this Court.

I. Summary and Short Statement of the Matter Involved.

Nature of suit and decisions below.

The present suit was brought in the District of Delaware by General Electric Company, for infringement of Langmuir patent #1,558,436, granted October 20, 1925, on application filed October 16, 1913.

Judge Morris in the District Court held the patent to be invalid on three distinct grounds (23 Fed. [2nd] 698):

1. Because of anticipation and want of invention—a question of mixed fact and law,

2. Because of prior invention—*a question of fact,*

3. Because of prior use—*a question of fact.*

Appeal was taken to the Circuit Court of Appeals for the Third Circuit, and that Court, on October 3rd, 1929, affirmed the decision of the District Court in a *per curiam* opinion *which adopted the opinion of Judge Morris,* with Judge Buffington dissenting *without opinion.*

On November 2, 1929, a petition for rehearing was filed, and was subsequently granted. In due course the case was reargued.

On November 14th, 1930, in an opinion written by Judge Buffington, the majority of the Court reversed the District Court and entered a judgment accordingly. Judge Woolley wrote an extensive and carefully considered dissenting opinion ending with the following paragraph:

> [1]"This is a long dissenting opinion. In view of the gravity of the Court's decision and its effect upon the art I make no apology for its length. I frankly

> admit that it is written with the hope that it will arrest the attention of the reviewing court."

Thus, this case has been heard three times. Twice the decision has been adverse to the patent and once in its favor. Four Judges have at various times decided adversely to the patent (the District Court Judge, the majority of the Court of Appeals at the first argument, and the dissenting Judge at the reargument), while three Judges have decided in favor thereof. Stated in another way, Judge MORRIS and Judge WOOLLEY, throughout the litigation have held the patent to be invalid., Judge BUFFINGTON has adhered to the opinion that the patent is valid. Judge DAVIS has decided once that the patent is invalid and once that the patent is valid.

A substantial part of Judge MORRIS' opinion was devoted to the question as to whether Langmuir or Dr. Arnold of the Western Electric Company was the prior inventor of the subject-matter of the patent, if that subject-matter constituted an invention. To this issue nearly four weeks of trial were devoted, and a vast amount of fact and expert testimony directed.

As the first opinion of the Court of Appeals adopted Judge MORRIS' opinion as its own, and as Judge DAVIS concurred in that opinion, it necessarily follows that he at that time adopted Judge MORRIS' *findings of fact* on the priority-of-invention issue. In the present opinion of the majority of the Court, *the evidence on this issue is not discussed, nor are any reasons given for disagreeing with Judge Morris on this point.* The result therefore is, *that Judge Davis has reversed not only his own finding on the priority issue, but that of the Judge who heard and saw the witnesses, and has advanced no reasons whatever for doing so; and Judge Buffington has never delivered any opinion on this point* ***whatever.***

Subject-Matter.

The patent is directed to electron discharge devices or vacuum tubes, commonly known as "audions" and "radio tubes," and if valid, covers all radio amplifier and oscillator tubes used today in either transmitting or receiving. As this Court may remember (from *Westinghouse Electric & Manufacturing Co.* v. *DeForest*, 278 U. S. 562), the three electrode vacuum tube or "audion" is the heart and soul of the radio industry. On its use depends present day wireless communication of every kind. It is, of course, an indispensable adjunct to the signal and communication work of the Army and Navy. Without it, present day broadcast and reception of radio programs for amusement and entertainment would be impossible. The usual radio receiver used in the homes throughout the Nation employs an average of seven or eight tubes in each set. Indeed, and this fact is not disputed, without the radio tube there would be no radio broadcasting or radio industry as we know it today.

The vacuum tube is also widely used and is indispensable in present day wire communication. The first transcontinental telephony from New York to California was accomplished by its use in 1915.

The vacuum tube is likewise necessary in talking motion picture equipment, and is employed in every talking-motion-picture theatre throughout the Nation.

The three electrode radio or vacuum tube has been in use since 1906 and was invented by Dr. Lee DeForest. The DeForest patent therefor (No. 879,532) issued in 1908 and expired on February 18, 1925.

Judge Woolley, in his dissenting opinion, stated the undisputed fact:

> "The audion as conceived by Fleming and improved by DeForest at once became and has ever since continued to be the basis of the modern art of transmitting sounds great distances both by wire and through the air."

On October 16, 1913, Langmuir's application for the patent in suit was filed, claiming as the invention *the process of treating the parts of a vacuum tube so as to degasify them.* In 1925, the year in which the DeForest patent expired, Langmuir's patent issued, *claiming the vacuum tube itself, an invention entirely different from that originally claimed when it was filed.* The language of the opinion of this Court, speaking through Mr. Justice ROBERTS, in *Powers Kennedy Contracting Corporation and Anthony G. Fleck* v. *Concrete Mixing and Conveying Company* (decided December 15, 1930), is literally applicable in the instant case. That language, with Langmuir and his dates substituted for McMichael, may be paraphrased as follows:

> "The Langmuir application was filed in the Patent Office on October 16, 1913. Its prosecution was most dilatory. Claims made were repeatedly disallowed, and at one time it lapsed (August 19, 1915) and had to be renewed (March 10, 1916). Radical changes were made in the statement of invention, and radically new claims were made in 1917 and expanded in 1919, again in 1921, and finally in 1925. The applicant eliminated from the scope of his invention the process of gas freeing by bombardment without heat (the subject-matter which he advanced as the invention when the application was filed)."

The patent application became involved in an interference proceeding with an application of Dr. Harold D. Arnold, an engineer of the Western Electric Company.

The Examiner of Interferences awarded priority of invention to Langmuir on a theory of *law* which is *untenable* and *was not accepted by any reviewing body or tribunal.* The Board of Examiners-in-Chief affirmed this decision, but upon grounds *entirely different* from, and *diametrically opposed to,* those relied upon by the Examiner of Interferences. The Commissioner of Patents reversed the Board and awarded priority of invention to Arnold. The Court of Appeals for the District of Columbia reversed the Commissioner, and, in a short opinion, accepted the decisions of "the lower tribunals (the Examiner of Interferences and the Board of Examiners-in-Chief) who had found for Langmuir" because, as the Court put it, those decisions "are so clear and satisfying" that it was content to rest its opinion "upon the reasoning there given," apparently quite overlooking the fact that those lower tribunals were *poles apart* in their "reasoning" and in their rulings as to the effect to be given the work done by Arnold and Langmuir, respectively.

Of course, during the interference hearings on priority, the question of whether or not a patentable invention had been made by either Arnold or Langmuir was not at issue. Nevertheless, it was necessary, in order to pass upon the question of priority, to ascertain what the supposed invention, if any, was.

As pointed out in the dissenting opinion of Judge Woolley, all of the tribunals in the Patent Office, as well as the Courts, found difficulty in defining or even stating what constitutes the supposed invention of the Langmuir patent.

The Board of Examiners-in-Chief stated:

> "The invention has been referred to as a 'thing compact of glass and metal.' *That description is*

> *correct as far as it goes, but that it is inadequate is evident from the fact that it applies equally well to the prior art devices."**

Again, this tribunal stated—

> *"Thus the count distinguishes from the prior art not by features of structure but by a characteristic which is manifest while the device is operating at or above a certain voltage."*

The Commissioner of Patents, in his opinion, stated—

> *"It will be seen then that the present invention lies not in discovering or producing something new,* but in perceiving the practicability of scientific facts known in the laboratory and in making practical useful devices embodying the scientific laws known in the laboratory."

The Examiner in the Patent Office, in Paper No. 3 (his rejection of February 28, 1914, found on pp. 677, 678, Vol. VI, Rec.) stated:

> "If applicant's device is an improvement over the (prior art) reference he should define the difference **by structural limitation."**

The answer made by applicant, to this requirement of the Examiner, is set forth in the amendment dated April 30, 1914 (Rec. Vol. VI, p. 685)—

> *"The 'structural limitations' in this case are to be found in the difference of vacuum."*

Respondent, in its reply brief before the Circuit Court of Appeals (p. 7), stated—

> "Defendant labors *unnecessarily* to prove that *the only structural difference between the invention*

---

* Italics in this Petition and Brief are ours.

> *and the audion is simply one of vacuum*—a vacuum which, as the District Court fully realized, must be maintained in operation, and which can only be maintained if all parts in the tube, particularly the anode, are specially treated to free them of gas. *We have never contended otherwise. It was so stated in the Patent Office, again in the Court below; to set any doubts at rest, we state it again now.*"

From the foregoing it will be readily seen that the invention of the Langmuir patent, as advanced by its exponent, is the identical old device of DeForest, assertedly differing therefrom, *only in the degree of vacuum therein.*

Every vacuum or radio tube made or in use today (with the exception of a few *detector* tubes which, for special purposes, operate best with a *low* degree of vacuum) comes within the scope of the Langmuir patent as adjudicated.

The present majority opinion of the Court below commented:

> "The simple fact is that we see such a tube in *universal* use today."

The effect of this adjudication, therefore, is to give to the Radio Corporation of America (through its contractual relations with the General Electric Company, see 24 Fed. (2) 565) *the absolute monopoly of the entire vacuum or radio tube industry for 12 years to come, not withstanding that the radio vacuum tube has been in use since 1906.* In view of the fact that the vacuum tube is a necessary and indispensable part of radio transmitting and receiving apparatus, it likewise gives to the Radio Corporation a similar monopoly of the radio apparatus industry of the United States.

Thus, there is established a monopoly of a vast, modern industry by means of a patent of such doubtful validity that in two of three adjudications it has been held to be invalid—a patent, moreover, which, by its very terms, covers DeForest audions used in commerce before the Langmuir application was filed in the Patent Office, and which, at best, distinguishes, if at all, from millions of vacuum tubes that have been manufactured under expired patents, and used in the various industries, by a difference in *the degree of vacuum* within the tube.

As Judge Woolley, in his dissenting opinion, pointed out:

> "The Langmuir patent now completely covers the field occupied by the audion of the expired DeForest patent, and will, on the decree of this Court, continue to cover it for twelve years more; *hence the importance of this litigation.*"

II. Reasons Relied Upon for the Granting of a Writ of Certiorari.

The discretionary power of this Court is invoked upon the following grounds:

(1) Because of the sharp conflict of opinion of the Judges in the Courts below in a case of very great and far reaching economic, industrial and public importance, involving as it does the monopolistic control of one of the greatest industries of the country, and an article of commerce used by millions of people.

2. Because the *present* majority decision of the Court of Appeals has reversed the dispositive findings of fact of the Trial Court, on an issue to which nearly four weeks of the trial were devoted, and which was dependent on conflicting testimony of witnesses who testified in open

court, and is thus in conflict with the rule stated by this Court in *Adamson* v. *Gilliland*, 242 U. S. 350. Moreover, the opinion of the present majority gives no reason whatever for disagreeing with Judge MORRIS' finding of fact on that issue, and does not even refer to the evidence on that point.

3. Because one of the Judges of the Court of Appeals, who once adopted the opinion of the Trial Court as that of his own, and hence accepted the dispositive findings of fact of the Trial Court, on the rehearing changed his opinion without expressing any reason therefor, and concurred in an opinion which makes no reference to the subject-matter of such dispositive facts or the decision of the Trial Court with reference thereto.

4. Because the present decision of the majority of the Court of Appeals establishes a patent monopoly for necessary articles of commerce, viz. vacuum tubes, the patents for which have expired, and from which old constructions the patented thing assertedly differs only in the degree of vacuum in the tube, thereby deciding an important question of patent law (finding patentable novelty for a mere difference in degree) in a way that is untenable and in conflict with a long line of decisions of this Court.

5. Because Judge WOOLLEY of the Court of Appeals virtually suggests, in the concluding paragraph of his dissenting opinion, that this Court review the case because of its importance to the public.

WHEREFORE, your petitioner respectfully prays that a writ of certiorari be issued under the seal of this Court directed to the United States Circuit Court of Appeals for the Third Circuit, commanding said Court to certify and send to this Court, on a day to be designated, a full and complete transcript of the record and all proceedings of the Circuit Court of Appeals had in this cause, to the end that this cause may be reviewed and determined by this Court; that the judgment of the Circuit Court of Appeals be reversed, and that Petitioner be granted such other and further relief as may seem proper.

THOMAS G. HAIGHT,
SAMUEL E. DARBY, JR.,
Counsel for Petitioner.

Dated, New York, N. Y., Jan. 6, 1931.

State of New York, }
County of New York, } ss.:

SAMUEL E. DARBY, JR., being first duly sworn, did depose and say:

That he is of counsel for Petitioner herein; that he prepared the foregoing petition in collaboration with the other counsel for Petitioner in the case, and that the allegations thereof are true as he verily believes.

SAMUEL E. DARBY, JR.

Subscribed and sworn to before me }
this 6th day of January, 1931. }

ROSE A. BATTERMAN,
Notary Public,
New York County.
N. Y. Co. Clk's No. 64, Reg. No. 2B46.
Commission expires March 30, 1932.

BRIEF FOR PETITIONER IN SUPPORT OF PETITION FOR WRIT OF CERTIORARI.

The Opinions of the Courts Below.

The opinion of the District Court is found in 23 Fed. (2nd) 698. The affirmance of the District Court's decision by the majority of the Circuit Court of Appeals for the Third Circuit was on an unreported *per curiam* opinion which adopted the opinion of the Court below. The opinion of the majority of the Circuit Court of Appeals for the Third Circuit, which resulted in the judgment which the present petition for writ of certiorari seeks to have reviewed, is unreported, but is reproduced in the record filed herewith.

Jurisdiction.

The grounds of jurisdiction are as follows:

1. The judgment to be reviewed was dated November 11th, 1930.

2. The judgment was rendered in a suit in equity brought under the patent statutes to determine the issues of validity and infringement of Letters Patent of invention issued by virtue of Section 4886 R. S.

3. The statute under which jurisdiction is invoked is Section 240 (a) of the Judicial Code, 28 U. S. C. No. 347, as amended by the Act of February 13, 1925.

4. Some of the cases believed to sustain the jurisdiction are *Alexander Milburn Co.* v. *Davis Bournonville Co.*, 270 U. S. 290; *White* v. *Mechanics Securities Corp.*, 269 U. S. 283; *Carbice Corporation* v. *American Patents Development Corporation, et al.*, 281 U. S. 714, in which writs of certiorari were granted without conflict between different Circuit Courts of Appeal.

Statement.

The facts, so far as this application is concerned, are sufficiently stated in the petition.

Specification of Errors.

The errors which petitioner will urge, if the writ of certiorari is allowed, are that the present majority of the Circuit Court of Appeals for the Third Circuit erred,

1. In reversing the decree of the District Court and holding the Langmuir patent No. 1,558,436 to be valid and infringed;

2. In failing to hold that the Langmuir patent No. 1,558,436 is invalid because of anticipation and want of invention;

3. In failing to hold the Langmuir patent No. 1,558,436 invalid because of prior invention by H. D. Arnold;

4. In reversing the dispositive findings of fact of the Trial Court, based on conflicting testimony, as to prior invention by H. D. Arnold;

5. In failing to hold the Langmuir patent No. 1,558,436 invalid because of prior knowledge and use by Lee DeForest and Federal Telegraph Company;

6. In reversing the dispositive findings of fact of the Trial Court, based on conflicting testimony, as to prior knowledge and use by Lee DeForest and Federal Telegraph Company.

Summary of Argument.

The points of the argument follow the reasons relied upon for the allowance of the writ of certiorari (*supra*, p. 9).

ARGUMENT.

Manifestly, it would not be feasible, within the reasonable limits of a brief in support of a petition for a writ of certiorari, to discuss the *merits* of a case of this magnitude and importance. Consequently, for the purposes of this brief, *on the question of the merits of the case, we will rely upon the opinions of Judge Morris and Judge Woolley in the Courts below.* For the convenience of the Court, we have printed these opinions in a separate pamphlet, copies of which are presented with this petition and brief.

The following part of the brief will, therefore, be devoted to a discussion of the "special and important" reasons why this Court should grant a writ of certiorari and review the case on its merits.

1. The case presents a sharp conflict of opinion of the Judges in the Courts below in a case of very great and far reaching economic, industrial and public importance, involving as it does the monopolistic control of one of the greatest industries of the country, and an article of commerce used by millions of people.

According to figures published by the trade journal "Radio Retailing" of March, 1930 (a McGraw-Hill publication), 69,000,000 vacuum tubes were sold throughout the United States for radio receivers in 1929, the retail purchase price for which was $172,500,000. Radio tubes are necessary devices for the operation of the 4,438,000 radio broadcast receivers which were sold in 1929 (according to the same authority) at retail prices totaling $592,068,000. The same publication, on its statistics in the trade, estimated the business for 1930 would be 84,000,000 tubes and 16,000,000 radio receiving sets.

According to the same authority there are approximately 150 established manufacturers of vacuum tubes each employing from 200 to 1,000 employees.

The Langmuir patent purports to cover, and the present majority decision of the Court of Appeals for the Third Circuit decrees that it does cover, every one of the above vacuum tubes made for every one of the above radio receiving sets. Respondent itself has asserted that there is no vacuum tube in use or being manufactured today that does not embody the invention of the Langmuir patent.

The use of vacuum tubes is necessary and indispensable in all telephone systems where amplifiers or repeaters are required, as they are in all long distance telephony.

The use of vacuum tubes is likewise necessary and indispensable in all talking-motion-picture reproduction equipment, in use in every talking-motion-picture theater in the United States.

All of the foregoing industries *depend* upon the vacuum tube for successful operation. The control of the vacuum tube gives a virtual control of these and other industries. The Langmuir patent, as construed by the present majority of the Court of Appeals, gives that control.

The effect of the decision of the present majority of the Court of Appeals is to close the doors of every vacuum tube manufacturer in the United States that does not obtain a license under the Langmuir patent, and throw the thousands of workmen in their plants out of employment. It is recognized that this fact, alone, furnishes no justification for the appropriation of a patented invention without license of the patent owner. *It does, however, furnish a cogent reason for the review and final determination of the validity of a patent of such great economic, public and industrial importance, and this is especially so when there is taken into consideration the sharp conflict in opinion of the Judges below, and the fact that the trial judge, who heard and saw the witnesses, has been reversed on a question of fact without any reasons being assigned for the reversal, and when one judge, who has now voted to reverse, at one time adopted the opinion of the trial judge as his own.*

It is respectfully submitted, therefore, that the validity of a patent of such industrial and public importance, affecting an article of commerce used by millions of people, should not be permitted to rest upon the decision of two judges, where two other judges have entertained a different view, and *where one of the judges now sustaining its validity once considered it invalid.*

2. The *present* majority decision of the Court of Appeals has reversed the dispositive findings of fact of the trial court, on an issue to which nearly four weeks of the trial were devoted, and which was dependent on conflicting testimony of witnesses who testified in open court, and is thus in direct conflict with the rule stated by this Court in *Adamson v. Gilliland*, 242 U. S. 350.

As we have pointed out (*ante*, p. 2), two of the three reasons advanced by the trial judge for his conclusion of invalidity of the patent were:

(a) If the subject-matter of the patent did constitute a patentable invention, it was first invented by Dr. Arnold and not by Langmuir, the patentee; and

(b) Because of prior use by Dr. Lee DeForest and the Federal Telegraph Company of California.

Each of these conclusions of the trial court was dispositive of the case, and both thereof were based on conflicting testimony in the case.

(a) *Priority of Invention:*

The trial of the cause consumed more than four weeks, extending from October 11, 1926, until November 11, 1926. Nearly four weeks of this time were consumed in the taking of testimony and evidence *bearing exclusively on the fact issue of priority of invention.*

On this issue petitioner presented the testimony, in open court, of the following witnesses:

Dr. Harold D. Arnold,
Dr. Otto B. Blackwell,
Dr. Edwin H. Colpitts,
Col. Frank B. Jewett,
Dr. Marvin J. Kelley,
Dr. Robert A. Millikan,
Dr. Joseph A. Becker,
Mr. George E. Folk.

Respondent, likewise, on this issue presented the testimony of the following witnesses:

Dr. Ernst F. Alexanderson,
Dr. William D. Coolidge,
Mr. John V. L. Hogan,
Dr. Irving Langmuir,
Dr. William C. White,
Mr. Fairfax Bayard.

Thus, on a sharp issue of fact—priority of invention—petitioner presented *eight* witnesses, and respondent presented *six* witnesses. The issue of fact thus raised was determined by the trial court, after seeing and hearing the witnesses testify, and observing their demeanor and attitude while testifying. The trial court held that if the subject-matter of the Langmuir patent was patentable at all, it was first invented by Arnold and not by Langmuir.

The rule of law applicable to the findings of fact by a trial court is stated by Mr. Justice HOLMES in *Adamson* v. *Gilliland*, 242 U. S. 350, in the concluding paragraph of the opinion at page 353, as follows:

> "Considering that a patent has been granted to the plaintiff, the case is preeminently one for the application of the practical rule that so far as the finding of the Master or Judge who saw the witnesses 'depends upon conflicting testimony or upon the credibility of witnesses, or so far as there is any testimony consistent with the finding, it must be treated as unassailable.' Davis *v.* Schwartz, 155 U. S. 631, 636."

In the case at bar, there was a conflict of testimony and the necessity of the trial judge passing upon the credibility of witnesses. Not only was there testimony "consistent with the finding" of the trial judge but, as a reading of his opinion will demonstrate, no other finding could reasonably have been made.

The present majority decision of the Court of Appeals for the Third Circuit has reversed the finding of fact of the trial judge, which finding alone was dispositive of the litigation, *without referring to the subject in its opinion, and hence without giving any reason whatever for so doing.*

(b) *Prior Use:*

The Langmuir patent is drawn to cover not only the structures of the expired DeForest audion patent 879,532, but also that of the still earlier expired patent to Fleming No. 803,684, both of which are for structures which have been continuously in use since 1906. The only asserted difference is that the vacuum tube, alleged to have been invented by Langmuir, has had sufficient air extracted therefrom so that 40 volts or more may be used in the plate circuit thereof without harmful effects due to the presence of the residual gas (see for example claim 26, Vol. 4, p. 9). In other words, the patent purports to cover any vacuum tube which can function properly when using 40 volts or more.

It was conclusively proved in the Court below, through the following witnesses: Mrs. A. W. F. Beck, Ralph Hyde, Palmer Hewitt, Leland B. Clark, G. E. Lamont, Ralph Beal, Austin Y. Tuel, James O. Watkins, Harold Lee Rodman (and the exhibits offered in evidence during the taking of such depositions), that the Federal Telegraph Company (a commercially operating company engaged in the commercial traffic of radio messages between San Francisco, Honolulu, and elsewhere) was using tubes, supplied it by Dr. DeForest, which had been especially pumped as free of gas as the pumping equipment then available permitted, and which tubes had been used with as high as 54 volts and 67½ volts, which amount of voltage was possible *only* because the tubes had been highly evacuated of gas to permit the use of such voltage. Under the well recognized principle of patent law,—that which infringes if later, anticipates if earlier,—such use by DeForest and the Federal Telegraph Company of California, being prior to any date claimed, even for *con-*

ception of the invention, by Langmuir, establishes a second independent bar to the validity of the patent. And the patent was held to be invalid for this reason by Judge Morris in the District Court, the Court of Appeals at the first hearing, and by Judge Woolley on rehearing.

In direct conflict with these nine witnesses, respondent offered the conflicting testimony of John V. L. Hogan and Dr. Irving Langmuir, the patentee.

Here, again, the finding of fact by the trial judge has now been reversed by the present majority decision of the Court of Appeals without mention of the evidence or, indeed, of the subject, in its opinion, and without reason, and thus the present majority decision is in conflict with the rule stated by this Court in *Adamson* v. *Gilliland*, *supra*.

3. One of the Judges of the Court of Appeals, who once adopted the opinion of the Trial Court as that of his own, and hence accepted the dispositive findings of fact of the Trial Court, on the rehearing changed his opinion without expressing any reason therefor, and concurred in an opinion which makes no reference to the subject-matter of such dispositive facts or the decision of the Trial Court with reference thereto.

Judge Davis on the first appeal *accepted* the dispositive findings of fact of the *trial court* when he concurred in the *per curiam* opinion of Judge Woolley. On the rehearing he has changed his opinion *without any expressed reasons* for reversing the findings of fact by the trial court, *and has concurred in an opinion which does not mention them or their subject-matter.* It is submitted that this fact alone warrants the review of the case by this Court *in view of the fact that the disposition of this* *important litigation has now turned upon this changed opinion of this one Judge who gives no reason for his change.*

4. The present majority decision of the Court of Appeals establishes a patent monopoly for necessary articles of commerce, viz. vacuum tubes, the patents for which have expired, and from which old constructions the patented thing assertedly differs only in the degree of vacuum in the tube, thereby deciding an important question of patent law (finding patentable novelty for a mere difference in degree) in a way that is untenable and in conflict with a long line of decisions of this Court.

As hereinbefore stated, the two and three electrode vacuum tubes were invented respectively by Dr. Fleming and Dr. Lee DeForest and have been in use since 1906. The patents therefor, Nos. 803,684 and 879,532, expired on November 7, 1922, and February 18, 1925, respectively.

The Langmuir patent is directed to these same evacuated devices, differing therefrom *only in the degree of evacuation.*

The Fleming patent (Rec. Vol. 5, p. 158), states (line 54):

> "I have discovered that if two conductors are enclosed in a vessel *in which a good vacuum is made,* one being heated to a high temperature, the space between the hot and cold conductors possesses a unilateral electric conductivity and negative electricity can pass from the hot conductor to the cold conductor, but not in the reverse direction."

Again, in the Fleming patent, with more specific reference to the *degree of vacuum* within the tube of the device, the patent states (line 96):

> "As *a very high vacuum should be obtained* in the bulb *a* and as a considerable quantity of air is occluded in the conductors, *these should be heated when the bulb is being exhausted.*"

Thus, the Fleming device is the same electron discharge device as that of the Langmuir patent. It is a *vacuum tube* device, and the degree of vacuum is stated by the Fleming patent to be "*a very high vacuum.*"

Likewise, the DeForest Patent No. 879,532 (Rec. Vol. 4, p. 274), for the three-electrode tube, states (p. 1, line 44):

> "D represents *an evacuated vessel,* preferably of glass, * * *."

Similarly, each claim of the patent describes the device as "*an evacuated vessel.*"

The tube of the Langmuir patent *admittedly* has no structural difference from the old Fleming and DeForest tubes except in the asserted *degree of vacuum.*

The present majority of the Circuit Court of Appeals proceeded, *solely by its own argument,* to the conclusion that the Langmuir device, with its *higher* degree of evacuation, operated on a principle different from the principle of operation of the identical devices of the prior art. We say that the Court proceeded to such conclusion "solely on its own argument," because of the fact that not only is there no support in the record for the conclusion reached, but indeed, the record is diametrically opposed thereto. In addition to the instances so clearly pointed out in the dissenting opinion, we call attention to the fact that it is established in the record of this case by the testimony of respondent's own expert, Hogan (Vol. 1, Rec. pp. 113 to 120, inclusive), that when evacuated electron discharge devices have any air or gas enclosed therein (and they *always* have some) the device operates due to "electron flow" and "gas ionization." If more air or gas is present the relative proportion of gas ionization, with respect to electron flow, is *increased*. Conversely, if more gas or air is extracted, the relative proportion of gas ionization, with respect to electron flow, is *decreased*. However, *always*, at *all* times, *the principle of operation of the device is the same*. Respondent's expert Hogan said so in so many words. He testified (Vol. 1, Rec. p. 118), that, with respect to an electron discharge device with a considerable amount of gas, and one with exceptionally little gas,

> *"the ultimate effects are of the same kind, and I cannot agree that 'they work on entirely different principles.'"*

Thus, the only difference between the device of the Langmuir patent and the prior devices of the art is one in *degree of vacuum*, without any difference in principle of operation. On this point, we earnestly invite the attention of the Court to the dissenting opinion of Judge WOOLLEY where this subject is fully and, as we think, conclusively covered.

This Court, in a long line of decisions, has consistently held that mere variations of degree are not patentable.

- *Munson* v. *New York*, 24 U. S. 601;
- *Milligan & H. Glue Co.* v. *Upton*, 97 U. S. 3, 6;
- *Pearce* v. *Mulford*, 102 U. S. 112;
- *Guiduet* v. *Brooklyn*, 105 U. S. 550, 552;
- *Slawson* v. *Grand Street*, 107 U. S. 649;
- *Estey* v. *Burdett*, 109 U. S. 633, 640;
- *Burt* v. *Evory*, 133 U. S. 349;
- *French* v. *Carter*, 137 U. S. 239;
- *Ansonia Brass & Copper Co.* v. *Electrical Supply Co.*, 144 U. S. 19;
- *Belding Manufacturing Co.* v. *Challenge Corn Planter Co.*, 152 U. S. 100.

Therefore, the opinion of the present majority of the Court of Appeals for the Third Circuit is in direct conflict with the decisions of this Court, and with the fundamental principle of patent law established thereby. In effect, the present majority opinion of the Court of Appeals establishes *new* patent law, quite radical in its nature and effect upon the judicial administration of patents.

5. Judge Woolley of the Court of Appeals virtually suggests, in the concluding paragraph of his dissenting opinion, that this Court review the case because of its importance to the public.

Judge WOOLLEY evidently fully recognized the great interest of the public in the litigation, and the far reaching importance of the latest decision of the majority of the Court of Appeals.

In his dissenting opinion, he observed:

> "The Langmuir patent now completely covers the field previously occupied by the audion of the expired DeForest patent, and will, on the decree of this Court, continue to cover it for twelve years more; *hence the importance of the litigation.*"

His dissenting opinion, moreover, evidences a conscientious and exhaustive study of an extremely voluminous record involving complicated technical questions. It shows a clear comprehension of all of the points involved, and constitutes a scientifically accurate discussion thereof that has seldom been equalled in judicial consideration of complicated technical matters.

The closing paragraph of his opinion, which we regard as an expression of a strong conviction that the case should be reviewed by this Court, is here again quoted for convenience:

> "This is a long dissenting opinion. In view of the gravity of the Court's decision and its effect upon the art I make no apology for its length. *I frankly admit that it is written with the hope that it will arrest the attention of the reviewing Court.*"

CONCLUSION.

From the foregoing it appears that the present majority of the Circuit Court of Appeals for the Third Circuit has now rendered a decision in conflict with its own previous decision, with conflicting opinions of the members of its own Court, and in conflict with the opinion of the trial court, and in conflict with controlling decisions of this Court. The case is of great public, economic, and industrial importance. The decision has seriously prejudiced petitioner, and if not reversed will compel it to discontinue the manufacture of the same devices that it and its predecessors have manufactured and sold since 1906, and which manufacture constitutes virtually its entire business.

It is earnestly urged, therefore, that the petition be granted.

Respectfully submitted,

THOMAS G. HAIGHT,
SAMUEL E. DARBY, JR.,
Counsel for Petitioner.

FILE COPY

FILED

FEB 2 1931

CHARLES [illegible]

[illegible]

Supreme Court of the United States

October Term, 1930.

No. 630.

DeForest Radio Company,
Petitioner,

v.

General Electric Company,
Respondent.

REPLY BRIEF ON BEHALF OF PETITIONER.

✓ Thomas G. Haight,
✓ Samuel E. Darby, Jr.,
Counsel for Petitioner.

IN THE

Supreme Court of the United States

October Term, 1930.

No. 630.

De Forest Radio Company,
Petitioner,
v.
General Electric Company,
Respondent.

ON PETITION FOR WRIT OF CERTIORARI TO THE CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT.

REPLY BRIEF ON BEHALF OF PETITIONER.

There are some statements made in Respondent's brief to which we think we should make brief reply in order that the Court may not be under any misapprehension as to certain of the facts which we assume will be taken into consideration in determining whether or not the writ of certiorari should be granted.

1. Perhaps we should point out, although it must be evident from our main brief, that this is not an "ordinary patent case with the usual issues", such as this Court in several cases has said that it would not bring before it for review. It is a very unusual patent case, in that the Circuit Court of Appeals has entertained two different views as to

the validity of a patent covering an article of very great public, economic and industrial importance. The patent now stands established as valid, by the last decision of the Circuit Court of Appeals, on the changed decision of one judge, who gives no reason for his change except in so far as he concurs in the opinion of another judge. As pointed out in our main brief, this opinion is silent on questions of fact which were dispositive of the case as found by the Trial Judge, and accepted by the first decision of the Circuit Court of Appeals against the Respondent. We submit for the careful consideration of the Court the question as to whether the validity of a patent of such very great public importance should be finally determined by the changed opinion of one judge.

2. Respondent's brief is so phrased (pp. 5, 27) as to carry the unmistakable meaning that all of the tribunals of the Patent Office and the Court of Appeals of the District of Columbia were unanimous in awarding priority of invention to Langmuir, the patentee, in the interference proceedings between him and Dr. Arnold of the Western Electric Company. The various holdings in the Patent Office are set forth on page 6 of the petition. The ultimate tribunal in the Patent Office—the Commissioner of Patents—found in favor of Arnold, and his opinion so intelligently deals with the question of priority and so thoroughly points out the unsoundness of the decisions of the lower tribunals that we have had the same printed as a separate pamphlet with a blue cover, and submit it herewith. It thus appears that the Commissioner of Patents, Judge Morris (who heard and saw the witnesses), Judge Woolley on two occasions, and Judge Davis on one, have awarded priority of invention to Arnold. Opposed are the opinions of the two lower tri-

bunals in the Patent Office (diametrically opposed in their theories), the opinion of the Court of Appeals of the District of Columbia, which professedly adopted these diametrically opposed positions, and the last decision of the Court of Appeals which does not mention the subject of priority.

3. In order that undue significance may not be given to the finding of patentable invention by the Law Examiner of the Patent Office—which finding is given prominence in Respondent's brief—it should be pointed out that the question of patentable invention had been raised by Dr. Arnold during the pendency of the interference proceedings; but before it had been disposed of, a license agreement had been entered into between the American Telephone & Telegraph Company and the General Electric Company, and, thereupon, the Examiner was so notified. The question of patentable invention was accordingly not argued on behalf of Arnold but the brief which had been prepared prior to the license agreement was submitted. Consequently, to all intents and purposes, this question when considered by the Law Examiner was academic. This question having been settled by the Law Examiner without further opposition by Arnold, it was not open to any of the other tribunals of the Patent Office for consideration. If it had been, the opinion of the Commissioner indicates that he would not have found invention. Certainly, he would not have found invention on any such basis as that on which the majority opinion of the Circuit Court of Appeals places it. Indeed, the Law Examiner did not find invention on any such theory as that adopted by the majority opinion of the Court of Appeals. As was said by the Commissioner, "the line between the prior art and the issue is attenuated and if there is patentability, it must be as set out in the decision of the Law Examiner on the motion".

4. On page 27 of Respondent's brief, the statement is made that Judge Woolley was incorrect in stating that the evidence before Judge Morris was substantially more favorable to Arnold's contention than the evidence before the Patent Office tribunals. Judge Woolley was absolutely right. The whole interference record (which comprised the evidence before the Patent Office tribunals) was introduced by stipulation before Judge Morris. In addition, there was produced on behalf of the petitioner, the following evidence which was not before the Patent tribunals, *and the failure of the record to contain such was the main ground upon which the Board of Examiners-in-Chief in the Patent Office awarded priority of invention to La[illegible]muir.*

Robert A. Milliken, one of the foremost physicists of the world, testified that *he had taught Arnold to do the very thing that the Board of Examiners-in-Chief held they were not satisfied from the evidence before them that Arnold knew how to do.* According to their explicit statement, the absence of such evidence was the only circumstance which prevented them from awarding priority to Arnold. In this respect, Dr. Milliken was corroborated by Dr. Jewett, Vice-President of the American Telephone & Telegraph Company in charge of the Department of Research and Development, and Dr. Colpitts, Assistant Vice-President of the Telephone Company and in charge, under Dr. Jewett, of the Department of Research and Development.

The question of conception of the alleged invention and the reduction to practice thereof by Dr. Arnold were gone into far more thoroughly than in the interference proceedings; many days and hundreds of pages being devoted to these subjects. The only person acting in a judicial capacity in this entire controversy who ever saw and heard the witnesses was Judge Morris, and he decided the issue of priority in favor of Arnold.

The testimony of Dr. Becker and Dr. Kelly given in open court before Judge MORRIS was entirely new, compared with the case in the Patent Office, and thoroughly rebutted Langmuir's pretense of having made the invention in 1912, on the dates assumed for him by the Patent Office tribunals that had decided in his favor.

5. Respondent's brief states (p. 4) that the issue of priority was not one of fact. If Judge MORRIS believed the testimony given in open court by Dr. Milliken, Dr. Jewett, Dr. Colpitts and Dr. Arnold, not even the Respondent can deny that he must have found Arnold was the prior inventor. Indeed, Respondent in its brief before the Circuit Court of Appeals contended that these men were not entitled to credence because they were testifying from memory. If there was not thus presented a question of fact, it is difficult to conceive when such an issue can be presented.

6. On page 5 of Respondent's brief, there is a quotation from the opinion of Judge BUFFINGTON wherein he refers to the subject matter of the patent in suit as a tube "known commercially as the Langmuir tube". The tube of the Langmuir patent has never been known commercially as the Langmuir tube. This is pointed out in Judge WOOLLEY's opinion (p. 46 of the pamphlet submitted with petitioner's petition and brief) where he states that "plaintiff frankly admitted at the argument" that this name had not been given to the tube by the art.

Respectfully submitted,

THOMAS G. HAIGHT,
SAMUEL E. DARBY, JR.,
Counsel for Petitioner.

PETITIONER'S BRIEF

FILE COPY

APR 18 193
CHARLES ELMORE CR

Supreme Court of the United States

October Term, 1930.

No. 630.

DeForest Radio Company,
Petitioner,
vs.
General Electric Company,
Respondent.

BRIEF FOR PETITIONER.

✓ Thomas G. Haight,
✓ Samuel E. Darby, Jr.,
Counsel for Petitioner.

✓ Carl A. Richmond,
✓ William R. Ballard,
Of Counsel as to "Point III" and the related part of "Point V" only.

INDEX

PAGE
Opinions of the Courts Below 1
Jurisdiction 2
Assigned Errors 2
Statement of the Case 3
  Subject Matter Involved 3
  What the Patent Purports to Cover 5
  Scientific Principles Involved 7
  Ionization and Its Effect 9
  The Methods of Getting High Vacuum 10
  History of the Langmuir Application 11
  Arnold Interference 14
Summary of Argument 16
Argument 19
  Point I—The patent discloses nothing new or patentable over the prior art; the difference is only in the degree of vacuum to be used for specific purposes 19
    What Langmuir disclosed to the Patent Office as the Alleged Invention 20
    Attainment of High Vacuum in the Prior Art 21
    Absence of Novelty in the Characteristics of a High Vacuum Discharge 26
    Physical Structure Not Novel 28
    Lilienfeld Paper 29
    Fleming 32
    Difference in Degree Is Not Patentable 36

PAGE

The Lack of Invention Over the Prior Art Disclosure as Evidenced by the Attitude of the Experts of the Telephone Company and the General Electric Company 39

Point II—The majority opinion of the Court below sustained the patent on an untrue definition of the alleged invention 41

Gas as a Detector 41

Earlier Attempts to Define the Invention 42

Terminology as to Gas Conduction 44

Langmuir's Testimony as to Gas Conduction 46

The Prior Art on Conduction of Electricity by Gas 47

Point III—If the subject matter of the patent involves patentable subject matter, then Dr. Arnold was the first inventor thereof, and not Dr. Langmuir, the patentee 55

Judicial Consideration Given Heretofore to This Question 55

The Supposed Invention Involved in the Priority Issue 58

Arnold's Work—Conception and Disclosure of the Invention by Arnold 60

Events After Arnold's Disclosure of the Invention 67

November, 1912—Audion 7A 72

The April and May Tubes 73

Philadelphia Tubes 75

Langmuir's Work—Langmuir's Two Preliminary Statements 78

PAGE

Langmuir Did Not Recognize the Invention in August, Assuming Its Presence 80

The August Tube Did Not, in Fact, Embody the Invention 84

Langmuir's Case After November 1, 1912 86

Langmuir's November Experiments 87

The Coolidge-Langmuir Conversation in December, 1912 89

Langmuir's Record After 1912 91

Resumé of Priority 93

Point IV—The patent is invalid because of prior knowledge and public use 95

Facts of Detector and Amplifier Operation 95

Facts of This Defense 96

Testimony from Langmuir Bearing on the Facts of This Defense 98

Tungsten Cathodes in the California Tubes 101

Point V—The present majority decision of the Court of Appeals has reversed the dispositive findings of fact of the Trial Court without advancing any reason therefor, and without mention of those facts or the defenses to which they were directed 104

Point VI—The patent is invalid because of double patenting 106

Conclusion 113

Table of Cases.

	PAGE
Adamson v. Gilliland, 242 U. S. 350	105
American Bell Telephone Co. v. National Manufacturing Co., 109 Fed. 976	110
Andrews v. Carmen, Fed. Case 371	82
Ansonia Brass and Copper Co. v. Electrical Supply Co., 144 U. S. 19	36
Anthracite v. Pollock, 175 Fed. 108	82
Belding Manufacturing Co. v. Challenge Corn Planter Co., 152 U. S. 100	36
Burt v. Evory, 133 U. S. 349	36
Byerley v. Barber Asphalt Co., 230 Fed. 995	83
Caldwell v. Firestone Tire and Rubber Co., 13 Fed. (2) 433	110
Carson v. American Co., 11 Fed. (2) 766	83
Corona Cord Tire Co. v. Dovan Chemical Corp., 276 U. S. 358	59
Detmold v. Reeves, Fed. Case 3831	89
Dey Time Register Co. v. Syracuse Time Recorder Co., 152 Fed. 440	110
Doble v. Pelton Co., 186 Fed. 526	83
In re Dunbar, 278 Fed. 334	110-111
Eagleton Co. v. West Co., 111 U. S. 490	20
Eibel v. Minnesota, 261 U. S. 45	82
Estey v. Burdett, 109 U. S. 633	36
French v. Carter, 137 U. S. 239	36
General Electric Co. v. DeForest Radio Co.	1-2
Guiduet v. Brooklyn, 105 U. S. 550	36
Industrial Manufacturing Co. v. Willcox and Gibbs, 112 Fed. 535	110
Kittle v. Hall, 29 Fed. 508	20
LeRoy v. Tatham, 14 How. 155	89
Marconi v. DeForest, 236 Fed. 942	52
Miller v. Eagle Manufacturing Co., 151 U. S. 186	110-111

PAGE
Milligan & H. Glue Company v. Upton, 97 U. S. 13 — 36
McCormick Harvesting Machine Co. v. Minneapolis Harvester Works, 42 Fed. 152 — 64
Morton v. N. Y. Eye Infirmary, Fed. Case 9865 — 89
Munissing v. American, 228 Fed. 700 — 82
Munson v. New York, 24 U. S. 601 — 36

Otis Elevator Co. v. Portland Co., 127 Fed. 557 — 110

Palmer Pneumatic Tire Co. v. Lozier, 90 Fed. 772 — 110
Pearce v. Mulford, 102 U. S. 112 — 36
Pittsburgh v. Cowles, 55 Fed. 301 — 82
Pittsburgh Plate Glass Co. v. American Window Glass Co., 276 Fed. 187 — 110

Railway Co. v. Sayles, 97 U. S. 554 — 20

Slawson v. Grand Street, 107 U. S. 649 — 36
Standard Co. v. Graywood, 1 Fed. (2) 667 — 83

Thompson Spot Welder Co. v. Ford Motor Car Co., 268 Fed. 836 — 110
Tilghman v. Proctor, 102 U. S. 707 — 81

Wells v. Curtis, 66 Fed. 318 — 82

Text Books.

Walker on Patents — 26
Robinson on Patents — 72, 80, 89

Supreme Court of the United States

October Term, 1930.

No. 630.

DeForest Radio Company,
Petitioner,
vs.
General Electric Company,
Respondent.

BRIEF FOR PETITIONER.

Opinions of the Courts Below.

This is a patent infringement suit.

Judge Morris in the District Court of Delaware rendered an opinion which is reported in 23 Fed. (2) 698[1] holding that the patent in suit was invalid on three distinct grounds.

(1) Because of anticipation and want of invention; a question of mixed fact and law.

(2) Because of prior invention, if invention in fact existed;—*a question of fact.*

(3) Because of prior public use—*a question of fact.*

Note. Italics on quotations are ours, unless otherwise stated.

[1] Rec., Vol. 3, p. 1943.

Appeal was taken to the Circuit Court of Appeals for the Third Circuit, and that Court affirmed the decision of the District Court in an unreported *per curiam* opinion *which adopted the opinion of Judge Morris,* Judge BUFFINGTON dissenting *without opinion.*

Thereafter, a petition for rehearing was filed and granted, and the case was reargued.

In an opinion written by Judge BUFFINGTON reported in 44 Fed. 2nd 931 [2] the majority of the Court reversed the District Court without referring to or discussing the findings of fact of the District Court, and entered a judgment accordingly. Judge WOOLLEY wrote an extensive and carefully considered dissenting opinion upholding the conclusions of the Trial Court, 44 Fed. (2nd) 938.[3]

Jurisdiction.

The case is here on writ of certiorari granted by this Court on February 25, 1931; the jurisdiction having been invoked under Section 347, U. S. Code, Title 28.

Assigned Errors to Be Urged.

(1) The Court of Appeals erred in reversing the decree of the District Court and holding the Langmuir patent No. 1,558,436 to be valid and infringed.

(2) The Court of Appeals erred in failing to hold that the Langmuir patent No. 1,558,436 is invalid because of anticipation, want of invention, and double patenting.

---

[2] Rec., Vol. 3, p. 2026.

[3] Rec., Vol. 3, p. 2043.

(3) The Court of Appeals erred in failing to hold the Langmuir patent No. 1,558,436 invalid because of prior invention by H. D. Arnold.

(4) The Court of Appeals erred in reversing the dispositive findings of fact of the Trial Court, based on conflicting testimony as to prior invention by H. D. Arnold.

(5) The Court of Appeals erred in failing to hold the Langmuir patent No. 1,558,436 invalid because of prior knowledge and public use by Lee DeForest and the Federal Telegraph Company.

(6) The Court of Appeals erred in reversing the dispositive findings of fact of the Trial Court, based on conflicting testimony as to prior knowledge and use by Lee DeForest and the Federal Telegraph Company.

Statement of the Case.

Subject Matter Involved in the Case.

This suit was brought by the Respondent, General Electric Company, against the DeForest Radio Company, alleging that the radio vacuum tubes made and sold by the latter were an infringement of Langmuir patent No. 1,558,436, issued October 20, 1925.

The "tubes" in question are the now well known vacuum tubes universally used in radio broadcast receiving sets, and in this record are variously referred to as "vacuum tubes", "electron discharge devices", "audions" and "valves". They comprise an evacuated glass bulb containing two or three metallic electrodes—usually three—which are connected in appropriate electrical circuits with suitable sources of current to produce the desired effects.

The two-electrode vacuum tube, for use as a wireless detector, was invented by Fleming and covered in his U. S. patent No. 803,684, which expired November 7, 1922.

The three-electrode vacuum tube or "audion" was the invention of DeForest for which he obtained patent No. 879,532 which expired February 18, 1925. The difference between the three-electrode tube and the two-electrode tube is by no means represented by the difference between two and three. The two-electrode tube gave the electrical art a current flow across a vacuous container, which accomplished certain useful purposes because of its characteristics. The introduction of the third electrode, however, gave the art, for the first time in history, a means for controlling a flow of current which was at once inertia-less and consumed practically no energy in the control circuit and capable of producing any desired variations in the discharge current with absolute fidelity.

The parties to this case are in agreement that the three-electrode tube involving this new principle of operation, revolutionized the electrical arts. It is the thing which is used in modern broadcasting systems for generating the radio waves, for modulating them in accordance with the speech or music, for "detecting" them in the receiving sets and for amplifying them at both sending and receiving ends.[4] It is used in wire transmitting systems, both telephone and telegraph, for a number of purposes. It is employed both in recording and reproducing talking motion pictures, in the production of modern phonograph records, and in a number of other commercial fields.

---

[4] A vacuum tube *detector* is one which receives current of one type or character, *e. g.*, oscillating or alternating current, and gives out current of a *different* type or character, *e. g.*, a pulsating direct (unidirectional) current; in radio it changes radio frequency currents to audio fre-

What the Patent in Suit Purports to Cover.

The patent in suit purports to cover an improvement in the vacuum tubes of Fleming or DeForest, and, according to Respondent, consists in removing more of the air from the tube during manufacture than was done by Fleming or DeForest, *i. e.*, in getting a higher vacuum. It is not claimed that *all* of the air is removed, because that is impossible, but that enough is removed so that what remains will not interfere with the operation of the tube. Respondent's position is, indeed, that any DeForest audion (except a "detector" tube), which properly performs its intended function, is covered by the Langmuir patent. The exception in favor of the "detector" tube is because of the fact

---

quency currents. In other words, the current which is passed through the tube is *altered* as to its character so that it can be "detected" by certain kinds of instruments. Thus, certain operational characteristics of a vacuum tube are made use of, when the tube is to be employed as a *detector*, which are *not* made use of when the tube is to be employed for another use, for example, as an *amplifier*. A *detector* is not as much concerned with *power output* as it is with the needed change in *character* of the output to make a feeble current perceptible.

The vacuum tube *amplifier*, on the other hand, is not concerned with detection, and its principal, if not sole function is to produce on the output side of the tube, current in the *same* form and of the *same character* as that received on the input side thereof, but in a greatly strengthened or *amplified* condition.

that the "detector" action of a tube is in some respects better when the vacuum is relatively poor. Respondent itself, at least until recently, has purposely made its detector tubes with a definite gas content. This distinction between detector tubes and amplifier or oscillator tubes has an important bearing on questions in this case, as will appear later.

The Langmuir patent was applied for October 16, 1913, and issued October 20, 1925. In the year 1915 and again in the year 1916 the application stood allowed and Respondent might have taken the patent out by simply paying the final fee within the six months allowed by law. It chose, however, to forfeit and renew the application on the first occasion, and the case was reopened for further amendment on the second occasion. The interference proceeding with the Arnold application, which came later, (and which will be hereinafter discussed, *post*, pp. 14, 56) would have been between Arnold's application and the Langmuir *patent* if Respondent had taken out the patent when allowed, and so would not have delayed its issue or postponed the running of its seventeen year term.

From July 1, 1920, on, the General Electric Company held an exclusive license for certain purposes under the DeForest vacuum tube or "audion" patent above referred to, and was very active in prosecuting infringers in its exclusive field which included the sale of radio broadcast receiving tubes to the public. That DeForest patent expired in February, 1925, as above noted. The Langmuir patent was brought out in October, 1925, and Respondent started this suit against the DeForest Company in January, 1926. If the Langmuir patent is valid it extends the vacuum tube monopoly, which Respondent was enjoying under the DeForest patent up to 1925, for an additional seventeen years.

The application of the patent in suit as filed in October, 1913, did not ask for a patent on a vacuum tube of any kind. The invention which it claimed was *a particular method of exhausting* vacuum tubes; a method, moreover, which is now admitted to be inoperative.

Besides this inoperative method the application also described procedure which *was* operative to produce a very good vacuum. This procedure in its entirety is also disclosed in patents and publications prior in date to the application, as we shall see, although it is doubtful whether Langmuir knew that fact. The application further described the characteristics of a discharge through a vacuum where the residual gas is reduced to the point where it does not affect the result,—a discharge frequently referred to as "a pure electron discharge". Such a discharge and its characteristics also were described in prior patents and publications, although it is doubtful whether Langmuir knew this.

Scientific Principles Involved.

Some understanding of the difference between a pure electron discharge and one affected by the residual gas, and of the methods for obtaining high vacuua, are necessary to a consideration of this case and we shall explain each briefly. These are matters of scientific fact and not in dispute.

If we have an evacuated glass tube into which are sealed two metal electrodes connected to the poles of a battery or other source of current, no current will flow through the tube under any ordinary voltages (electric pressure). If we heat one of the electrodes, which can be done, for example, by making it in the form of a filament and passing a current through it as in an electric lamp,—a current *will* flow across the space in the tube and through the wires connecting the electrodes to the battery, if the hot electrode is connected to the negative pole. This is because the heat causes "electrons" to be liberated from the surface of the hot electrode and these are drawn across the space under the influence of the electrical pressure between the two electrodes. *These electrons constitute the electric current.* They are minute *negative* charges of electricity. The amount of the current depends upon the number drawn across the space. The number drawn across (assuming a sufficient supply) depends upon the voltage applied to the two electrodes. With a higher voltage more electrons go across and they move faster. If gas molecules are floating around in the tube, some of them will be hit by the electrons which are flying across toward the positive electrode, and if the voltage applied to the electrodes is greater than a definite amount (15 to 25 volts depending on the kind of gas in the tube) the electrons will be going fast enough to split up the gas molecules. This is called "gas ionization", so named because when the electron hits the molecule it splits it into two parts, an electron (quite like the one that did the hitting) and a much larger and more slowly moving part called an "ion" which carries a *positive* charge of electricity. The amount of gas ionization which occurs in a given tube depends mainly upon two things, (1) the number of gas molecules in the space and (2) the applied voltage. Increasing either the gas content or the applied voltage will increase the amount of ionization. With a given state of vacuum and voltage, the amount of ionization will not be changed by increasing the voltage if the gas content is suitably reduced, or by increasing the gas content if the voltage is suitably reduced.

Ionization and Its Effect.

The effect of ionization on the discharge is in general to increase it,—not because the resulting positive and negative charges carry any considerable amount of current—but because the positive ions act like traffic police for the electrons which do constitute the current, and facilitate their passage. With no positive ions present the electrons which are boiled out of the hot filament crowd together in the immediate neighborhood of the filament, repelling one another (because they are all negative) so that some may even be forced back to the filament. Thus the number getting across to the positive electrode in a given time, is held down in much the same way that the progress of a person coming out of a crowded theater is slowed down. This effect of the crowd of negative electrons upon their own movement is called the "space charge" effect (sometimes called "volume charge"). But with any considerable number of positive ions (ionized gas molecules) present, this negative space charge is greatly reduced inasmuch as positive and negative charges neutralize each other, thus permitting the electrons freely to pass across to the opposite electrode.

This "policing" of the electrons by the ionized gas molecules sounds like a very desirable thing, and in some cases it is (in detector and rectifier tubes, for example); perhaps it would always be desirable if the "policemen" were reliable and uniform in performing their duties. For reasons which need not be here stated, however, the gas content in a tube, and so the amount of ionization, varies with temperature, the life of the tube and other things, so that erratic and undesirable operation may result. Moreover, in the *three*-electrode tube the characteristic operation is due to the control over the discharge which the third electrode—the "grid", exercises by more or less neutralizing the "space charge". Obviously then, much gas ionization in a DeForest tube might be expected to interfere with the desired effect.

In general, it is clear from the foregoing that the amount of the gas residue permissible in any particular tube depends upon the use to which the tube is to be put and the voltage under which it must operate.

The Methods of Getting High Vacuum.

As to the methods for getting vacua high enough for tubes of the kind here considered, the patent in suit points out that two things are necessary, first a good vacuum pump (the "Gaede molecular" pump is suggested), and second a thorough heating of the glass walls and metal electrodes to drive out the gas occluded in their surfaces so that it can be drawn off by the pump. The glass walls can be heated sufficiently by baking the tube in an oven during the exhaust. The filamentary electrodes are heated by passing a current through them until they glow. The other electrodes are heated by "bombardment". This term is used to describe the impact of the electrons upon a positive electrode when they fly across the space under the influence of an applied voltage, as above described. Millions of these, striking the electrode in this way, raise its temperature just as the blows of so many tiny hammers would.

These requirements for producing a high vacuum and all of these expedients for producing the necessary heat are repeatedly disclosed in publications and patents antedating Langmuir's work, as we shall point out later.

We may note here in passing that the invention claimed in his application when it was filed in the Patent Office, to which we have referred above, was the idea of freeing an electrode of gas by *bombarding without heating*. Afterwards Langmuir discovered that this was a mistaken idea, and that the only way to remove occluded gases is by heating, and that bombardment is effective only as it *heats* the electrode, just as the prior art had disclosed. Consequently, claims to this original idea were cancelled.

Lastly, it is to be noted that the patent further points out (p. 4, line 109) that the amount of heating required in the exhausting process, and specifically the voltage required in the bombarding, depends upon the voltage to be applied to the tube in the circuit where it is to be used. Some of the patent claims assert that a tube operating without ionization effects, at only 40 volts and carrying very minute currents (1/10 of one milliampere), comes within the supposed invention. Others specify voltages all the way up to 200, and much heavier currents.

History of the Langmuir Application.

Although the Langmuir application as filed claimed as its invention the impossible and scientifically absurd method of gas freeing, viz.: *bombardment without heat*, the patent issued for an entirely different thing—the vacuum tube itself, assertedly differing from tubes of identical structure only in operational characteristics in use. We invite the Court's attention to the history of the Langmuir application in the Patent Office.[6] Space forbids our following, step by step, the continuing and radical changes that occurred in the specifications and claims, which involved the cancellation of all of the claims originally presented and the substitution of claims for an entirely different thing; and, in some instances, for a diametrically opposite thing; and continual addition to the specification to keep the application abreast of Langmuir's education in the art. On this phase of the matter, we direct attention to the summary contained in the dissenting opinion of Judge WOOLLEY, as follows:[6a]

> "A recital of the prosecution of a patent application through the Patent Office is dreary reading yet, in this instance, it shows quite clearly that even the applicant was far from certain what he had invented. Naturally I hesitate to say this about Irving Langmuir, a great physicist, yet, saying it with entire respect, I am convinced that the history of the application establishes that fact and therefore is pertinent to the ever present inquiry: What did Langmuir invent?
>
> The patent issued on October 20, 1925. The application was filed on October 16, 1913; renewed March 14, 1916. These are critical dates. The original application contained five claims; two for process of removing ionizable gas from vacum electron discharge devices, that is, in plain words, for obtaining a high vacuum, and three for methods of preparing such devices, and no claims for discharge devices themselves. The specification conformed to these claims, referred to the art, stated the problem, dis-

---

[6] Rec., Vol. 6, pp. 660-773.

[6a] Rec., Vol. 3, p. 2044.

closed construction adapted to the operative principle of such tubes and showed how they can be 'evacuated' of gases by heating the glass walls, heating and bombarding the metal parts thereby expelling occluded gases, and drawing off both free gases and expelled gases 'by a suitable evacuating means, for example, a Gaede molecular pump'.

It should be noted that when the application was filed in 1913 the radio art was in its infancy but that, in 1925, when the patent issued, the art had attained an amazing growth. It is pertinent to inquire what happened to the application during this span of twelve years during which the mysteries that had enveloped the early art were largely dispelled and replaced by a broad knowledge of its principles.

After the application was filed in 1913 it lay practically dormant for several years, the applicant filing enough amendments by additions and cancellations to keep it alive. Amendments to the specification occurred as follows: two in 1913; eight in 1914; one in 1915; five in 1916; three in 1917; three in 1919 and forty-five in 1925, the year the patent issued.

Amended claims were filed and additions thereto and cancellations thereof made as follows: four in 1913; fifteen in 1914; twenty in 1916; five in 1917; nine in 1919; five in 1921 and forty-two in 1925, the year of the patent.

Analyzing these amendments, it appears that the five original claims (which were for process and method) were at different times wholly cancelled. Late in the year 1913 Langmuir first made claim to invention of a structure or device, that is, to invention of a tube. This he did by four claims. The first was amended four times and cancelled in 1925. The second also was amended four times and cancelled in 1925. The third was amended four times and was

> not cancelled. The fourth was amended once and cancelled in 1925. Of the thirty-two claims allowed in the issued patent, four are for method and process, being amplifications of the original method and process claims cancelled; twenty-eight are for a device. Of these device claims one was filed by amendment in 1913; one in 1917; nine in 1919; three in 1921 and fourteen in 1925, the year the patent issued. Bearing on the question whether Langmuir knew and disclosed in 1912, or indeed in suceeding years, what he had invented, it is significant to note that during twelve years, and mainly in the latter part of that period when the art had grown and reached a high stature, he rewrote, by sixty-seven amendments, the major part of his specification and cancelled all the original method and process claims and by one hundred amendments added, changed and cancelled claims until finally he was allowed the thirty-two claims of which twenty-eight, the claims for a device, are entirely new. It would be instructive, yet impossible within the permissible bounds of an opinion, to trace the progressive changes from the method and process claims of the original application to the device claims of the matured patent."

There is, therefore, a striking analogy between the file history of the Langmuir patent and that of the McMichael patent considered in *Powers-Kennedy Constructing Corporation, et al. v. Concrete Mixing and Conveying Company*, decided December 15, 1930, by this Court.

Arnold Interference.

As the result of an application for a patent filed on November 2, 1915, by Dr. H. D. Arnold, an engineer employed by the Western Electric Company, an interference was declared between the Langmuir application and the Arnold application. This interference was carried through all of the Tribunals of the Patent Office, resulting, as will be hereinafter set forth in detail,[7] in various holdings, and finally in an award of priority of invention to Langmuir by the Court of Appeals of the District of Columbia, overruling the Commissioner of Patents. The evidence in the present case has been extended to include certain specific evidence, the absence of which was assigned as ground for such award to Langmuir. The application of Arnold was admittedly filed to provoke an interference because, shortly before the application was filed, the engineers of the Western Electric Company and the American Telephone & Telegraph Company had learned of Langmuir's application and they felt, if the subject matter thereof was patentable, that Dr. Arnold was the first to invent it. Up to that time, it had not occurred to Dr. Arnold that the subject matter was patentable and, in the interference, he moved to dissolve on that ground, and six of seven claims were stricken out on his motion. We point out in passing that Dr. Millikan, the foremost of American physicists, when he learned that Langmuir was attempting to patent a high vacuum tube, advised the engineers of the Telephone Company that it was their duty to the public to provoke the interference, because he did not believe that any such thing was patentable.[8]

---

[7] *Infra*, pp. 56 *et seq.*

[8] Interf. Rec., pp. 874 to 876 and context.

The "Interference Record" is the record made up in the Patent Office for the Court of Appeals of the District of Columbia for the priority contest between Dr. Langmuir the present patentee and Dr. Arnold of the Telephone Company. This "Interference Record" is an exhibit in the present case and was stipulated as evidence in this case at Rec., Vol. 1, page 133.

Summary of Argument.

1. The patent discloses nothing new or patentable over the prior art. Long before Langmuir's earliest claimed date of conception, the art was fully familiar with pure electron discharge devices claimed by the patent, as well as all of the methods and means for producing the high vacuum necessary for such tubes. Indeed, the prior art structures are admittedly identical with those of the Langmuir patent, and the only difference therefrom asserted by Respondent is in the degree of evacuation of said devices. The invention at the most, therefore, is merely for a difference in degree, which this Court has from the earliest times held is unpatentable.

2. The majority opinion of the Court below sustained the patent on an untrue definition of the alleged invention. After Respondent abandoned its original claim that the invention was a new method of producing high vacuum, it thereafter advanced in the Patent Office and in the Courts several different definitions of the invention; always seeking to escape the legal effect of a finding that the invention was merely a difference in the degree of vacuum. Finally, after the District Court had decided that the patent was invalid, and the Circuit Court of Appeals had affirmed that decision, Respondent brought forth an entirely new definition different from anything that it had theretofore suggested. This definition the majority of the Court below on reargument accepted, and its decision is based thereon. The new definition is unsupported by the evidence and is contradicted by the testimony of the patentee himself.

3. If the subject matter of the patent in suit involves patentable invention, then Dr. Arnold was the first inventor thereof and not Dr. Langmuir, the patentee. Whether the invention be that which the defendant variously defined in the Patent Office and before the Courts until the rehearing in the Circuit Court of Appeals, or whether it be in accordance with the definition advanced on the reargument, the evidence conclusively establishes that Arnold was prior to Langmuir in date of conception, in reduction to practice and in the production of commercially useful articles. His claim to priority has been established by the Commissioner of Patents, by Judge MORRIS, who heard and saw the many witnesses who were called on this point, and by the majority of the Circuit Court of Appeals before the reargument. Langmuir was awarded priority by the Examiner of Interferences upon an untenable proposition of law which the Respondent has never subsequently asserted, and by the Examiners-in-Chief because they gave Langmuir an early date of conception, which conception he admits in this case he did not have at that time, and because they did not believe that Arnold knew how to get a high vacuum at the time they found he conceived the invention. In this case, it has been shown that Arnold *did* know how to get the high vacuum. Langmuir has also received an award of priority from the Court of Appeals of the District of Columbia, which overruled the Commissioner of Patents on an opinion which simply adopted the opinions of the Examiner of Interferences and the Board of Examiners-in-Chief. These opinions, however, were as far apart as the poles on the legal principles relied upon and the facts found. Judge MORRIS, the only judge who heard and saw the witnesses, has decided in favor of Arnold.

4. The patent is invalid because of prior knowledge and use. The claims variously describe the patent as a tube capable of operating without harmful effects of ionization with an impressed voltage of 40 volts or more. The uncontradicted testimony in the case is that Dr. DeForest, while employed by the Federal Telegraph Company in California in 1911 and 1912, used tubes as amplifiers, employing voltages considerably in excess of 40 volts, without harmful ionization. The use of such tubes with such voltage as amplifiers would be impossible if ionization in any appreciable amount existed. The preparation and use of the tubes with this vacuum was deliberate and intentional on the part of Dr. DeForest.

5. The present majority decision of the Court of Appeals has reversed the dispositive findings of fact of the Trial Court without expressing any reason therefor, and without mention of those facts. Either prior inventorship on the part of Dr. Arnold or prior knowledge and use on the part of Dr. DeForest—*both questions of fact*— was a complete defence to this suit. Judge Morris heard and saw the witnesses who testified on the priority of invention issue. While he did not hear those who testified on the prior use, their testimony was not attacked, except by inferences sought to be drawn therefrom by experts whom Judge Morris saw and heard on the stand. The rule is that where a question of fact depends upon conflicting testimony, or upon the credibility of witnesses, the finding of the judge who saw the witnesses will be treated as "unassailable", unless clearly wrong.

6. The patent is invalid because of double patenting. Respondent caused to be issued to it, on October 31, 1916, a

patent covering an invention made by one of its engineers, Dr. Coolidge, claiming the same invention now asserted for the Langmuir patent, which Respondent likewise caused to be issued to itself. The Coolidge application was filed before the Langmuir application and the Coolidge patent issued before the Langmuir patent. The later patent is therefore invalid.

ARGUMENT.

POINT I.

The patent discloses nothing new or patentable over the prior art; the difference is only in the degree of vacuum to be used for specific purposes.

To deal with the question of patentability it would be most helpful if we had a clear definition of the alleged invention. As above noted, difficulty has been experienced throughout this case in finding any definition which will serve the purpose. The Respondent's eleventh-hour definition is clearly a failure for reasons to be stated. The claims of the patent in suit, which should serve as the needed definition, signally fail to do so. One cannot read these thirty-two claims through without becoming altogether bewildered.

We shall meet this situation, therefore, by showing that everything within the four corners of the disclosure of the Langmuir patent is to be found in the prior art. And in doing this we shall refer primarily to the Langmuir application *as it was filed in the Patent Office,* for it is well settled that valid claims cannot be based upon new matter added after filing.[1] This rule is so well recognized that it needs no argument, but it is important to note the fact here because the Langmuir application was so extensively amended after filing as to be scarcely recognizable.

What Langmuir Disclosed to the Patent Office as the Alleged Invention.

Looking then to the original application, we find that it described first a process of making vacuum tubes. Briefly stated, this process is the exhaustion of the enclosed space by some efficient vacuum pump, together with heating of the glass, glowing of the filaments and bombarding of the electrodes so as to drive out the occluded gases from these parts.[1a] In short, it is simply an evacuation which includes evacuation of the surfaces of the walls and electrodes as well as of the free gases. The specification states that this shall be carried to a point depending upon the discharge which it is expected to put through the tube when in use, *i. e.*, the voltage to be applied.

So much is said in this record about the importance of a "high" vacuum that we should expect to find something definite in the disclosure as to what this means in relation to the present alleged invention. We find in the specification of the patent nothing more definite than this,

---

[1] *Railway Co.* v. *Sayles*, 97 U. S. 554, 563; *Eagleton Co.* v. *West Co.*, 111 U. S. 490, 498; *Kittle* v. *Hall*, 29 Fed. 508, 513.

[1a] This process was not claimed in the original application, but an alternative process, "bombardment without heating", was also described *and claimed*. Later this was acknowledged to be futile and such claims were canceled.

> "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned".[2]

Respondent takes the position that the limiting pressure is far more uncertain than even this statement would indicate. Dr. Saul Dushman, an associate of Dr. Langmuir in the Research Department of the General Electric Company, states in his book on "High Vacuum" that "a pressure of 0.01 bar (0.0075 micron) is a maximum pressure for the efficient operation of a hot cathode high vacuum dedevice".[3] This limiting pressure assigned by Dr. Dushman is less than a single hundredth of a micron.

On the other hand, one of Langmuir's tubes on which he is compelled to rely in his effort to anticipate the date of invention proved for Arnold, was admitted by him to have a pressure of 0.4 microns of gas, that is, *40* hundredths of a micron.[4]

It is apparent how vague and uncertain is the patent as to the degree of the vacuum required. The invention cannot be the *degree* of vacuum.

Attainment of High Vacuum in the Prior Art.

Neither can the invention be the procedure Langmuir describes for attainment of a sufficient vacuum. It was widely and thoroughly understood long before Langmuir, that to get a good vacuum required more than mere pumping,—that it required heat treatment of all the interior surfaces of the vessel pumped, in order to free the occluded gases therefrom so that they could be evacuated by the pump. This requirement is clearly set forth in the Dwyer U. S. patent No. 59,654 of 1898.[5] This patent states, at line 19 of the first page of the specification:

---

[2] Rec., Vol. 4, p. 6, lines 3-6.

[3] Rec., Vol. 3, pp. 1655, 1656, Hogan XQ's. 349, 349a, 353.

[4] Rec., Vol. 2, pp. 1302, 1304, XQ's. 257, 267.

> "A partial or incomplete vacuum, but one not carried sufficiently high to serve the purposes of the best grade of incandescent lamps, is readily obtained by a good mechanical or mercurial pump, *but it is in the removal of the residual gases remaining after such exhaustion that the greatest difficulty is encountered,* since that part removed by each stroke of the pump or by the successively falling drops of mercury in the case of the Sprengel pump, becomes continually smaller and smaller, being simply a certain fraction of the expanding remaining gases; and soon a limit is reached, which is, however, still below the desired vacuum, beyond which no further exhaustion by this means is possible. *To carry the vacuum still higher, it has been a common practice to heat the lamp-bulb by either an external source of heat,* such as a gas-flame, *or by an electric current passed through the lamp filament or by both of these means combined,* so as to expand the gases in the lamp, *and also to drive off from the lamp-filament itself and its supports,* more particularly the joint between the leading-in wires and the filament, which joint is usually made of some form of hydrocarbon paste, *gases occluded therein, while continuing the pumping operation.*"

This is also pointed out in the Soddy patent No. 859,021 of 1907 for "*Means and Apparatus for Producing High Vacuums*".[6] This patent states (p. 186, line 17)—

---

[5] Deft's. Ex. 7, Rec., Vol. 5, p. 42.

[6] Rec., Vol. V, p. 186.

> "In the production of high vacua not only has the air to be removed, but also the gases occluded or condensed on the walls of the vessel being exhausted, and the electrodes or filaments or other contents of the said vessel, which condensed gases are given up slowly after exhaustion and if not removed during exhaustion cause the vacuum to deteriorate."

Again at line 96 the patent points out—

> "*The heating and expelling of the condensed and occluded gases may be effected in any usual or suitable manner of expelling condensed and occluded gases from the walls and contents of vessels being exhausted.* The usual manner of effecting such an operation is to heat the vessel while it and its contents are subjected to the same treatment as they are subjected to in after years. In incandescent lamps, for example, an electric current is passed through the filament and *in X-ray bulbs electric discharge is passed between the electrodes during the continuation of the exhaustion.*"

It is here seen that long before Langmuir entered this field, the very method of gas freeing that he proposed, viz., pumping and thoroughly heating the interior parts, specifically including bombardment, and which he admits will produce a device of his invention, is recited as being standard practice in the art.

In a paper published in the year 1904, S. E. Doane stated with regard to incandescent lamp exhaustion,[7]

> "The completed lamp must not only be free from gases and vapors, but must also have had those parts capable of giving off gases and vapors thoroughly free from them. The only way we knew to accom-

---

[7] Rec., Vol. 5, p. 122, Deft.'s Ex. 11.

> plish this was to highly heat everything we wished to free from gas."

Here again are stated, at a time long before the alleged Langmuir invention, the very things which the Langmuir patent says will obtain the desired vacuum.

Compare the foregoing authorities of the prior art with the following statement in the Langmuir patent itself:[8]

> "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening, and in general the most approved methods of incandescent lamp exhaust are used."

It will be seen that the requirement of the patent in suit is fully satisfied by the foregoing references, Doane, Soddy and Dwyer of the prior art.

Another prior art authority to the same effect is Bessel-Hagen. In 1881 he set forth clearly that thorough evacuation meant getting the gas out of the electrodes and glass walls as well as out of the space within those walls.[9]

Heating of the walls and electrodes as a means to this end is described in no less than ten of the prior articles and patents.[1]

---

[8] P. 4, lines 60 *et seq.*

[9] Rec., Vol. 5, p. 15.

[1] These are in Vol. 5 of the Record as follows: Bessel-Hagen in 1881, p. 16; Edison patent in 1889, p. 37; Duncan in 1896, p. 47; Dwyer patent in 1898, p.42; Lenard in 1900, p. 62; Doane in 1904, p. 122; Merritt patent in 1909, p. 138; Soddy patent in 1907, p. 181; Friedrich patent applied for in 1910, p. 309 (Ex. 24), and Lilienfeld in 1910, p. 315.

Bombardment by a discharge through the tube as a means of heating electrodes, for the purpose stated in the foregoing quotations, particularly the quotation from Soddy, is described in at least six of the prior articles and patents.[2]

Langmuir himself made the unqualified general admission

> "that prior to 1912, there were some experimenters who took precautions to remove gases from the walls of vessels and from electrodes".[3]

Although the Law Examiner of the Patent Office adjudged that the Langmiur application had patentable subject matter, he distinctly denied that it lay in any method of attaining the necessary vacuum. He said:[4]

> "An evacuated tube having therein an incandescent electron-emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube, were also well known and available to persons skilled in the art."

Clearly, there is nothing new in the method of getting the vacuum,—nor in the idea of a vacuum which will stay good in use.

---

[2] These are in Vol. 5 of the Record as follows: Duncan in 1896, p. 47; Lenard in 1900, p. 62; Doane in 1904, p. 122; Soddy patent in 1907, p. 181; Hupka in 1909, p. 241, and Lilienfeld in 1910, p. 315.

[3] Interf. Rec., p. 1287.

[4] Interf. Rec., p. 2468.

Absence of Novelty in the Characteristics of a High Vacuum Discharge.

We find also that the original specification defines, to some extent, the character of the thermionic discharge through a well-evacuated tube. But the *discharge*, itself, even if new in kind, cannot be the invention because it is neither an "art, machine, manufacture or composition of matter" which are the only things patentable under the laws of the United States.[5] The discharge, whatever its nature, is merely a physical phenomenon.

Besides, it was not new,—and it will be well to keep this in mind because Langmuir and Respondent's counsel have a way of referring to his "new type of discharge" as if this were really new.

The characteristics of the discharge named in the original specification[6] are found on page 3, lines 11 to 27 of the patent as issued, and are given, as it says, "In order to distinguish electron-discharge devices made in accordance with my invention from the prior art, * * *" (p. 1, line 25). These are;

(1) Gas ionization absent or negligible,
(2) Cathode not heated by the discharge,
(3) No blue glow nor visible evidence of discharge,
(4) 3/2 power relation of current to voltage,
(5) Discharge independent of degree of vacuum within intended limit for the particular tube,
(6) Regularity and reproducibility.

---

[5] Sec. 4886, Revised Statutes, Walker on Patents Fifth Ed., § 2, p. 2, Robinson on Patents, § 69, p. 105.

[6] Rec., Vol. 6, p. 662.

All these criteria are summed up in the simple statement that there must be absence of "harmful ionization", as this term was employed by Respondent's witness Hogan. His statement was:

> "How far that evacuation has to go in terms of pressure is not at all material. The important thing is to carry it to a point beyond which it is unnecessary to go in order to avoid the harmful ionization effects".[7]

The original DeForest audion gave a discharge having all the above listed characteristics when operated *in October, 1912,* below certain voltages, as is evident from the testimony of Jewett, Colpitts and Arnold, concerning DeForest's demonstration to the Western Electric Company.[8] *It could not have so beautifully amplified the weak speech currents if there had been any harmful ionization.*

Lilienfeld had discharges satisfying all these conditions as described in his 1910 paper.[9] Also such discharges occurred between the filament legs of incandescent lamps after "clean-up".[1]

Note that the six characteristics named are all inherent in the discharge in question and are interrelated. In general any one implies all of the others. If a thermionic discharge is without substantial ionization, all the other characteristics will be present. If the discharge is independent of the vacuum below a certain pressure of gas, the other characteristics will be present, and so on. Langmuir admits that Lilienfeld had thermionic discharges "substantially free from the effects of positive ionization";[2] also that he had discharges unaffected by further lowering of the gas pressure in the tube.[2a] Lilienfeld's discharges were at voltages of the order of thousands of volts.[3]

---

[7] Rec., Vol. 1, p. 68.

[8] Rec., Vol. 1, p. 410, Q50; p. 497, Qs. 81, 82; p. 555, Q8.

[9] Deft's. Ex. 25, Rec., Vol. 5, p. 315.

[1] Rec., Vol. 2, p. 1348, XQ452.

So the patentable thing cannot be the particular kind of discharge defined by the original specification since it is inherently unpatentable subject matter, and moreover was all old.

Respondent advanced the contention for the first time on the rehearing in the Court of Appeals, that the alleged invention lay in the substitution of a vacuum conductor for a gas conductor. We shall consider the prior art on this question at page 47 of this brief.

Physical Structure Not Novel:

The physical structure of the tube described in the original specification of the Langmuir patent is not the invention because it was old. The Petitioner's tube said to infringe is substantially the same physical structure as the old DeForest Audions, exhibited to the Western Electric Company in 1912. Compare, for example, Plaintiff's Exhibit 7, a sample of the alleged infringement with Defendant's Exhibit 139, the old DeForest tube. None of the patent claims deals at all with such details of structural difference as there are.

The simple fact is that an old DeForest audion pumped a little cleaner, especially as to the walls and electrodes, is a tube of the Langmuir patent; no other change is necessary. There is no dispute about this,—it was admitted explicitly by the Respondent, as quoted on page 35 of this brief. No artful articulation of phrases characterizing the discharge through such a tube by one or another group of its inherent, natural qualities, can conceal this simple fact.

---

[2] Interf. Rec., p. 1378 top; p. 1521 middle.

[2a] Interf. Rec., p. 1786 bottom.

[3] Hogan, Rec., Vol. 3, p. 1703, l. 11.

Lilienfeld Paper—

The Lilienfeld 1910 paper[4] above referred to, contains so complete and explicit a disclosure of all the structures, methods, functions and principles of the Langmuir patent in suit, that it deserves more detailed consideration. The paper begins with the statement that Lilienfeld wished to obtain the highest possible vacuum, and proceeds at great length to describe elaborate means for obtaining the extreme vacuum desired, including heating the filament and walls, electron bombardment, and the use of liquid air and charcoal to get out any residual gas. He describes the space (or volume) charge effect in the following language:

> "One can formulate more generally the conditions for high vacuum and large current density as follows: the production of a state in which the volume density of the electrons carrying the current is as large as possible compared with the density of gas molecules in which there exists, therefore, a tendency for the formation of the maximum possible volume charge in the path of current."

The space charge effect here disclosed by Lilienfeld was not mentioned in the Langmuir original specification, but it is a fundamental criterion in his patent, and is explicitly recited in numerous claims, for example, claims 10 and 12.

---

[4] Rec., Vol. 5, p. 315, Deft.'s Ex. 25.

Lilienfeld states as a characterization of his device:

> "From a definite maximum density of the gas downwards the discharge phenomena are independent of the gas density in the region investigated."

This is, in simple language, Langmuir's fifth characteristic as above listed (*supra*, p. 26).

Again he states:

> "Now as a matter of experience it not only makes no difference at all whether the cathode is very strongly or feebly heated during the discharge provided, of course, that its temperature is high enough to insure its proper functioning."

This is a characteristic which has been much referred to by Langmuir in this litigation and is the basis of his patent claims 7 and 24.

Lilienfeld made readings of the current passing through his device and the potential across the sounding terminals that he employed, and he plotted his results and deduced his laws concerning the discharge. He made his plots logarithmically and one part of the curve follows the 3/2 power law, which he states thus:

> "More exactly formulated; the characteristic consists of two parts. In the first part the potential drop (gradient) increases as J 2/3, in the second as J 1/2. In both parts, the connection between J and V is represented simply by a power."

As pointed out in the Langmuir patent, page 2, lines 36, *et seq.*, expressing the law in terms of current (J 2/3) is identical with the 3/2 power of the voltage. Here we find

Langmuir's fourth characteristic as above listed, which is, the criterion of the patent claims 6, 13 and 15.

It will be seen from the foregoing, therefore, that the Lilienfeld articles describe not only every treatment or process which Langmuir advances as necessary to produce his devices, but formulates the same laws, earmarks, or characteristics, by which a device so processed and treated may be identified when once produced.

It is unnecessary for *us* to speculate as to the effect of the disclosure of the Lilienfeld articles, for Langmuir has committed himself with respect thereto in the record of the case, as we will now show from excerpts of Langmuir's testimony. It is interesting to note in connection therewith that Langmuir, himself, disposed of Respondent's contention which apparently was accepted by the majority of the Court of Appeals, viz., that the term "high vacuum" as used today means something different from what it meant before Langmuir's time.

Langmuir testified with reference to Lilienfeld's work as follows:[8]

> "Lilienfeld proved beyond question, I think, that he obtained discharges, in some cases at least, in which the effects that he measured *were not dependent upon gas ionization* * * *.
>
> "Lilienfeld probably succeeded in obtaining a discharge in high vacuum *substantially free from effects of positive ionization* in the device he described in his 1910 paper * * *.
>
> "Lilienfeld in his experiments of 1910 heated the walls of the vessel, he reduces the gas pressure to a

---

[8] Interf. Rec., pp. 1378, 1521, 1784, 1786.

low value, and in some of his experiments he heated his electrodes by electronic bombardment * * *.

"Heating of glass and electrodes, and exhaustion to low pressure, are elements which were used by Lilienfeld and were known long prior to Lilienfeld's article * * *.

"Factor No. 1 which I gave in answer to XQ84, viz., that the bulb should be heated during exhaust to a temperature materially higher than the operating temperature, was used by Lilienfeld in much of his work * * *.

"Factor No. 4, which is that which I gave in the first part of my answer to XQ87, refers to the lowering of the pressure to such a point that a further lowering brings about no further change. In many of Lilienfeld's experiments, this condition was realized".

Fleming.

Respondent claims no structural difference between a tube embodying the Langmuir invention and the Fleming valve. Indeed counsel for the Respondent admitted in open Court in response to a question by Judge MORRIS that the only asserted difference between them was in the degree of evacuation.[6] The Fleming publications disprove the existence of even this difference.

Fleming, the inventor of the Fleming valve, published many statements as positive as anything we find in the Langmuir patent, to the effect that the very highest vacuum possible was to be desired in such vacuum tubes. In his article,[7] he states:

---

[6] Rec., Vol. 3, p. 1528.

[7] Deft.'s Ex. No. 14, p. 144, Vol. 5, Rec.

> "An ideal and perfect rectifier for electric oscillations may, therefore, be found by enclosing a hot carbon filament and a perfectly cold metal anode *in a very perfect vacuum.*"

He also states (p. 144):

> "The bulb must be highly exhausted to about the pressure usual in the case of carbon filament incandescent lamps *and the metal cylinder or plate must be freed from occluded air.*"

In the Fleming patent No. 803,634,[8] it is stated (p. 158, l. 96):

> "As a *very high vacuum* should be obtained in the bulb (*a*) and as a considerable quantity of air is occluded in the conductors, *these should be heated when the bulb is being exhausted.*"

In Fleming's article of 1906,[9] Fleming states (p. 167):

> "Imagine a bulb of glass, made as in fig. 1 (see p. 165), containing two loops of platinum wire, or, better still, two carbon filaments."

This is the identical construction used by Langmuir in 1912, and which in the interference with Arnold he advances as embodying his invention. The Fleming article continues—

> "*Let this bulb be exhausted as completely as possible, so that in it the highest attainable vacuum is made. To achieve this, the filaments must be heated to bright incandescence, while the exhaustion is going on.* Having done this, if the secondary terminals of

---

[8] Deft.'s Ex. 15, p. 157, Vol. 6, Rec.

[9] Deft.'s Ex. No. 16, p. 165, Vol. 5, Rec.

> an induction coil are connected to the two separate filaments when cold, no discharge will take place across the vacuum between them; thus apparently showing that the space is a very perfect non-conductor."

Again he states (p. 174):

> "Let us define these conditions more closely. The vacuum is said to be low when the original normal air pressure in it is reduced to one-thousandth of an atmosphere, or it may be only one one three-hundredths. *It is said to be high when it is reduced to one hundred millionth of an atmosphere.*"

These Fleming articles are accurate descriptions of the Fleming valves which at the date of their writing were in actual use and have been used continuously since. The Court will readily recognize that the degree of vacuum specified by Fleming comes well within the most exacting limits advanced by Langmuir as embodying his invention. His one hundred millionth of an atmosphere is less than a hundredth of a micron, which compares favorably with the Langmuir patent's recital of "a few hundredths of a micron". The Court will further recognize that Fleming not only recognized the *desirability* of obtaining a high vacuum, *but recognized how to obtain such a vacuum.*[1] *The means for obtaining the high vacuum advanced by Fleming are the same as those described by Langmuir.*

Waterman's testimony to the effect that the Fleming valve had a very high vacuum and depended entirely upon the electron flow and not at all upon the residual gas, will be referred to later (p. 49 this brief) in discussing Respondent's new definition of the invention. Accordingly we shall not quote it here. We may, however, call attention to the fact that Waterman's testimony was given from first-hand experience with Fleming valves. He stated that he was familiar with these tubes, having used some supplied to him by the Marconi Company (owner of the Fleming patent) which had obtained them from the British Marconi Company, by which they were manufactured under the Fleming patent.[3]

---

[1] Chaffee, Q123, p. 65, Vol. 1, Rec.

From the foregoing we think it clear that the Langmuir patent application, especially as filed in the Patent Office, disclosed no new kind of vacuum, no new method of obtaining a vacuum, no new ideas as to the effect of residual gases in vacuum tubes and no new physical structure for vacuum tubes. The most that can be said is that present-day vacuum tubes of the kind here said to infringe, are exhausted more completely than were DeForest's early tubes, in order that they may meet present-day commercial requirements as to voltage and methods of use. That this is the limit to what can be said was conceded by counsel for Respondent in its brief before the Court of Appeals (p. 30) at the first argument in the following words:

> "On the other hand, the invention may be realized by "producing and maintaining", as the District Court put it, a pressure of a few thousandths of a micron in a DeForest audion".

This comes down to a mere difference in degree.

---

[3] Rec., Vol. 3, p. 1426.

Difference in Degree Not Patentable.

This Court, in a long line of decisions, has consistently held that mere variations in degree are not patentable:

Munson v. *New York*, 24 U. S. 601;
Milligan & H. Glue Co. v. *Upton*, 97 U. S. 3, 6;
Pearce v. *Mulford*, 102 U. S. 112;
Guiduet v. *Brooklyn*, 105 U. S. 550, 552;
Slawson v. *Grand Street*, 107 U. S. 649;
Estey v. *Burdett*, 109 U. S. 633, 640;
Burt v. *Evory*, 133 U. S. 349;
French v. *Carter*, 137 U. S. 239;
Ansonia Brass & Copper Co. v. *Electrical Supply Co.*, 144 U. S. 19;
Belding Manufacturing Co. v. *Challenge Corn Planter Co.*, 152 U. S. 100.

The sole exception to this rule is where the change in degree produces some wholly unexpected result causing the device to function in an entirely different manner.

The rule and not the exception applies in the present case.

The early DeForest audion amplifiers clearly operated without any harmful ionization when used with voltages suitable to the degree of evacuation, and that is all that can be said of the tubes alleged to infringe. When DeForest exhibited the amplifier to the Western Electric Company in 1912, it amplified the weak voice currents with great fidelity, according to the testimony of Jewett and Colpitts, who were experts in the art.[8]

---

[8] Rec., Vol. 1, p. 410, Q50; p. 497, Qs. 81, 82; p. 555, Q8.

Its perfect performance in amplifying the speech currents is proof positive that there was no harmful ionization. Actual use is the ultimate test on this point, from which there can be no appeal.

There is no question, therefore, that this prior art tube operated precisely as the patent says the patented tubes should operate, *i. e.,* by a grid-controlled space charge effect substantially unaffected by positive ionization. And no matter how far up along the scale of improved vacuum we go we cannot get any other kind of performance than that. The advantage of improving the vacuum lies not in getting a *new* kind of performance but in getting *more* of the same kind. That is, instead of getting this amplification with only a little electrical power, we can get it with a large power. *The patent itself, both in the specification and the claims, teaches that very thing* and speaks much more loudly than Respondent's counsel when they try to assert, without supporting evidence, that there is some sort of zero point or dead-line between the DeForest amplifier performance and that of more highly evacuated tubes. The specification of the patent, as we have already noted *supra* (p. 20), says that the degree of evacuation will be proportioned to the voltage it is desired to apply to the tube, and the claims describe the invention as including tubes performing at voltages all the way from 40 up to 200 or more. As shown above (p. 98) DeForest audion amplifiers were operated at voltages up to 50 and 60 volts. The patent claims might just as well have begun at 30 volts instead of 40. What Langmuir sought to do was to patent the use of vacuum tubes at any and all voltages above what he *then* knew was being used. Indeed, on January 29, 1917, Langmuir did add a claim numbered 25 directed to cover a tube deprived of sufficient gas to permit its use with 30 volts.[4] This claim was canceled July 30, 1925,[5] after he had apparently learned that audions had been used with 30 volts. He no doubt had no knowledge of the practice in California of using as high as 67½ volts or he would undoubtedly have canceled all claims for use of voltages below that amount.

In this connection, Respondent relies heavily upon an early statement or two of DeForest expressing the view that the operation of his audion was in some way affected by the residual gas. Well, DeForest was wrong (except to the extent that the detectors are even now considered somewhat better with a gas content). For a long time, it is likely, he did not altogether understand the scientific explanation of his own invention; and it was not required that he should. But that does not change the facts as now clearly established by the evidence. Respondent will admit that even Langmuir made some very serious mistakes in connection with the very patent application here involved, some of which we have already pointed out.

Since, then, the tubes now asserted to infringe operate like the old DeForest tubes except as to the amount of *power* some of them can handle, we think it clear that the patent, even considered in its most favorable light, is invalid as covering a mere difference in degree of vacuum.

---

[4] Rec., Vol. 6, p. 736.

[5] Same, p. 764.

The Lack of Invention Over the Prior Art Disclosures as Evidenced by the Attitude of the Experts of the Telephone Company and the General Electric Company.

As to the question whether the tube of the patent in suit presents any *invention* in view of prior art, we find a most unusual situation, and one of very persuasive force. The thing which is *now* asserted to be a wonderful and important invention was separately produced in 1912 and 1913 by two eminent engineers working in this art for two large industrial companies—Arnold of the Western Electric Company and the American Telephone and Telegraph Company and Langmuir of the General Electric Company—*and neither one of them thought at the time that he had made any invention at all.* Langmuir claims to have produced a tube of the kind covered by the patent before the end of 1912. He did not file an application for patent until late in 1913, and *then even it did not occur to him to claim such a tube as his invention. He claimed merely a specific process for exhausting gases from the contained electrodes* (bombardment without heating). Arnold produced the same kind of tube in the Fall of 1912. Neither he nor those associated with him in the Western Electric Company and the Telephone Company thought of looking upon it as an invention, and no application for patent upon it would have ever been filed by Arnold, had it not been learned that the General Electric Company was attempting to patent such a tube in Langmuir's name. Arnold, convinced of his own priority, then filed an application so that if a patent was to issue at all it should issue to the *first* inventor as required by law.

As we shall see in discussing the question of priority, both Arnold and Langmuir produced tubes, like those now said to infringe this patent, by starting with DeForest audions and improving the vacuum sufficiently to carry the desired loads without gas ionization, and it is quite evident that it seemed to each of them that in so doing he had merely employed obvious engineering expedients. Under these circumstances, one cannot escape the feeling that the idea of claiming such a tube as an *invention* arose later, only when someone awoke to the possibility of controlling the vacuum tube and dependent industries by means of a patent therefor.

It is therefore submitted that the Langmuir patent is invalid because it is anticipated and discloses no patentable invention.

POINT II.

The majority opinion of the Court below sustained the patent on an untrue definition of the alleged invention.

Gas as a Conductor.

In the petition for rehearing in the Circuit Court of Appeals, Respondent told the Court that Langmuir's invention was a tube in which he substituted a vacuum for the "column of conducting gas" upon which the Fleming and DeForest vacuum tubes depended.[8]

This was a brand new definition of the invention. In presenting it to the Court below, Respondent definitely meant, we think, to assert that the Fleming and DeForest tubes actually *did* depend upon a gaseous conductor, not merely that it was popularly *supposed* that they did. If it meant the latter, it was, of course, crediting Langmuir, not with producing a new *thing*, but merely with furnishing the true explanation of an *existing* thing; and the whole argument falls at once. Patents are not granted for new explanations. It was necessary to Respondent's new theory that it assert positively, dependence upon a gaseous conductor by Fleming and DeForest, and we find that it does. For example, on page 21 of its brief, upon the rehearing, it is stated:

> "The principle of the DeForest audion was conduction by a column of gas."

The majority opinion accepted the definition of the invention thus advanced, saying in so many words[9] "the

---

[8] Rec., Vol. 3, p. 2014.
[9] Rec., Vol. 3, p. 2028.

Langmuir tube is a tube in which for example the gaseous conductor incident to a Fleming valve and a DeForest audion is dispensed with and a vacuum substituted therefor", and upon the assumption that this was true, it found that Langmuir had made a patentable invention. Indeed, if we accept the definition, patentability follows almost as a matter of course, for to take an old combination and get the same or a better result by removing one of the elements is the very sort of thing generally accepted as involving invention. Such a simple and striking accomplishment might expect a ready allowance from the Patent Office.

But this definition is false, and with it must fall the entire theory upon which the Court found the patent valid. It is contradicted by the whole history of the Langmuir patent in the Patent Office and in this litigation, by undisputed scientific facts as to discharges in vacua, and *by the explicit testimony of Langmuir himself.*

The Fleming and DeForest vacuum tubes did *not* have a "conductor of gas", so that Langmuir could not have made an invention by taking it out. We shall show this in a moment out of Langmuir's own mouth, but first let us consider how incredible the assertion is upon its face.

Earlier Attempts to Define the Invention.

Note that this asserted substitution of a vacuum for an alleged "gas conductor" is not the invention that is claimed by the patent. The application for this patent was in the Patent Office twelve years. Most of that time was spent by counsel for Respondent in trying to show that there was *something* patentable in the case or trying to define the patentable thing to his own satisfaction and that of the Patent Office. The application was amended thirteen different times, involving no less than eighty distinct changes in the specification besides innumerable changes in the claims, and a total of sixty-two different claims were submitted at different times in an effort to avoid the prior art and to define a patentable invention. The changes involved in the repeated re-writing of the description of the invention, bulk one and one-half times the original specification. *If the invention had been the simple, clear cut thing we are now told it is, Langmuir would not have begun in 1913 by claiming an inoperative process of gas-freeing electrodes, and ended up in 1925 with thirty-two claims to something defined by references to a 3/2 power law, logarithmic plots and flat-topped temperature curves.* He would have received his patent in short order, and it would have had two or three claims to an audion, or like tube, with a vacuum in place of the gas conductor. *No such claims were ever presented to the Patent Office.*

In the early days in the Patent Office the Examiner of Interferences stated

> "A controversy has arisen as to just what improvement over the prior art is in issue * * * *Langmuir contends* it is a correlation of the physical structure of the tube with relation to the degree of vacuity, resulting in a new device."[9b]

But even after the twelve years in the Patent Office, Respondent's troubles in trying to define the invention were not over. When it came to try and argue this case, both the Trial Judge and the Court of Appeals had great difficulty in ascertaining from the patent claims and the general discussion what the invention really was, and counsel for Respondent was urged time and again to define it clearly and simply. As late as the hearing on appeal, the following was the best he could do:

[9b] Interf. Rec., p. 2476.

> "The Langmuir invention is a coordination of elements having a new functional relation between various factors, producing a new result. It is not a matter merely of maintaining a certain vacuum, far less of *producing* a certain vacuum which will be destroyed the moment the tube begins to operate. It involves primarily a relation between the shape, size and space relation or 'geometry' of the parts of the tube and the nature and pressure of the gas therein contained, coordinated and adjusted with respect to the conditions of the electric circuit."[a]

This rather appalling definition was written as late as 1928 and signed by the same attorney who prosecuted the Langmuir application before the Patent Office and who represented Respondent at the trial of this case.

To us it is past belief that, if the Langmuir invention really had consisted in removing a gas conductor upon which the DeForest tube depended, he would not have discovered that simple fact during his seventeen years' acquaintance with the case prior to 1930, when the new definition was first advanced.

Terminology as to Gas Conduction.

Respondent attempts to support its present assertion that the tubes of Fleming and DeForest depended upon a gaseous conductor (which Langmuir took out), mainly upon a loose terminology which grew up before anybody understood much about what went on in a hot cathode vacuum tube.

---

[a] Quoted by Judge Woolley (Rec., Vol. 3, p. 2060).

When Edison discovered in 1884 that a current would flow across a vacuum tube from a hot filament to a cold electrode, no one had ever heard of electrons. It was years thereafter before anyone could explain scientifically what happened in such a tube. They knew that there was some gas left in the tube (as there always must be), and that somehow the current got across the gap. Accepted electrical terminology as of that time, and indeed today, refers to anything that permits the passage of an electric current as a "conductor". Quite naturally, therefore, the attenuated residue of gas in vacuum tubes was referred to as a "gaseous conducting medium", and in the ordinary sense it is not at all an inaccurate name. It is *only* a name, however, *and in the sense just referred to applies just as accurately to the vacuum tube of the patent in suit as it does to the preceding vacuum tubes of Fleming, DeForest or Edison.* Everyone knows how terminology—right or wrong—persists once it is accepted and used for a while. For instance, we find that the Patent Office, as late as 1925 when the Langmuir patent issued, classified this very patent under the title "Detectors, *Gaseous Elements*".

It seems to us quite unjustifiable for Respondent to try to establish as a scientific fact that the Fleming and DeForest tubes depended upon "a conductor of gas" in a sense not applicable to later vacuum tubes, by quoting, as it did in the Court below, random cases where this terminology has been used in referring to the early tubes. In deciding the question whether the Fleming and DeForest tubes did have an actual "conductor of gas" in the sense that it was something Langmuir "left out" of his tubes, the Court will doubtless rely, not upon the mere matter of terminology, but upon the positive evidence which this record contains as to whether there is in fact such a difference.

Langmuir's Testimony as to Gas Conduction.

Langmuir himself has definitely testified that the residual gas in such tubes as Fleming's and DeForest's, even when there was enough to cause ionization, was *not* a "conductor" of the current. His testimony on this point got into the record because Langmuir in his application for this patent, as first filed, made the mistake (as is now admitted) of saying that the gas, at least if ionized, [illegible] act as a conductor. His statement there was:

> "The positive ions [gas molecules] *take part* in the conduction of current, giving at first erratic readings on measuring instruments connected in circuit".[1]

And, in the following paragraph, he stated that the "audion", the DeForest tube, was a device taking advantage of that phenomenon. This statement by Langmuir was one of several blunders he made in his early work along this line. *He was careful to cancel it before the patent issued and he entirely repudiated any theory of gas conduction in his testimony.* He was examined[2] with respect to the above quoted statement in his patent application and was asked whether the sentence would be true if it read

---

[1] Rec., Vol. 6, p. 663.

[2] Interf. Rec., p. 1775, XQ70.

"the positive ions take part in the conduction of current by *acting as conductors* or carriers of current." The answer he gave was:

> "In my opinion the sentence would have *no sensible meaning* if the word 'conductor' was left in *for it is inconceivable that ions could be conductors of current.* I will, therefore, confine myself to the case where the positive ions act as 'carriers.' With this correction I can say that *the statement would not have been true.*"

Note that Langmuir says that it is not "sensible" to use the word "conductors" as referring to the ionized molecules of the gas, because *"it is inconceivable that ions could be conductors of current."* Thus he emphatically rejects the use of the word "conductor" as applied to the gas in the sense of Respondent's belated definition. And he goes on to say that even construing the word conductor to mean carrier, still the statement is not true.

With Respondent's own witness Langmuir, the patentee himself, thus positively denying that the gas content, even when ionized, is a conductor of the current in a vacuum tube, we do not see how Respondent can be heard to assert the contrary. This seems to us itself entirely to dispose of Respondent's eleventh hour definition of the invention upon which it apparently now stakes its whole case.

The Prior Art on Conduction of Electricity by Gas.

Such being the fact about the gas content, it would make little difference whether Fleming and DeForest or those familiar with their vacuum tubes, *thought* that the residual gas was the conductor. Their theory as to that would be a *mere theory* as to the method of operation. As already mentioned, the patent law does not require an inventor to understand the scientific explanation as to how his device operates, nor does it provide for the granting of a patent merely for discovering the true method of operation of a known device.

There is no testimony in the record that either Fleming or DeForest ever purposely left a definite residue of gas in their tubes for the purpose of conducting the current or of making them operate. On the contrary, there is very definite evidence in the record that both Fleming and DeForest sought to obtain the best vacuum attainable with the exhausting apparatus available for commercial purposes. In Fleming's patent[3] it is stated:

> "As a *very high vacuum* should be obtained in the bulb (a) and as a considerable quantity of air is occluded in the conductors, these should be heated when the bulb is being exhausted" (p. 158, line 96).

In an article by Fleming[4] he states:

> "An ideal and perfect rectifier for electric oscillations may, therefore, be found by enclosing a hot carbon filament and a perfectly cold anode *in a very perfect vacuum.*"

In his article in the Scientific American Supplement of January, 1906, Fleming says that

> "a high vacuum may be a very good conductor provided that the negative electrode is rendered incandescent. This shows that the obstruction which a high vacuum offers to the passage of electricity is

---

[3] Deft.'s Ex. 15, Rec., Vol. 6, p. 157.

[4] Deft.'s Ex. 14, Rec., Vol. 5, p. 144.

> not due to the mere reduction of the matter in the space (that is, to the rarifaction of the gas), but is in some way or other, largely dependent upon the temperature of the electrodes; the resistance to the passage of electricity through a vacuum can be rendered very small by intensely heating the negative electrode."[5]

In this same paper he says that by certain experiments he is able to show that the highest vacuum producible may be "a very good conductor", and describing the experiments in question he says:

> "Let this bulb be exhausted as completely as possible, so that in it the highest obtainable vacuum is made. To achieve this, the filaments must be heated to bright incandescence while the exhaustion is going on."

This aptly illustrates the point we made above about the meaning of the word "conductor" as hitherto applied to a vacuum, and illustrates as well how insistent Fleming was upon the highest vacuum obtainable even when he referred to the residual gas as a "conductor".

Certainly Fleming was not intending to leave any gas in the tube in order that he might use it to "conduct" the current, as Respondent would have us believe.

The testimony of Waterman given in a suit by the Marconi Company against the DeForest Company and stipulated into this case[6] fully confirms these facts about the Fleming tube. He said (p. 1487):

> "I think I forgot to say yesterday that the action which Fleming was talking about was one which

---

[5] Rec., Vol. V, pp. 167, 168, 169.

[6] Rec., Vol. 3, pp. 1485 *et seq.*

> would take place to best advantage in a *perfect vacuum,* any space containing *no gas whatever,* because the electrons which Fleming referred to are derived from the filament."

And, again (p. 1488):

> "The action is, as Fleming stated, purely electronic, an action which gives us conductivity as the result of electrons emitted from the filament, and not as the result of any matter contained in the space surrounding the filament."

And, again (p. 1488):

> "But one thing is very conclusively established, and that is that the action which takes place is an electron action just as Fleming said it was, and as most of the writers agree with this, and that is shown by the fact that the same action takes place exactly if we make bulbs which have what is now called the absolute vacuum which means a vacuum so high that no known test will reveal any attribute of gas."

There is similar evidence that DeForest did not depend upon gas as a conductor and did not intentionally leave it in the tubes (although he may have purposely selected the more poorly exhausted tubes for "detectors" for reasons already indicated). In 1912 DeForest, then with the Federal Telegraph Company in California, wrote to the McCandless Company in New York, the manufacturer of his audion tubes, saying:

> "Out of the last lot of 24 audion bulbs which you manufactured for us there are only [illegible] that came up to proper sensitiveness test. *Apparently the vacuum in the other bulbs is too low,* because in these latter

> bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive''[7]

And the following month he wrote:

> "We took two of the poorest of the discarded 20 to a San Francisco glass-blower, unknown to fame, *and had him exhaust same to as high a vacuum as his pumps would take.* These reexhausted bulbs now show a sensitiveness equal to those of the first four, *which proves conclusively that our contention is correct.*"

Respondent's own witness Hogan testified concerning the DeForest tubes in a suit brought by Hewitt against the American Telephone and Telegraph Company, and he reaffirmed and adopted that testimony in this record.[7a] The Telephone Company was using high vacuum tubes corresponding entirely to those asserted here to infringe. Hogan having testified that he was familiar with the DeForest tubes, was asked to state how they "differed from the Telephone Company's tubes". He answered (p. 119) that the "Telephone Company's devices were much more highly evacuated than are most audions", and continued (p. 120):

> "In regard to the relation of defendant's vacuum tubes and the audions of DeForest, I believe that the residual gases must play some part in the operation of both and that the magnitude of the part played in either will be determined by the particular design, voltage and exhaustion used, and that there is no strict line of demarcation between them.

---

[7] Deft.'s Ex. 79A, Rec., Vol. 6, p. 1061.

[7a] Rec., Vol. 1, pp. 101-118.

> "Tubes made by the defendant's company amplify, and audion tubes made by DeForest amplify, and I do not think that you can set one of them on one side of the fence and say, 'They are audions' and the others on the other side of the fence and say 'they are defendant's vacuum tubes which are quite different things.'"

In the *Marconi-DeForest* case above referred to,[8] Judge MAYER had to decide, among other things, whether the DeForest tube contained gas which affected its characteristic operation. His conclusion was:

> "If anything was shown in this record, it was rather, as plaintiff contends, that the device [DeForest's tube] operates in spite of, and not because of, ionization by impact."

In support of its new definition of Langmuir's invention, Respondent attempted below to create the impression that Langmuir was indeed the first one to discover that a current could be made to flow in an extremely high vacuum without dependence upon a gaseous medium. The testimony in the case shows that this is far from the fact. Langmuir himself testified:

> "Lilienfeld proved beyond question, I think, that he obtained discharges, in some cases at least, in which the effects that he measured were not dependent upon gas ionization.[9]
>
> "Lilienfeld probably succeeded in obtaining a discharge in high vacuum substantially free from effects

---

[8] 236 Fed. 942, 954.

[9] Interf. Rec., p. 1378.

of positive ionization in the device he described in his 1910 papers."[1]

Lord Kelvin in 1904 made a very careful statement summarizing the scientific facts as of that day in the following language:

> "The labors of many experimenters during the last fifty years, and the comparatively modern atomic theory of electricity, have thoroughly confirmed the view that the space of our best modern vacua, interstellar and interplanetary space, and generally, space occupied only by the luminiferous aether is a very perfect non-resister of electricity passing through it".[2]

Von Baeyer, who takes high rank in the scientific world (Interf. Rec., p. 868), stated in 1909, referring to his own work with electric currents through vacuum tubes:

> "These experiments were of course carried out in the highest possible vacuum to avoid the influence of ionization".[3]

In support of its new definition of the Langmuir invention, Respondent's counsel also referred to an advertising circular of the DeForest Company, put out in 1919. They refer to this to prove that DeForest tubes were inoperative where the vacuum became too good, thus indicating that they depended upon a "conductor of gas"; and the majority opinion below apparently leaned rather heavily upon this circular, referring to it as showing "that gas was an element of operation" in the DeForest tube.

---

[1] Interf. Rec., p. 1521.

[2] Rec., Vol. 5, p. 171.

[3] Rec., Vol. 5, p. 284.

The circular was not put in evidence for such purposes, and does not prove the point. It was put in by Respondent through the testimony of Mr. Hogan, being one of a number of circulars, catalogues, etc., used by him to show sale by the DeForest Company of various types of tubes.[4] *Hogan did not testify that these tubes required a "conductor of gas" or that it was a necessary element in their operation.* He testified, quite to the contrary, that the DeForest tube and the so-called high vacuum tube were the same in principle, as shown by the above quotations from his testimony (p. 51). No one from the DeForest Company responsible for the circular was put on to testify or be cross examined as to the statements contained in it. It has no more standing here than any other trade circular manifestly put out to promote the sale of goods. It is obviously designed to impress prospective purchasers with the idea that the new tubes are much better than the old. It does *not* say that the old tubes depended upon a "conductor of gas". Its reference to former tubes becoming inoperative when they became too "hard" (high in vacuum), can refer only to "detector" tubes of which it is measurably true for reasons indicated above. It could not apply to amplifier or other tubes because the very next sentence of the circular says that the tubes whose sale it is boosting are "purely electronic", "exhausted to a very high vacuum", which, by the same sign, would make *them* inoperative.

Indeed, it appears to us rather fantastic for Respondent to say, as in effect it does, that if the vacuum in a DeForest tube was made better by him or became better in use, the tube was no longer operative, but that if it was made better by Langmuir, the usefulness was greatly increased.

---

[4] Rec., Vol. 3, pp. 1623-1633.

It is apparent therefore that the theory and definition of the Langmuir invention upon which the decision of the Court of Appeals is based is not only unsupported by any evidence in the record, but is flatly contradicted thereby and expressly repudiated by Langmuir himself. The judgment of the Court should therefore be reversed on this ground alone, if for no other.

POINT III.

If the subject matter of the patent in suit involves patentable invention, then Dr. Arnold was the first inventor thereof and not Dr. Langmuir, the patentee.

Judicial Consideration Given Heretofore to this Question.

This defense was sustained by the District Court and by Judge Woolley, and is not referred to in the majority opinion of the Court of Appeals.

The alleged invention of the patent in suit was anticipated by the work of Dr. H. D. Arnold of the Telephone Company, who prior to Langmuir, produced vacuum tube amplifiers which were unquestionably of the kind now asserted to infringe, and therefore the patent is void. This was one of the main defenses presented at the trial of this case, in which more than three weeks were devoted to testimony on this one point. Although this defense was separately considered and sustained by the Trial Court, the majority opinion of the Court of Appeals entirely ignores it.

This question of priority between Arnold and Langmuir was the subject of an Interference in the Patent Office, and is still pending in a proceeding under Sec. 4915 R. S. in the Southern District of New York.[1]

The patent in suit was issued to Langmuir as the result of an award of priority to him in the interference, by the Court of Appeals of the District of Columbia. That decision reversed the decision of the Commissioner of Patents who had awarded priority to Dr. Arnold. The opinion of the District of Columbia court covers less than four pages including quoted claims,[4] and itself gives no reasons at all why the award should go to Langmuir. After very briefly relating the history of the case, it merely accepts without comment, the decisions of "the lower tribunals" (the Examiner of Interferences and the Board of Examiners-in-Chief) who had found for Langmuir, because, as the court put it, those decisions "are so clear and satisfying" that it was content to rest its opinion "upon the reasoning there given", apparently quite overlooking the fact that these lower tribunals were poles apart in their "reasoning" and in their rulings as to the effect to be given to the different steps in the work by Arnold and Langmuir respectively. For example, the Board found that Langmuir conceived the invention in August and reduced it to practice in November, 1912, while the Examiner of Interferences held that neither his August work nor his November work showed even a conception of the invention, but found that he conceived and reduced to practice in April, 1913. As to Arnold, the Examiner of Interferences refused to hold his disclosure of November 1st, 1912 effective to prove conception of the invention because of an odd theory he indulged that, as to this particular invention, conception and reduction to practice must have been simultaneous, while the Board held the disclosure sufficient except for the fact that they were not sure that Arnold knew how to get the vacuum he proposed to use in the audion.

---

[1] As this present suit was brought on for trial before the proceeding under Section 4915 R. S. could be heard, and as the Petitioner here had pleaded in this suit that Arnold was the prior inventor of the alleged invention of the patent and thus the issue of priority between Arnold and Langmuir would be tried and passed upon in this case, the American Telephone & Telegraph Company, which owns the Arnold application, offered to assist the Petitioner in the presentation of the priority issues before the District Court. This offer was accepted by Petitioner and the priority issue was very largely handled by counsel for the Telephone Company in both the District Court and the Circuit Court of Appeals, as it is being in this Court (Rec., Vol. 1, p. 399). Meanwhile the case under Sec. 4915 has not yet been tried. Of course, if the priority issue had been inadequately presented by lack of evidence or otherwise in this proceeding, there might have been a decision adverse to Arnold. Such a decision, coupled with that of the Court of Appeals of the District of Columbia, would have made it difficult for the Telephone Company to succeed in the suit brought under Section 4915 R. S. It was therefore advisable for that Company for its own protection to assist in this suit.

[4] Rec., Vol. 4, pp. 41-44.

These holdings of the "lower tribunals" were not only divergent (as stated above), but were in the main erroneous both in law and in fact on the evidence presented at the trial of the case, as we shall point out below (pp. 63 *et seq.*).

At the trial of the case before Judge MORRIS, a very large amount of testimony as to Arnold's priority was introduced which was not before the Patent Office and the Court of Appeals of the District of Columbia. It covered important points in the case for Arnold upon which one or more of the Patent Office tribunals had expressed doubt, as for example, whether Arnold did in fact know how to get the desired vacuum at the time of his conception of the improved tube in November, 1912. Altogether, the Petitioner examined eight witnesses and the Respondent six witnesses on this question of priority, and their testimony comprises a large portion of the printed record. It is in addition to the testimony taken in the Patent Office Interference, which was also introduced in evidence in this case.

In connection with this branch of the case we believe that the decision of the Commissioner of Patents in the Interference proceeding, which is remarkable for its clarity, and the decision of Judge MORRIS upon priority, rendered as it was in the light of the additional proofs, will be of material assistance to this Court, and we commend them to its consideration. These decisions will be found printed in separate pamphlets for the court's convenience. The decision of the Commissioner is also found in the Interference Record, the part we particularly refer to beginning at page 2514, and Judge MORRIS' opinion will also be found in Vol. 3 of this record, pages 1966 to 1969.

The Supposed Invention Involved in the Priority Issue.

It is usually difficult to decide priority of invention without knowing quite definitely what the invention is; and when we say "invention" we mean the thing as to which priority is in dispute, without implying anything as to its patentable quality.

In the present case, as we have seen, Respondent itself has never been able to state clearly and briefly what the supposed invention is. However, from the evidence we shall consider below, it will be quite clear that whether it be as stated in the eleventh hour definition presented by Respondent at the rehearing, or what the Commissioner of Patents said he would assume it to be for the purposes of deciding priority, or however it be defined, *Arnold was the first to produce it.* The Commissioner of Patents evidently doubting the presence of invention at all but, under the Patent Office practice, assuming invention for the purposes of deciding priority, expressed it as follows:

> "It will be seen that the present invention lies not in discovering or producing something new, but in perceiving the practicability of scientific facts known in the laboratory, and in making practical, useful devices embodying the scientific laws known in the laboratory".[4a]

When we come to the evidence in the case it will indeed become clear that what both Arnold and Langmuir *actually contributed* in this connection, was precisely the suggestion that the usefulness of the DeForest audion be extended by the application of certain known facts concerning thermionic discharges in vacua.

The simple fact is that, under *any* definition, an old DeForest audion pumped a little cleaner, especially as to the walls and electrodes, is a tube of the Langmuir patent; no other change is necessary. There is no dispute about this,—it is admitted by the Respondent.[5]

[4a] It is interesting to note that even *this* is not patentable to the newcomer in the field (*Corona Cord Tire Co.* v. *Dovan Chemical Corp.*, 276 U. S. 358).

[5] See page 35, *ante.*

Arnold's Work.

Conception and Disclosure of the Invention by Arnold.

The evidence shows that Arnold was sought out and employed by the Western Electric Company officials in 1911 because of the extensive training and experience he had had in the field of electrical discharges in vacuum,[6] and for the express purpose of designing a repeater[6a] for telephonic purposes. The Telephone Company had shortly before committed itself to the furnishing of transcontinental telephone service by the time the San Francisco Exposition was supposed to open in 1914, and its engineers knew that this would require the production of a telephone repeater quite different from anything then in sight, and probably employing some form of vacuum or gaseous discharge.[7]

President Vail of the Telephone Company had placed Dr. Frank B. Jewett in charge of the technical development work for this projected New York-San Francisco telephone line. Dr. Jewett was then Assistant Chief Engineer of the Western Electric Company in charge of its research and development work, the Western Electric Company being the manufacturing subsidiary of the Telephone Company. Under Dr. Jewett was Dr. E. H. Colpitts, directly in charge of the Research Laboratory of the Western Electric Company. In more recent years this laboratory has been separately organized as the "Bell Telephone Laboratories, Inc." Both Dr. Jewett and Dr. Colpitts were highly proficient as telephone engineers, and as theoretical and practical physicists.[7a] Under Dr. Colpitts was Dr. Arnold.

---

[6] Rec., Vol. 1, pp. 404 *et seq.*

[6a] The farther the speech modified electric currents go on their way from the transmitter at one end to the receiver at the other end in a long distance telephone conversation, the weaker they get. A "repeater" is a device interposed in a long telephone line which receives the weak telephone currents on the input side and sends out corresponding strong currents on the output side. In present day practice there may be a score or more of such repeaters at regular intervals in a telephone line extending as far as from New York to San Francisco.

[7] Rec., Vol. 1, pp. 402-404.

For nearly two years prior to his conception of the present invention, Dr. Arnold had been working upon this telephone repeater problem for his employer and had about perfected a very satisfactory, though comparatively complex repeater element of the vacuum type using mercury vapor.[8] On November 1, 1912, he first saw a DeForest audion set up ~~an an~~ amplifier. DeForest himself had brought the apparatus to the Western Electric Company two days earlier and demonstrated it to Dr. Jewett and Dr. Colpitts, officials of that Company, in the hope of selling rights under his patents to the Company. Both Dr. Jewett and Dr. Colpitts were electrical engineers of high standing and long experience, and were quite capable of appreciating the virtues and defects of the audion, but they did not know what the defects were due to or how to remedy them. For the purpose of appraising the possibilities of the audion they turned to Dr. Arnold because of his specialized training in this field.

On November 1 Arnold was called in, and in company with Colpitts and Jewett, he examined and tested the audion amplifier as an amplifier of speech currents. All three were impressed with its remarkable performance on weak speech currents.[9] All saw its defects when larger currents were applied; it would then choke or distort the speech, sometimes showing a blue haze in the discharge space. To all three it was clear that these limitations made it unsuitable for telephone work, as it then stood.[1]

[7a] See Rec., Vol. I, pp. 396 *et seq.* and 482 *et seq.*

[8] Rec., Vol. 1, p. 495, Qs. 64, 65.

Then and there Arnold saw the cause of the trouble and named the cure. He said they would make the vacuum better and so eliminate these erratic ionization effects at the heavier currents.[2] He made other suggestions as to better filaments and better mechanical structure but these have nothing in particular to do with the patent in suit. When, however, Arnold said to make a telephone repeater by taking the physical structure of the audion and improving the vacuum so as to eliminate the ionization, he had in mind, and disclosed to his associates, a complete conception of the invention,—it was this idea to which we referred above, of accomplishing a definite, useful purpose by the application of principles then known to him, governing thermionic discharges in vacua. A DeForest audion more completely evacuated is, as above noted, admittedly a tube within the Langmuir patent.

It is highly significant that within a few days Dr. Arnold also made a thorough disclosure to Dr. Colpitts of the fundamental operating principles of the audion when it operated with a substantially perfect vacuum. It came about in this way. Colpitts questioned whether the electrons would be emitted from the hot filament if the vacuum were substantially perfect, that is he questioned whether some gas might not be necessary for the emission of the electrons. Arnold informed him that this question had been faced and settled by the scientific world, and that electrons undoubtedly would be emitted from the hot cathode in the absence of gas. Colpitts went on and questioned further why the electrons, if emitted, would not all easily rush across the space when only a volt or so of positive potential was applied to the plate; thus keeping the power output of the tube too low to be useful. In other words, if the electrons were emitted so easily why should any considerable voltage be necessary merely to move them across the empty space from the hot cathode to the cold anode? In reply to this question Arnold explained to him the space charge effect, the mutual repulsion [illegible]tween the electrons by which those ahead in the stream tended to push those behind back into the hot cathode, whence they had issued. To overcome this space charge effect a substantial voltage must be applied.[24] According to Langmuir this space charge effect is the fundamental principle of the invention.[25]

---

[9] Rec., Vol. 1, p. 410, Q50; p. 497, Qs. 81-82; p. 555, Q8.

[1] Rec., Vol. 1, p. 417, Q83; p. 500, Qs. 99, 104, 105; p. 599, Q11.

[2] Rec., Vol. 1, p. 559, Arnold, Q11; p. 501, Colpitts, Qs. 107-113; p. 413, Jewett, Q67.

The Examiners-in-Chief in the Patent Office recognized Arnold's disclosure to Jewett and Colpitts as a complete disclosure of the invention, but refused to give Arnold the benefit of it for proof of conception, because they were not they said, convinced he knew how to get the necessary vacuum.[3] Here they were wrong both on the law and the facts. There is no rule of law that requires an inventor to have in *himself* the knowledge and skill to physically produce his conceived invention. The physical construction may, and frequently will, require a technique known to comparatively few; but obviously the inventor's conception is completed when his *idea of the thing to be constructed* is complete and he knows its useful application to the arts. Any other rule would be absurd. Was the DeForest audion patent, one of the greatest and most useful inventions of all time, invalid because, forsooth, DeForest was not a glass blower and so not himself possessed of the skill or knowledge necessary to construct the thing?

---

[24] Rec., Vol. I, p. 503, Qs. 115a to 124, p. 415, Q71.

[25] Interf. Rec., p. 1936, line 7 from bottom.

If the inventor also devised a new method of manufacturing the device, that would be another and separate invention.

The Commissioner noted and disposed of the Board's error as follows:[4]

> "If I say a rubber button is a good thing to use in a hose supporter, I have conceived the button, even if I do not know how to make such a button. I may go to a rubber manufacturer and have him reduce my invention to practice and it will be my invention. So here, one skilled in the art could produce the device in issue as soon as told to do so by Arnold";

and he cites, *McCormick Harvesting Machine Co. v. Minneapolis Harvester Works*, 42 Fed. 152-155, where it was said:

---

[3] Interf. Rec., p. 2506.

[4] Interf. Rec., p. 2519.

> "He who first conceives and gives expression to the idea of an invention in such clear and intelligent manner that a person skilled in the business could construct the thing, is entitled to a patent provided he uses reasonable diligence in perfecting it".

However, the fact is that in *this* case, Arnold *did* know how to get the necessary vacuum. This was proved, beyond any doubt, by the new evidence taken in the Trial Court to supply what the Board thought was lacking.

Getting the necessary vacuum for the patented tubes, admittedly involves nothing in addition to the use of the usual pumping equipment, except expulsion of the occluded gases by some form of heat treatment of the walls and electrodes. The patent itself suggests nothing else.

Dr. Millikan, one of the greatest of living physicists, testified most positively and in detail that he taught Arnold to heat tubes under evacuation in an oven and to heat the electrodes by bombardment, for this purpose, while Arnold was at the University of Chicago from 1907 to 1910, inclusive. This was done in connection with a pumping system using liquid air, usually charcoal and liquid air, so that the very highest vacua could be obtained.[5] The process then taught Arnold would have been entirely sufficient to exhaust audions so that they would operate at 100 or 200 volts or higher without harmful ionization.[6] As we have already seen, the prior literature told of baking and bombardment during evacuation and Millikan taught Arnold these matters from the literature as well as by actual direction of his work.[7] Moreover, Arnold had himself been practicing baking and electrode bombardment in the evacuation of his mercury vapor repeaters at the Western Electric Company Laboratories, for over a year, prior to November 1, 1912.[8] That problem of evacuation was quite as difficult as the evacuation of a high vacuum audion, because, while he purposely retained mercury vapor, *all* other gases had to be removed, not only from the space but from the walls and the electrodes.[9]

---

[5] Rec., Vol. 1, p. 442, Qs. 9, 10.

[6] Rec., Vol. 1, p. 448, Qs. 20, 21, 22; p. 457, Qs. 38, 39, 40.

So when Arnold said he could make a good telephone repeater out of the DeForest audion by so improving the vacuum as to get rid of the gas which caused the ionization effects he and Jewett and Colpitts had observed at the higher current values, there can be no question,—on any theory,—that he had a complete conception of the thing in issue.

And this disclosure by Arnold, be it observed, does not stand on his testimony alone, but is vouched for by both Jewett and Colpitts, to whom it was made,—men of the highest professional standing and personal character. Moreover, connected as it was with the trans-continental telephone project, and with their first experience with that marvelous instrument, the audion, it is a thing they would never forget. The disclosure is furthermore confirmed by the contemporaneous written records of the 7-A audion and the derivation of the 3/2 power law by Arnold, and by the whole course of conduct of the Telephone Company thereafter.

---

[7] Rec., Vol. 1, p. 458, Q41.

[8] Rec., Vol. 2, p. 746, RDQ723; Vol. 1, p. 584, Qs. 33-34; p. 490, Qs. 45 to 56.

[9] Rec., Vol. 1, p. 572, Q21; p. 583, Q31.

Events After Arnold's Disclosure of the Invention.

The disclosure of this conception by Arnold so convinced and impressed his superiors Colpitts and Jewett, that he was at once given the job of carrying it into effect, together with the other improvements,—in filaments, etc., necessary to make a commercially practical telephone repeater;—likewise, the job of fitting it to the telephone plant, which, in itself, was a task of some magnitude.[2]

Immediately after November 1, 1912, the character of Arnold's responsibilities was changed. Instead of working at the laboratory bench, he was put at a desk and given supervision of the work of others. A number of assistants were assigned to him—some especially employed for the purpose.[3] Negotiations and patent investigations were started with a view to acquiring rights under the DeForest patents which would enable the Telephone Company to put audion repeaters into the plant.[4]

All these things show that Arnold's suggestion for improvement of the audion was not a mere passing remark falling unnoted in the course of routine business, but on the contrary, *marked a turning point in the affairs of the department working upon repeaters,*—and for the reason that it convinced those in charge that the audion, then unsuitable for telephone use, could indeed be made practical for that purpose in the way outlined by Arnold.

Work upon this project was begun at once by Arnold and his assistants, and continued without interruption up to the following October when the high vacuum repeaters began to go into commercial use in the telephone system,—the license from DeForest having been secured near the end of the preceding July.

---

[2] Rec., Vol. 1, p. 418, Qs. 86 to 91; p. 508, Qs. 138, 145, 146; p. 595, Qs. 51, 52.

[3] Rec., Vol. 1, p. 508, Qs. 139, 140; p. 594, Qs. 49, 50.

[4] Rec., Vol. 1, p. 422, Qs. 92 to 95.

In considering this work, it should be remembered that what Arnold set out to make was a practical telephone repeater, not merely a tube embodying the supposed invention here in issue. There is a big difference. It would have been very easy for him with his then knowledge and experience, to have taken an audion and improved its vacuum so that it would have embodied every claim in the Langmuir patent, and still it would have been far from ready for telephone repeater use; and, moreover, it would have taught him nothing, and advanced his work not at all. The tube needed also to have its electron emission improved and its filament life lengthened and its internal impedance made right and its mechanical structure improved before it could go into the telephone plant. So what Arnold worked toward was a *practical, commercially useful* embodiment of this high vacuum idea for a very definite purpose, not merely a laboratory demonstration of it.

During November and December, 1912, Arnold had extensive tests made on audions to determine their operating characteristics and efficiency. He made plots of his data, and one of these[5] shows the relation between current and voltage by an exponent of 1.59—rather close to the theoretical exponent 1.5 of the 3/2 power law which the patent says characterizes the invention in issue. Also he worked out mathematically the theoretical 3/2 power law covering this relation, late in December—some weeks prior to the time it was first deduced by Langmuir.[6]

---

[5] Sketch E. S. 87498 in Deft.'s Ex. 245.

[6] Rec., Vol. 1, p. 506, Qs. 126 to 134; Vol. 2, p. 1186.

In December, 1912, Arnold made a mathematical study of "Efficiency of the Audion", which was recorded by his assistant Pierce. More particularly, this was a precise ascertainment of the law of the marvelous "grid" effect by which slight variations of voltage in the grid circuit produce corresponding, but much larger, variations of current in the plate circuit. It was the *first calculation ever made by anybody of how an audion works.* This study was premised definitely on the assumption of high vacuum. When the theoretical part of the study was completed, Arnold directed Pierce to make comparison with an actual case of amplification of voice currents. This was done with Audion 7-A and the agreement was remarkably close.[6a]

This piece of work shows Arnold's penetrating understanding of the principles of the high vacuum audion and is one of the many items of his activity falling between his conception of the invention and its introduction into commercial use.

A new Gaede molecular pump was ordered by cable from Germany at his request in January, 1913, after he had failed to locate one in this country. From January to April, one of his assistants, Trimble, was working on the mechanical construction of tubes, experimenting with tantalum filaments,[7] and another assistant Nicholson, was working upon the Wehnelt oxide coated filaments,[8] which eventually were adopted. Also, during this time Arnold visited Princeton where a Gaede molecular pump was in use, and took measurements so that the proper base and driving mechanism might be ready when their own pump arrived.[9] Also a new type of instrument for measuring vacuum was designed and constructed,—one which would not introduce mercury vapor.[1]

[6a] Deft.'s Ex. 247, formerly Arnold Priority Ex. 10; Interf. Rec., pp. 2185 *et seq.;* Deft.'s Ex. 244, former Arnold Priority Ex. 7, p. 41 bottom.

[7] Rec., Vol. 2, p. 661, XQ323; p. 748, RDQ26.

[8] Rec., Vol. 1, p. 614, Q91.

When the new pump came in April, 1913, it was tested for performance by using it to evacuate several tubes upon which they had been or were then experimenting.[2] It was found to give good results. On it they produced vacuum tubes capable of carrying high voltages without ionization effects, as we point out below.

Nicholson's work on the oxide coated filaments was interrupted for a month or so, beginning about the first of March, by his assignment to work with some German inventors, who had come over to demonstrate the Von Lieben-Reisz-Strauss tube as a repeater. Thereafter, his work on audion filaments was resumed and continued on through the summer.[3] The license from DeForest was secured in July, after considerable delay due to involved title and other complications.[4] The same month, the manufacture of tubes intended to go into actual telephone use was commenced.[5]

Arnold was ill and away during August and September and Kendall was assigned by Colpitts, about the middle of August, to make up and install a repeater (amplifier) set in the toll lines at Philadelphia,—this work to begin as soon as Kendall returned from his vacation about September 1,

---

[9] Rec., Vol. 1, p. 609, bottom.

[1] Rec., Vol. 1, p. 609, middle.

[2] Rec., Vol. 2, p. 755, RDQ734; Interf. Rec., Arnold, p. 50.

[3] Interf. Rec., Nicholson, pp. 2251-2; Trimble, p. 2248.

[4] Rec., Vol. 1, p. 422.

[5] Interf. Rec., Arnold, p. 53—top; Trimble, p. 2248—middle.

1913. Experiments with the improved audion repeaters in the toll lines between New York and Washington were begun at Philadelphia, September 5, 1913,[6] and a field trial under commercial service conditions was begun October 18, 1913.[7] Such repeaters have been in continuous and increasing use ever since. The following summer they were put into the new trans-continental telephone line.

During this period from November, 1912, to October, 1913, while the DeForest audion was being converted into a condition suitable for a commercial telephone repeater, there were at least three occasions, probably more, when there was an actual reduction to practice of the high vacuum improvement here in issue. Once in November when a "clean-up" of the residual gas was effected in one of the DeForest tubes ("7-A Audion"); again in April and May, 1913, during the try-out of the new Gaede pump when a number of the audions evacuated showed good vacuum and no ionization effects under high voltage tests; and again in September and October, in tubes built for and used in commercial service at Philadelphia.

It really makes no difference at all which of these dates is considered Arnold's date of reduction to practice, for he was abundantly diligent at all times from November 1, 1912, on; so that under the familiar rule,[8] his effective date of invention, in any case, becomes November 1, 1912, when the improvement was conceived.

We refer briefly to each of these occasions.

---

[6] Interf. Rec., Kendall, p. 2257, middle.

[7] Interf. Rec., Kendall, p. 2259.

[8] The first to conceive is the first inventor, if he proceeds thereafter with due diligence to a reduction to practice. This rule is recognised by Respondent itself (p. 215 of its brief before the District Court).

November, 1912—Audion 7A.

Audion 7A was a reduction to practice of Arnold's conception of November 1, 1912, and occurred the same month. This was one of the original DeForest Audions (No. 7) in which the vacuum was improved by certain experiments which Arnold had performed upon it.[*] During these experiments the impressed voltage, in a long series of runs, was forced higher and higher, and eventually one of its two filaments was burned out (after which it was called 7A). From these things there resulted a "clean-up" of gas within the tube like that well known in electric lamps from the burning of the filament[*] and akin to that referred to by Langmuir in connection with his own experiments of November, 1912.[1] It is true that in this work, Arnold was primarily interested in discovering the characteristics of the tube when operating with a pure electron discharge and the "clean-up" was in a way incidental.[2] But this makes no difference. Assume that it was wholly *accidental*. The only important facts are that a proper vacuum was attained and that *Arnold recognized its presence and effect.*[3] On this point the testimony is quite clear. Arnold knew that the clean-up was going on; knew why it was going on and knew that it was giving him freedom from ionization effects at higher and higher voltages.[4]

Audion 7A, after the clean-up, was in fact so clear an embodiment of the supposed invention that there can be no real question on the point. It stood plate voltages up to 80 volts without any evidence of ionization.[5] The patent claims cover anything down to 40 volts. Compared with a General Electric tube of 1919, it gave almost the same logarithmic plot up to 81 volts on the plate, with a plate current of 3 milliamperes.[6] The fact that so clear an embodiment of the subject matter of the patent could be obtained so simply from one of the prior DeForest audions does not alter the fact that this was plainly a reduction to practice of the thing covered now by the patent in suit, and establishes Arnold's priority as against Langmuir.

---

[*] Rec., Vol. 1, p. 602, Q59.

[1] Rec., Vol. 2, p. 1140.

[2] Rec., Vol. 2, p. 758, Q743.

[3] Robinson on Patents, Vol. 1, Sec. 83, p. 126, and Sec. 79, p. 121 and cases quoted this brief, pp. 61 *et seq.*

[4] Rec., Vol. 1, p. 596, Q52; Vol. 2, p. 763, end of Q747; p. 758, end of Q743; p. 736, XQs. 680, 688.

The April and May Tubes.

Even the lower Patent Office tribunals which decided against Arnold, found that tubes made under his direction in April and May, 1913, were embodiments of the improvement in issue. The Examiner of Interferences and the Examiners-in-Chief, both gave him a reduction to practice as of this period.

These tubes were evacuated on the new Gaede molecular pump which is the one suggested by the patent in suit.[7] During evacuation they were thoroughly heat treated to remove all occluded gases, the glass by baking, the filaments by glowing, and the other electrodes by bombardment under voltage up to 300 volts which is higher than would be applied in use.[8] *These are precisely the precautions and the*

---

[5] Interf. Rec., p. 2183, top; Rec., Vol. 1, p. 603, Q63.

[6] Deft.'s Ex. 246—Interf. Priority Ex. 9, Interf. Rec., p. 2183, bottom; Rec., Vol. 1, p. 602, Q60.

[7] One of them was made earlier on the Gaede mercury pump but tested in April.

[8] Interf. Rec., pp. 2276 to 2278, 2247, 2191; Rec., Vol. 1, p. 618, Q98.

only precautions taught by the Langmuir patent application.

The testimony, fully supported by contemporary written records, shows that when one of these tubes, audion 20.2, was tested *as a voice amplifier, it multiplied the power 26 times, with 69 volts in the plate circuit.*[9] The witnesses say the quality was good on that occasion,[1] and there is no evidence to the contrary.

A great deal of experimenting was going on at that time relating to the various phases of audion improvement above outlined and many of the specimens produced, of course, were not intended to, and *did* not, embody the particular high vacuum improvement here in issue.[2] However, records were found of a number of the specimens that did embody it, and are in evidence. Defendant's Exhibit 255[3] gives test runs on four or five tubes that stood voltages up to 240 volts without blue glow or other evidence of ionization.

These early tubes doubtless had many faults from the present day point of view, but, for use at the proposed voltages, *gas ionization troubles were not among them.* Beyond question they embodied the improvement due to better vacuum covered by the Langmuir patent.

---

[9] Deft.'s Ex. 255, formerly 18, p. 105. Here we translate "miles" of "gain" into the power amplification factor "26 times" by a rule given by van der Bijl, Interf. Rec., pp. 627, 666.

[1] Rec., Vol. 1, p. 517 *et seq.*, Q179; p. 612, Q80.

[2] Rec., Vol. 3, p. 1881, XQs. 46 to 56.

[3] Interference Priority Exhibit 18, pages of Pierce's Notebook.

Philadelphia Tubes.

In September and October, 1913, Arnold's assistant Kendall installed a repeater with high vacuum audions at Philadelphia. After suitable tests and adjustments, this repeater was switched in on the line between New York and Washington for regular commercial service. This was on October 18, 1913, and since that date the commercial use of high vacuum audions as telephone repeaters has never been interrupted, and has expanded enormously.

Most of the tubes which first went into service in the telephone plant in September, October and November, 1913, have, naturally, been lost or destroyed. Three, however, were found and put in evidence, and original data on one other sufficient to show its character, are in evidence. The three tubes in evidence are Audion 6.11, 64 and 100, and the other tube is Audion 9.111.[7]

These tubes were evacuated with the Gaede molecular pump, baked, glowed and the electrodes bombarded just as with the tubes of April and May, above referred to;[8] so they were made as specified in the patent in suit. A contemporaneous record[9] shows that on December 20, 1913, Audion 6.11 had had 152 hours service as a commercial repeater; that Audion 64 had had 56 hours; Audion 100, 96 hours, and Audion 9.111, 267 hours; so there can be no doubt that these tubes showed the steadiness and reliability under service conditions, characteristic of the proper vacuum and which is the very essence of the alleged invention of this patent. The patent itself points out that the removal of gas is to be proportioned to the use to which the tube is to be put, and that *relief from erratic operation is the end to be attained,*—not some particular degree of evacuation.[1]

---

[7] The three tubes in evidence are Deft.'s Exs. 265 (formerly numbered 28), 267 (formerly numbered 30) and 269 (formerly numbered 32). For data of Audion 9.111 see Deft.'s Ex. 271 (formerly numbered 34).

[8] Interf. Rec., p. 2212.

[9] Deft.'s Ex. 264, Interf. Priority Ex. 27.

Besides these controlling facts, there are the original data taken on Audion 9.111 in September, 1913,[2] showing that it stood voltages up to 125 volts and carried currents of over one milliampere without showing blue glow (one of the tests mentioned in the patent in suit for tubes embodying the supposed invention). As to Audions 64 and 100, measurements of their vacuum taken before the trial show one and a half hundredths of a micron for the first and well under one hundredth of a micron for the other.[3] The patent in suit says (p. 5, line 5) the vacuum "should preferably be carried to a pressure as *low as a few* hundredths of a micron" so these vacua were very good indeed, judged by the patent itself. These vacuum measurements were carefully made by a procedure approved by Dr. Millikan[4] and fully described on the stand by Dr. Kelly.[5] Dr. Kelly (who is in charge of the tube manufacture for the Western Electric Company), also made load tests on each of these tubes showing the permanence of their vacuum under working conditions, and states that either of them will operate at upward of 100 volts with a pure electron current amounting to 3/10 milliampere or more for tube 64, and 4/10 milliampere or more for tube 100.[8] These are higher voltages and currents, than specified in a number of the claims of the patent, as for example claims 26 and 29.

---

[1] Pat. Spec., p. 4, lines 105-110; p. 5, lines 7-10; p. 1, line 60; p. 2, lines 111-114; p. 5, lines 116-130.

[2] Deft.'s Ex. 271.

[3] Rec., Vol. 2, pp. 813, 830, 851.

[4] Rec., Vol. 1, p. 456, Qs. 35-37.

[5] Rec., Vol. 2, pp. 813 to 821.

The foregoing is the direct and positive evidence as to the character of vacuum, the performance and the usefulness of these Philadelphia tubes.

At various times Respondent has urged various reasons why Arnold should not be awarded priority. However, in the petition for reargument in the Circuit Court of Appeals, all of these reasons were abandoned but one. We shall therefore in this brief refer only to this reason. Referring to a demonstration by one, Richards, of the Western Electric Company to some company officials in February, 1913, in which he used DeForest audions instead of more highly evacuated tubes made by Arnold, the argument was advanced that the higher vacuum tubes would have been used if Arnold had been then able to produce them. There is absolutely no point in this criticism. The demonstration had relation to the *quality* of audions, not their *power capacity*. It was intended to show that a large number of them could be connected in series or tandem without introducing distortion of the speech currents. The telephone system was then using mechanical repeaters but they were not good enough to work *in tandem*.[9]

The test showed that it was possible to use as many as seven of the audion type repeaters in tandem and so served its entire purpose. It was, as a matter of fact, a distinctly by-the-way incident and not at all an important or official test, as Respondent has sought to imply. Arnold was then waiting for the arrival of the new Gaede molecular pump and there was no reason why a special effort should have been made to produce, for that test, higher vacuum tubes than the audions which were on hand.

---

[8] Rec., Vol. 2, p. 826, Q29; p. 835, Q50.

[9] Rec., Vol. 1, p. 403.

Langmuir's Work.

Langmuir's Two Preliminary Statements.

November 1, 1912 being clearly proved as the effective date of invention by Arnold, the defense based upon Arnold's priority is established unless Langmuir can show at least a *conception* of the supposed invention prior to that date, coupled by due diligence with a reduction to practice.

When the priority controversy began in the Patent Office in 1916, Langmuir did not even *allege* an earlier date of invention than November 1, 1912.

Each party to an interference is required to file a sworn "preliminary statement", before he knows anything of his opponent's case, telling when he claims to have conceived, disclosed, and reduced to practice, the invention in controversy. *Langmuir's first preliminary statement* filed August 21, 1916,[1] *says that he conceived, disclosed and reduced to practice, all* "during the month of November, 1912".

Arnold's preliminary statement filed about the same time gives dates in the same period.

It is the regular practice of the Patent Office, when a party gives an indefinite date close to the date alleged by his opponent, to require of him a more definite statement. Accordingly, in a letter from the Patent Office dated September 8, 1916, Langmuir was required to give "a more definite date" than "the month of November".[2]

---

[1] Interf. Rec., p. 1994.

Of course Langmuir's attorney knew what this meant. He telegraphed to Washington for more time on the plea that this would "require extensive investigation",[3] and then in due course came in with a new statement alleging conception, disclosure, sketches, written description, and reduction to practice,—all—"between the middle of July, 1912 and the first day of September, 1912".[4]

And there is a singular thing about the language of this second statement that is worth noting. The *first* statement said that he "conceived the *invention*", on the date alleged; the *second* said he conceived a "*device embodying* the invention", on the date alleged.[5] The distinction may seem slight at first glance but, in the light of the subsequent testimony as to what Langmuir really did in this earlier period, it is very significant, for the language is, in effect, a subtle admission that Langmuir was not at that time conscious of the *invention* but only of some physical "device", *now* claimed to have embodied it. That, of course, would not be invention at all. And this, precisely, is one of the fatal defects in Langmuir's work prior to November 1, 1912 so far as its effect in this controversy is concerned.

This work of Langmuir's, prior to November 1, 1912 (which we shall refer to as the August work) does not establish even a conception of the supposed invention, for two reasons, either of which is sufficient to make it worthless here: *first*, he did not then realize that the alleged invention was embodied in the tube relied upon, *as he fully admits; second*, the supposed invention was, in fact, not embodied there.

---

[2] Rec., Vol. 6, p. 1069.

[3] Rec., Vol. 6, p. 1070.

[4] Interf. Rec., p. 1995.

[5] This point did not escape the notice of the Commissioner of Patents, and he comments on it in his decision (Interf. Rec., p. 2516).

Langmuir Did Not Recognize the Invention in August, Assuming Its Presence.

The essence of every invention, in the very nature of the case, is the "conception",—the mental act by which the new idea comes into existence. To be rewarded by the patent law the conception must also be put into concrete form by a "reduction to practice",—either actual or by filing a patent application—but, as must be obvious and as the decisions cited hereinafter show, an accidental physical embodiment without a conception is no invention at all. *Clearly there can be no such thing as a conception of which the inventor is not conscious,—it would be a contradiction of terms. Equally clearly no physical thing can be the "reduction to practice" for an unconceived idea; for it is the ability to instruct others, which flows only from a consciousness of the idea, that the patent law stands ready to reward.*

And so it has always been held that no physical structure can serve to establish either a conception or reduction to practice for any claimant unless, at the time, he appreciates the fact, if true, that it embodies the improvement in question. Robinson on Patents says:

> "Moreover, no exercise of the creative faculties can form a part of the inventive act, unless the idea resulting from such exercise is fully apprehended by

the mind of the inventor. To create by accident without a recognition of the fact or nature of his own creation, and consequently without the power to repeat the same creative act, is not invention. While previous intention to create in this especial form, or even to create at all, is not required, it is essential to the inventive act that the inventor should not only *conceive*, but should also *perceive* his original idea, and should do both so clearly as to make this idea an actual addition to his fund of knowledge, and to be able to communicate it to the public."[8] (Italics the author's.)

This Court, in *Tilghman* v. *Proctor*, 102 U. S. 707-711, in disposing of several alleged anticipations of the Tilghman patent said:

> "We do not regard the accidental formation of fat acid in Perkin's steam cylinder from the tallow introduced to lubricate the pistom (if the scum which rose on the water issuing from the ejection pipe was fat acid) as of any consequence in this inquiry * * *.
>
> "The accidental effects produced in Daniell's water barometer and in Walther's process for purifying fats and oils preparatory to soapmaking, are of the same character. They revealed no process for the manufacture of fat acids. If the acids were accidentally and unwittingly produced, whilst the operators were in pursuit of other and different results, *without exciting attention and without its even being known what was done* or how it had been done, it would be absurd to say that this was an anticipation of Tilghman's discovery."

---

[8] Vol. 1, Sec. 79, p. 121.

In *Pittsburgh* v. *Cowles*, 55 Fed. 301-307, Judge TAFT, late Chief Justice, said:

> "But suppose it be a fact that in DeVille's process alumina was dissolved in the bath from the anode and that thereupon it was electrolyzed as in the Hall process. It was a mere accident of which DeVille made no note and which therefore we may reasonably infer he did not observe. Accidents of this character cannot be relied on as anticipations of a patented process * * * *when the operator does not recognise the means by which the accidental result is accomplished* and does not thereafter consciously and purposely adopt such means as a process for reaching the result. DeVille did not intend that the alumina should be dissolved in the bath. If he did, why did he unite it with carbon by means of pressure and a binding material? *If he had intended to dissolve the alumina, he could not have done anything which would have so interfered with his purpose.*"

(The application of this case to Langmuir's work will be apparent from the fact we refer to below that as soon as the alleged high vacuum occurred in his August tube, it was again refilled with nitrogen gas; Rec., Vol. 2, p. 1349, XQs. 455, 456).

To the same effect are

Eibel v. *Minnesota*, 261 U. S. 45-66;
Wells v. *Curtis*, 66 Fed. 318-322, C. C. A., 6th Circuit;
Andrews v. *Carmen*, Fed. Case 371;
Munising v. *American*, 228 Fed. 700-703, C. C. A., 6th Circuit;
Anthracite v. *Pollock*, 175 Fed. 108-111;

Doble v. Pelton Co., 186 Fed. 526-532;
Byerley v. Barber Asphalt Co., 230 Fed. 995-997;
Standard Co. v. Graywood, 1 Fed. (2nd) 667-670;
Carson v. American Co., 11 Fed. (2nd) 766-771, 772, C. C. A., 9th Circuit.

In the August work, what Langmuir had was a vacuum tube with a hot filament and a cold filament, which he was using to study the rate at which nitrogen was "cleaned up" during the passage of the Edison current across the space. He *now* claims that on some of the runs with this tube, he had a vacuum through which there was a pure electron discharge unaffected by positive ionization. *But he admits that he was not then conscious of the alleged fact.* He testified:[8]

> "XQ380. You did not know at the time, or you did not suppose at the time, that you had a pure electron discharge substantially unaffected by positive ionization, did you?
>
> A. *No, I did not draw that conclusion at that time. I know it now but I did not know it then.*"

And like admissions are contained elsewhere in the record. See Interference Record, pages 1560, 1569 and 2094.

So that, even if the supposed invention here were merely an electron discharge substantially unaffected by ionization, the August work would not show a conception of it.

But the invention, as we have seen, can not *merely* be this (which was already known in the art, *supra*, p. 31). It must at least include the idea of *applying the principles* governing such a discharge *to the useful purpose* of improving vacuum tubes for amplifying, etc. *There is not one word of evidence in the whole record that Langmuir had any conception of this, or any other useful result to be secured by such a discharge prior to November 1, 1912, nor for some time thereafter.*

---

[8] Rec., Vol. 2, p. 1328.

Our opponents argue that the tube Langmuir then had *could* have been used for rectifying alternating currents with improved results. This is not true because it is recognized the rectifiers, like detectors, work better with considerable residual gas. But if true, it would make no difference. The only important inquiry is whether Langmuir *then recognized* such alleged fact. His admission, above quoted, answers that.

So no matter *what* the August work was, it is of no consequence here.

The August Tube Did Not in Fact Embody the Invention.

But evidence taken *before the Trial Court* which was *not before the Patent Office* shows that the August tube was, in fact, not an instance of "pure electron discharge substantially unaffected by ionization", as Langmuir now claims,—much less an example of the application of such a discharge to a useful purpose,—so that even had Langmuir recognized the full truth about the discharge at its highest vacuum points, still he would have been far from the supposed invention.

Langmuir says that a sudden drop in the space current which he got at times in the August tube, from about 16 milliamperes to about 5 milliamperes, as the nitrogen gradually cleaned up, indicated the disappearance of ionization effects. He is wrong. What it really indicated was the *beginning* of the space charge effect,—still greatly affected by ionization.[9] Space charge alone means nothing. It is not even mentioned in Langmuir's original application. Respondent admits that the old DeForest audions had it. Only when the space charge is substantially *unaffected by positive ionization* does it begin to have any significance here. It is upon the substantial *absence of ionization* that the original application repeatedly insists, and upon which Arnold insisted in his November 1st disclosure.

The presence of substantial ionization in the August tube is shown first by the very fact of the sudden change of current value[1] and also by the fact, shown by Langmuir's own data, that every reduction in gas pressure thereafter was followed by a further drop in current.[2] Also Becker testified that he duplicated this experiment and then continued to reduce the gas pressure in steps to a really good vacuum, and he found that the current continued to fall,—as the gas was removed—, to about one-half or one-third of what it was soon after the drop. Langmuir stopped when it had decreased only 20%. This shows beyond question that Langmuir's discharge was very materially affected by the gas ionization.[3]

Langmuir also points to a logarithmic plot of two points, taken in two different runs, at 250 and 200 volts, respectively,[4] as indicating that the discharge was substantially unaffected by ionization because, as he says, the slope of the line connecting these points is nearly 1.5, thus conforming nearly to the 3/2 law. But on cross-examination, he admitted, after some urging, that the actual slope through the points was 1.83 rather than 1.5,[5] and that plotting just those two points didn't have much significance anyway![6]

---

[9] Rec., Vol. 3, p. 1792, Qs. 7 and 11.
[1] Rec., Vol. 3, p. 1796, Q. 11.
[2] Same, Q12.
[3] Same, Qs. 19 and 20.
[4] Interf. Rec., p. 2091.

Moreover, in his "Physical Review" paper of December, 1913, page 470[7] Langmuir exhibited a logarithmic plot of an experimental run with a vacuum tube of like character which showed a large number of points, giving a slope of 1.71; and comparing this with the theoretical 1.5 slope he said in that paper, "This difference is certainly due to residual gas"; yet he asks the Court to believe that a plot of *two* points showing a slope of *1.83* with a tube of the same kind, means *no* gas effect![8]

It does not seem to us necessary to discuss the August work any further.

Langmuir admits that he did not then know what sort of discharge he had. The facts show that he did *not* have a discharge unaffected by ionization. And it is not even *claimed* that he then thought of applying such a discharge to a useful purpose.

Langmuir's Case After November 1, 1912.

Since Respondent has failed to show even a conception for Langmuir prior to Arnold's date of November 1, 1912, the defense of prior invention by Arnold is established, and the patent is accordingly invalid. Nothing Langmuir may have done after November 1, 1912, can give him priority, because it is too late.

---

[5] Rec., Vol. 2, p. 1346, XQ443.

[6] Same, XQ450.

[7] Pltf.'s Ex. 21.

[8] Even to get his 1.83 he had to carefully choose this pair of points out of many. Other pairs would have given slopes anywhere from .953 to 2.58; see Deft.'s Ex. 295 (Rec., Vol. 6, p. 1202; Vol. 3, pp. 1797-8).

As to the priority issue, we might logically rest our case here.

There are, however, one or two things after November 1st in Langmuir's story which show so clearly that he did *not* have the invention until a much later date, that we shall take space to refer to them briefly.

Langmuir's November Experiments.

Between the 18th and 22nd of November, 1912, Langmuir made some more experiments on tubes generally similar to his August tube,—*i. e.*, with two electrodes, both filamentary. This time, however, he was watching changes in the Edison current as the filament temperature was changed, rather than the clean-up effect upon the gas. He made the experiments because Richardson, the great authority on thermionic discharges, was coming to Schenectady to make an address, and Langmuir wanted "to get an understanding of the fundamental laws involved".

What he did was to apply a single voltage between cathode and anode,—(sometimes 125 volts and sometimes 250 volts)—, then vary the heating current of the filament in steps and note the resulting variations of the Edison current.

The great trouble with Langmuir's attempt to rely on these experiments in this controversy is that they make no pretense of being anything but investigations in pure science. There is evidence that they did serve to instruct Langmuir in some "fundamental principles" (already known to others) but there is not one word of evidence that they stirred in his mind the faintest glimmer of an idea that these principles could be turned to a definite useful purpose.

Langmuir himself says that the experiments were undertaken

> "* * * in order to get an understanding of the fundamental laws involved, and thus settle once for all whether or not pure electron currents could be obtained in a practically perfect vacuum"[9]

and

> "* * * with the object of measuring the electron emission from tungsten filaments in the best vacuum, or at least, a very good vacuum".[1]

That was his state of mind *before* the experiments. What was it afterward? At the time he testified in the interference, he said this:

> "Their importance to my mind lay in the fact that they gave a clear understanding of the characteristics of a pure electron discharge in high vacuum at high voltages. They enabled me to understand clearly the distinction between the space charge part of the curve and the saturation part of the curve, and to realize that on the space charge part of the curve, the current is independent of filament temperature but depends upon the voltage of the anode, and the area of the anode".[2]

Pure unapplied science. One may know all these things and yet not appreciate any useful application for them. In fact, they all were known to others, as shown by the references herein to the work of Lilienfeld and by the work of Richardson and Child;[2a] and they, like Langmuir, had noted them simply as scientific facts.

---

[9] Interf. Rec., p. 557—top.
[1] Rec., Vol. 2, p. 1139—top.
[2] Interf. Rec., p. 2109, lines 5-14.

It is an axiom of patent law that patentable invention lies in producing practical results in the useful arts, not in merely discovering scientific facts or principles.[3] *LeRoy* v. *Tatham*, 14 How. 155-174; *Detmold* v. *Reeves*, Fed. Cas. No. 3831; *Morton* v. *N. Y. Eye Infirmary*, Fed. Case 9865.

At the end of this November work, then, it is clear that Langmuir was not possessed of the invention.

Coolidge-Langmuir Conversation in December.

Plaintiff has emphasized an alleged disclosure of the invention by Langmuir to Coolidge on December 10, 1912, as to which both men gave testimony. At that date X-ray tubes commonly had gas and cold cathodes, and Coolidge entertained the idea of an X-ray tube without gas and with a hot cathode. In ignorance of the prevailing scientific knowledge, both Coolidge and Langmuir had doubted whether a hot cathode would emit electrons in the absence of gas. According to respondent's contention, the whole sum and substance of the alleged disclosure was that Langmuir encouraged Coolidge to suppose—what the scientific world well knew—that a hot cathode would emit electrons in the absence of gas.[4] If, as respondent asserts, the X-ray tube of the Coolidge Patent No. 1,203,495[5] grew out of this encouraging remark from Langmuir to Coolidge, that was the only invention that grew out of it. Having elected to claim it for Coolidge, the General Electric Company cannot now claim it for Langmuir (*post*, p. 106).

[2a] Child, Rec., Vol. 5, p. 437; Richardson, Interf. Rec., pp. 226 *et seq.*

[3] Robinson on Patents, Vol. 1, Section 96, p. 142 and Section 231, p. 314.

[4] Compare Coolidge's answer to Q103, Rec., Vol. 3, p. 1512, with the statements in Lilienfeld's 1910 paper, for example, at Rec., Vol. 5, pp. 316, 325, 356 and 392.

[5] Rec., Vol. 6, p. 1021.

The theory of the General Electric Company is that Langmuir was the inventor of the "broad aspect" and Coolidge was the inventor of the X-ray tube.[6] But a "broad aspect" is not an invention. No invention of apparatus comes into existence until someone has in his mind a conception of specific apparatus functioning to accomplish some definite, desirable, useful purpose. To disclose an invention one must disclose a complete idea of means to accomplish such a purpose. The only definite practical purpose entertained by Langmuir and Coolidge, was to construct a certain kind of X-ray tube. What was said between them fell far short of an adequate disclosure of a complete idea of means for that purpose, as Respondent freely admits.[6a]

Hence, the alleged disclosure by Langmuir to Coolidge fails, (1) because the only invention mentioned was an invention that Respondent has elected to claim for Coolidge instead of Langmuir, and (2) because according to Respondent's admission a complete idea of means was not reached until a much later date. But even if the conversation between Langmuir and Coolidge could be considered to show a realization on the part of the former of a useful purpose to which a pure electron discharge could be put, it is of no importance in this case, because Arnold antedated him by a month and a half.

---

[6] See paragraph preceding the claims in the Coolidge Patent, Rec., Vol. 6, p. 1026.

[6a] Main brief in court below, p. 222, top; "it took Coolidge months of hard work before he was ready to file his application for this patent".

Langmuir's Record After 1912.

The time of Langmuir's actual conception is not left to speculation. His own record shows exactly *when* it was and *what* it was. And it was, as we have already remarked, exactly the thing Arnold had conceived some months earlier, namely, a DeForest audion with a better vacuum.

Langmuir got his first audion early in February, 1913, and put White to studying it.[7] Some two weeks later they were testing one of their own make but found that even the 0.1 micron vacuum they had would not "stay put"—apparently because gas poured out of its electrodes when in use.[8]

Then after about a month more of groping[9] he sees the light, and writes in his note book under date of March 21, 1913:

> "Now what I intend to do is to construct an audion which will operate entirely and exclusively on the electron discharge. I shall attempt to get the vacuum so good that positive ions are present in negligible amounts".[2]

---

[7] Pltf.'s Ex. 101, Interf. Ex. 81, p. 242.

[8] Same, pp. 305, 308, 309.

[9] One may trace his steps from his own notes, Pltf.'s Ex. 101, pp. 287, 298, 299 and 306, and Pltf.'s Ex. 131 (Interf. Ex. U), pp. 32 and 33. He has wholly wrong ideas of the audion operation, as to "sensitiveness" and "sluggishness" for instance; as to electron emission from Wehnelt cathodes, etc.

[2] Pltf.'s Ex. 131, p. 34, Interf. Ex. U. The plain meaning of this paragraph cannot be explained away, as has been attempted by Respondent. The words "This we have already done" on the following page of the notebook obviously refer to the attainment of sensitiveness by proper electrode structure and spacing, the description of which they immediately follow.

Here is Langmuir just taking the step that Arnold took nearly five months before! And still he is not sure. He says he will "attempt" it; Arnold spoke with such assurance that his department was straightway reorganized on the strength of his statements, to put them to commercial use.

So we think the fact that Langmuir did not have the invention prior to November 1, 1912, is shown not only by the failure of his proofs as to that period, but by the above mentioned positive evidence from his own note books as to events subsequent thereto. Going on in these note books we find many entries to show that he was slow to affect a practical use of the invention, as he had been to attain its conception. On the date December 19, 1913 he wrote

> "*Proposed Demonstration* of our devices for wireless telegraphy and telephony.
>
> Hawkins says Davis is going to try to arrange to have us demonstrate our devices to the Marconi Company and the Western Electric Company. I pointed out that we should *first arrange a trial demonstration with some wireless experts friendly to us,* or preferably in our employ. Hawkins suggested getting in touch with the wireless men at Pittsfield. I spoke to White and Dushman and asked White to arrange all his work with the end of preparing apparatus for demonstrating the following lines of work • • •."[1]

Langmuir's precaution to "first arrange a trial demonstration with some wireless experts friendly to us" was well conceived, for with date June 18, 1914, he records an effort extending over several days, the culmination of weeks of preparation, the object being to effect a wireless telephone transmission between Schenectady and Pittsfield, less than 50 miles. All that was accomplished was that a portion of the phrase "Hello, White" was heard at one time.[1a] It was in April, 1915, ten months later, when the "Proposed Demonstration" was carried out and Langmuir showed his products to Arnold and his associates.[1b] It will be remembered that the Arnold tubes had been used commercially by the Telephone Company beginning in October, 1913, and that they were actually used in the first transcontinental telephone line in the summer of 1914.

---

[1] Pltf.'s Ex. 132 formerly priority Ex. V, p. 82.

Resumé on Priority.

It thus appears from the overwhelming weight of the evidence (some of which was not before the Patent Office Tribunals) that Dr. Arnold conceived the alleged invention of the patent and disclosed it to others on November 1, 1912, and thereafter used due diligence in reducing it to practice, so that by the following October, tubes embodying the alleged invention of the patent were in commercial use as repeaters in the lines of the American Telephone & Telegraph Company, and in the following year were used as repeaters in the first transcontinental line ever built. On the other hand, Langmuir cannot be said to have made any invention until long after November 22, 1912, when, so he testified, he was conducting experiments to "settle once for all whether or not pure electron currents could be obtained in a practically perfect vacuum". After he discovered that they could be so obtained, he apparently conceived no useful purposes therefor until March, 1913, when he wrote in his notebook that he intended "to construct an audion which will operate entirely and exclusively on the electron discharge". Moreover, although the Arnold repeaters were being used in commercial telephone lines in the fall of 1913, and in the transcontinental line in the summer of 1914, the first practical thing we find done by Langmuir with his tubes, was the attempted wireless telephone transmission of less than fifty miles in June of 1914 where only a part of the phrase "Hello White" was heard.

[1a] Plf.'s Ex. 132 formerly priority Ex. V, pp. 329 to 331.

[1b] Interf. Rec., pp. 484 to 487.

It is clear therefore that if the Langmuir patent discloses any invention of a patentable nature, Arnold was the first inventor and not Langmuir. The Langmuir patent is obviously invalid for this reason, as was held by Judge Morris and Judge Woolley.

The majority opinion of the Court of Appeals did not advance any reason for a different conclusion as to the effect of Arnold's work, nor point out any error in the conclusion of the lower Court, nor criticize its reasoning. The Court of Appeals was in error in not upholding Arnold's priority and should be reversed on that ground.

POINT IV.

The patent is invalid because of prior knowledge and public use.

This defense was sustained by the District Court and by Judge Woolley, and is not referred to in the majority opinion of the Court of Appeals.

Facts of Detector and Amplifier Operation.

As to this defense, the established facts are as follows:

1. It is abundantly shown by the record (and stated in the Langmuir patent) that the ordinary DeForest audion *detector* was recognized as a gas device and as such had an ionizing voltage of about 25 volts. It was and is therefore, customary to use the same with an impressed voltage of approximately 22½ volts.[1]

2. When voltage very slightly *above* ionizing voltage (25 volts) was impressed upon the DeForest audion *detector*, it would "blue glow".

3. The use of an audion as an *amplifier* was known prior to August, 1912, the earliest date claimed by Langmuir.

4. When "blue glow" appears, due to ionization at an impressed voltage very slightly above the ionizing voltage, the amplifier becomes inoperative.[2]

---

[1] Hogan was never able to use more than 30 volts with an audion detector prior to 1914; XQ46, p. 100, Vol. 1.

[2] Hogan XQ35-XQ39, p. 97, Vol. 1, Rec.

All of the foregoing facts are not only conclusively established, but are undisputed.

It is perfectly obvious at the outset, therefore, that if an audion tube was used or was capable of being used as an *amplifier* with voltages over 25 or 30 volts, *it was so used or capable of being used only because the gas in the tube had been evacuated to a degree which would permit the use of such higher voltages.*

Facts of This Defense.

The facts of the California use may be briefly narrated as follows:

The Federal Telegraph Company of California, for whom Dr. DeForest was working in 1911 and 1912 (until September of that year), was engaged in the commercial transmitting and reception of radio messages. This work included the employment of audion *detectors* as well as audion *amplifiers.* The amplifiers were "three stage amplifiers", *i. e.,* three audion *amplifiers* connected in series or tandem. The audion tubes used as *amplifiers* were distinguished from and classified apart from audions used as *detectors.* It is, of course, common knowledge that when an audion is used as an *amplifier,* the higher the voltage impressed between the plate and filament, the greater the amplification secured. We therefore find Dr. DeForest writing to the McCandless Company (the concern which manufactured DeForest audions for the Federal Telegraph Company) under date of July 26, 1912,[8] as follows:

> "Out of the last lot of 24 audion bulbs which you manufactured for us there are only 4 that came up to

---

[8] Defts.' Ex. 79*a*, p. 1061, Vol. 6, Rec.

> *proper sensitiveness test. Apparently the vacuum in the other bulbs is too low, because in these latter bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive.*"

The operators of the commercial stations of the Federal Telegraph Company, using the DeForest audions, encountered the trouble of "blue glow" when the voltage on the plate was increased, and discussed the matter with Dr. DeForest. He explained to them that the vacuum was not high enough. This, of course, was entirely consistent with DeForest's letter to the McCandless Company. Likewise, the question was discussed as to where else, other than by the McCandless Company, could evacuation of the bulbs be secured. Dr. DeForest located a glass blower in San Francisco, by the name of Lamont, who put in tungsten filaments and repumped the tubes at DeForest's request. As a result, Dr. DeForest wrote the McCandless Company under date of August 14, 1912,[4] stating, in part, as follows:

> "We took two of the poorest of the discarded 20 to a San Francisco glass-blower, unknown to fame, *and had him exhaust same to as high a vacuum as his pumps would take.* These reexhausted bulbs now show a sensitiveness equal to those of the first four, *which proves conclusively that our contention is correct. For the work which we demand from these bulbs they are not sufficiently sensitive and we would be glad therefore if you will reexhaust them.* You certainly should be able to put them in as good condition as the aforesaid San Francisco glass-blower."

---

[4] Deft.'s Ex. 79B, p. 1062, Vol. 6, Rec.

"We here see, therefore, that for use as an *amplifier*, DeForest not only realized that he wanted a higher degree of vacuum, and that the degree of vacuum he wanted should be as high as possible, but that he made a record of his knowledge of this fact, not in the sense of establishing a date of invention, however, because it is evident from DeForest's correspondence and his operations in California that a difference in the degree of vacuum was not considered by him to be an invention, but a mere manufacturing operation.

Amplifier tubes were employed by the Federal Telegraph Company in 1911, 1912 and 1913 and formed part of its standard commercial equipment[5] with a B battery comprising 36 cells (54 volts).[6] We further find that Hewlett used a three electrode tube evacuated on Lamont's pump with 45 cells in series.[7] Forty-five cells gives a voltage of 67½!!

Testimony from Langmuir Bearing on the Facts of This Defense.

From the foregoing, it is apparent that these devices operated at voltages much above gas ionization voltage (25 volts) and still functioned as amplifiers in amplifier circuits; hence they could not have operated otherwise than as "pure electron flow devices". And this is established by Langmuir's own testimony[8] in connection with his diagram.[9] Langmuir was asked,—

---

[5] See Beale blueprints, Deft.'s Exs. Nos. 81 and 82, pp. 1065-1067, Vol. 6, Rec.

[6] Beale testimony Qs. 18 and 19, p. 1052, Vol. 2, Rec.

[7] Q14, p. 1008, Vol. 2, Rec.

[8] P. 1427, Vol. 3, Rec.

[9] Pltf.'s Ex. No. 168 E, reproduced on p. 55, Vol. 4, Rec.

"XQ761. I want to ask you just one question in connection with Plaintiff's Ex. No. 168, which was the curve of the output against the plate voltage of a three electrode device, as an amplifier with gas, and a three electrode device, as an amplifier without gas, and I think that you testified as the result of the experiments on which this curve was based, that there is a point in a gassy tube where it operates in a very successful manner as an amplifier; is that correctly stated?

"A. Yes.

"XQ762. And I notice that your curve stopped on the gassy tube when you brought the voltage up to forty volts, the point being well below the steep part of the curve, which I understood you to state was the operating portion of the curve; is that correct?

"A. Of course this is not a volt ampere characteristic at all.

"XQ763. I understand that it is the amplifying quality of the tube, is it not?

"A. Yes, but in your reference to the upward bending part of the curve, I think you were referring to volt ampere characteristics, that I had previously spoken of and this is not at all comparable with that.

"XQ764. I see, but as I understand this curve, the higher up on the millivolt ampere output ordinate that you go, the more sensitive the amplifier is; was that the purport of your testimony?

"A. Why, we were plotting as ordinates the amplifying power, *the amplifying power reached to a maximum at about twenty-seven volts.*

"XQ765. *And the amplifying power of the tube at forty volts reached how much?*

"*A. Well, it was very small; about 0.34.*

"XQ766. *And what would have been the amplifying power of the tube, if you had raised it to fifty volts?*

"A. *Probably very much less.*

"XQ767. *In accordance with the slope of the last portion of the curve, it would be practically nothing, would it not?*

"A. *Very likely.* I do not know that. You can not safely extrapolate, because you go to higher voltages, the current becomes limited by saturation from the filament, *and then the amplifying power becomes zero, and remains zero, as higher voltages are reached.*"

From the foregoing testimony in connection with Plaintiff's Exhibit No. 168E, it is perfectly apparent that *maximum amplifying power of an amplifier tube containing gas is secured at approximately 27 volts,* and the Court will see that a mere fraction of a volt above that causes the amplifying power of the tube to drop to practically zero. It is therefore obvious that *it would have been impossible for the Federal Telegraph Company to employ audion amplifiers in their commercial operations with voltages of 30 volts or more without* (*a*) blue glow and hence paralysis of the tube, and (*b*) with any amplifying power whatsoever, *unless the tube had been evacuated below the degree of vacuum contained in a soft audion detector tube which was the only type of audion Langmuir in his patent acknowledges as prior art.*

In this connection, attention is called to claim 26 of the patent which covers an electron discharge device operating at 40 volts.. Obviously, the amplifiers used at the Federal Telegraph Company's stations would infringe this claim, because they operated with over 40 volts. If they infringe *any* claim they embody the *invention* of the patent, *and if they infringe if later, they anticipate if earlier.* The only difference between claim 26 and the remainder of the claims is in the recitation of the *characteristics*, which are inherent in the operation of such a tube, or the recitation of different values of voltages and currents. It is believed that it is too obvious to require discussion, that the claims specifying 50, 60, 100 and 200 volts do not describe separate inventions from those specifying 40 volts. Otherwise we might as well have a thousand claims to as many separately patentable inventions by the simple expedient of increasing the specified voltages by small steps.

It is indeed significant that Langmuir made no reference in his patent to the use of an audion as an *amplifier*. It is indisputable that his description of the audion and its limitations as to gas content and operating voltages was incomplete and inaccurate.

Tungsten Cathodes in the California Tubes.

Another avenue of approach is that of considering the inherent results of using tungsten as the filament in a vacuum tube. Langmuir stated in his paper of 1915, in the proceedings before the Institute of Radio Engineers:[1]

> "It was known that the vacuum in a tungsten lamp is extremely high, and measurements indicated that in well exhausted lamps after one hundred hours life, *the pressure was probably less than one-millionth of a millimeter of mercury.*"

This was due to the "clean up effect" of tungsten to which many references appear in the record. It therefore follows as a logical result that the mere existence of a tungsten filament in an audion tube would inherently cause the vacuum to be much improved.[2]

---

[1] He confirmed the same in his testimony in answer to XQ730, p. 1419, Vol. 3, Rec.

Likewise the record is replete with references to the standard incandescent lamp practice of "flashing" the filament, so as to produce "blue glow". In other words, in the manufacture of incandescent lamps, a "blue glow" was intentionally brought about and Dr. Dushman points out in his book:[3]

> "In general, *over 90% of the residual gas is cleaned up in a lamp during the blue glow.*"
>
> * * * * * * *
>
> "and the rate of clean up during this time is much more rapid than that obtained subsequently. The final pressure attained in flashing varies from 0.01 to $0.001 \times 10 = 3$ mm.[3a] of mercury".

Mr. Hogan's translation of this (in answer to XQ366) is

> "If, I heard you, it is .01 to .001 microns."

It will thus be seen that if a tungsten filament is employed in an audion tube, and if given the usual "flashing" treatment, the vacuum is inherently reduced to a degree well within the limit specified by Langmuir, and hence the device automatically comes within the scope of the alleged invention.

With these facts in mind, consider the evidence showing how the DeForest tubes were repumped in California. We find from the depositions of Lamont and Mrs. Beck that new filaments were always inserted from 1911 on. *We find that these filaments were tungsten filaments.* We find from the deposition of Ralph Hyde, that the filaments he employed were drawn tungsten filament, *i. e.*, thoriated tungsten filaments. Hyde testified that from 1911 on he repumped and replaced filaments of vacuum tubes.[4] He also testified:

---

[2] See also XQ743, p. 1421, Vol. 3, Rec.

[3] See XQs. 364-366, inc., pp. 1657-8, Vol. 3, Rec.

[3a] Misprint for 0.01 to 0.001×10^{-3} mm.

> "Q17. What material filament did you use for the repair or replacement work? A. *Drawn Tungsten* wires.
>
> "Q18. Did you use any other filament? A. No, you mean since I started, from that time up to the present?
>
> "Q19. I mean up to 1914, particularly? A. *Nothing but drawn tungsten wires.*"

It developed from his testimony that the drawn tungsten wire that he used was obtained from the General Electric Company.

Counsel for Respondent admitted in the record for the purpose of this point at pages 1442, 1443, Vol. 3, Record, that thoriated tungsten filament lamps were put on the market in the fall of 1912.

The fact then is, therefore, that beginning as early as 1911, tungsten filaments were used with audion tubes and that by reason of their inherent "clean-up" effect, a higher degree of vacuum was obtained which readily permitted their use as amplifiers. To operate as such they had to function, "without appreciable gas ionization" and they used voltages substantially above ionizing voltages.

But this is all that the Langmuir invention is said to be.

We submit, therefore, that the patent is invalid because of this prior use which has been conclusively established, and as held by Judge Morris and Judge Woolley.

---

[4] Q6, p. 995, Vol. 2, Rec.

POINT V.

The present majority decision of the Court of Appeals has reversed the dispositive findings of fact of the Trial Court without advancing any reason therefor, and without mention of those facts or the defenses to which they were directed.

Judge Morris, in the District Court, held that the patent was invalid for the reasons, *inter alia,* (a) prior invention by Arnold[7] and (b) prior knowledge and use by Dr. DeForest and the Federal Telegraph Company [illegible] California[8].

We have considered the evidence bearing on these two separate defenses (*supra,* pp. 55-103). The trial of the cause consumed more that four weeks, extending from October 11, 1926, until November 11, 1926. Over three weeks of this time were consumed in the taking of testimony and evidence bearing exclusively on the fact issue of priority [illegible] invention by Arnold.

On this issue Petitioner presented, in open court, the testimony of eight witnesses. Respondent, likewise, on this issue presented the testimony of six witnesses. Sharp issues of fact were raised, and the solution thereof was largely dependent upon the credibility of witnesses.

These issues were determined by the Trial Court after seeing and hearing the witnesses testify and observing their demeanor and attitude while testifying. The Trial Court held, on this evidence, that if the subject matter of the Langmuir patent was patentable at all, it was first invented by Arnold and not by Langmuir, and held the patent invalid for this reason.

---

[7] Point III, *ante,* pp. 55 *et seq.*

[8] Point IV, *ante,* pp. 95 *et seq.*

Similarly, Petitioner produced the depositions of nine witnesses taken in California bearing on the defense of prior knowledge and use. Testimony of two witnesses was given in open court by Respondent, directed to the same subject matter.

The Trial Court, on this evidence, likewise sustained this defense.

The Court of Appeals, after the first hearing, in its *per curiam* opinion adopted as its own the findings and conclusions of the District Court (with Judge **Buffington** dissenting *without opinion*). On rehearing, however, the majority of the Court of Appeals reversed the above findings of fact of the Trial Court, which alone were dispositive of the litigation, without referring to the evidence, the defense to which it was directed, or the findings of the Trial Court, and hence without giving any reason whatsoever for so doing.

The rule of law applicable to the findings of fact by a Trial Court was stated by Mr. Justice **Holmes** in *Adamson v. Gilliland*, 242 U. S. 350, in the concluding paragraph of the opinion at page 353 as follows:

> "Considering that a patent has been granted to the plaintiff, the case is preeminently one for the application of the practical rule that so far as the finding of the Master or Judge who saw the witnesses 'depends upon conflicting testimony or upon the credibility of witnesses, or so far as there is any testimony consistent with the findings, *it must be treated as unassailable.*' Davis v. Schwartz, 155 U. S. 631, 636."

In the case at bar there was a conflict of testimony and the necessity of the Trial Judge passing upon the credibility of witnesses. Not only was there testimony, "consistent with the finding" of the Trial Judge but, as a reading of his opinion will demonstrate, and as we have shown, no other finding could reasonably have been made.

The reversal of the District Court by the Court of Appeals, under such circumstances, we assign as an error which should be corrected by this Court.

POINT VI.

The patent is invalid because of double patenting.

The Court below did not pass upon this defence.

The Langmuir patent in suit is void for the reason that Langmuir's assignee, the General Electric Company, previously sought and obtained a patent on the same invention in the name of its employee William D. Coolidge.

The application [1] for the Coolidge patent 1,203,495 [2] was filed on May 9, 1913. It disclosed the conception of a pure electron discharge tube, and particularly exemplified this disclosure in a high vacuum hot cathode X-ray tube. Thus, it disclosed the invention now claimed in the Langmuir patent and, quite unlike the original application for the Langmuir patent, the original application for the Coolidge patent *claimed* that invention.[3] It is clear that in May, 1913 the General Electric Company considered that the only patentable invention involved in the high vacuum tube had been made by Coolidge, and this invention was claimed broadly for Coolidge.

---

[1] Rec., Vol. 6, p. 941.

[2] Rec., Vol. 6, p. 1021.

[3] See for example, claim 9 of the original Coolidge application, Rec., Vol. 6, pp. 957, 958.

Between five and six months later, that is, on October 15, 1913, the General Electric Company filed an amendment in the Coolidge application with additional claims numbered 32, 33 and 34, specially emphasizing the broadest aspect of the invention as belonging to Coolidge.[4] Then, one day later, that is, on October 16, 1913, the General Electric Company filed a patent application in the name of its employee Langmuir. This is the application on which the present patent in suit issued. Consistently with the earlier Coolidge application and consistently with the amendment therein filed the day before, this Langmuir application explicitly acknowledged Coolidge's priority,[5] as Respondent admitted in its main brief in the court below (p. 241).

Also, consistently with the situation as it had been developed to that time, the Langmuir application made no claim to the high vacuum tube as an invention, but claimed only a specific process of effecting the evacuation of such a tube.

Again, on March 30, 1915 Respondent presented the broadest kind of a claim in the Coolidge case.[6] It is clear that when the Coolidge application was filed in May, 1913 and when the Langmuir application was filed in the following October, and as late as March 30, 1915, the position taken by the General Electric Company was that Coolidge was the inventor of the high vacuum tube. Whatever wavering attitude the General Electric Company may have shown in the meantime, *it claimed the invention of the high vacuum pure electron discharge tube in the Coolidge patent as it issued on October 31, 1916.* Among the claims of that patent, we direct attention particularly to claims 1, 16 and 32. Claim 1 is as follows:

---

[4] Rec., Vol. 6, pp. 969, 970.

[5] Rec., Vol. 6, p. 664.

[6] Claim 33, Rec., Vol. 6, p. 1007.

> "In a device for the production of X-rays, the combination of a tube provided with electrodes, the vacuum in the tube being so attenuated as practically to eliminate the production of positive ions, and means for generating electrons at the cathode or negative electrode substantially independently of the voltage impressed upon said electrodes".[7]

The only pretense of a distinction that this claim makes from the alleged invention of the Langmuir patent in suit is that this claim is limited "for the production of X-rays". Similarly for claims 16 and 32 of the Coolidge patent. In other words, the invention of the Langmuir patent was claimed for Coolidge within a certain domain, "for the production of X-rays". But it is not permissible to apportion a patentable monopoly *on a single invention* in separate patents according to different uses. The invention of the high vacuum electron discharge tube, if it be an invention, is a single invention, and the entire protection to which it is entitled must be had in one and only one patent. If, arbitrarily, the patentee chooses to restrict his claim to the field of X-ray uses, he may do so, but having received a patent on the invention of the high vacuum electron discharge tube, that patentee cannot secure another valid patent on the same invention. That is precisely what the

---

[7] Rec., Vol. 6, p. 1026.

General Electric Company is attempting to do by its Langmuir patent here in suit.

The last paragraph of the Coolidge patent before the claims, a paragraph that went in by attorney's amendment the last thing before allowance of the patent says:[a]

> "Certain broad aspects of the apparatus and methods herein disclosed are not of my invention but are the invention of Irving Langmuir and are defined by the claims of his allowed application [on which patent 1,558,436 was issued]."

Speaking strictly and properly, inventions are neither broad nor narrow; breadth and narrowness are attributes of claims of patent, not of inventions. The Coolidge X-ray tube as claimed in claims 1, 16 and 32 is one invention and the "broad aspect" is not another invention. Once having secured the grant of the Coolidge patent on a certain invention, whether or not there claimed as broadly as possible, the patentee, the General Electric Company, cannot thereafter have the Langmuir patent as a valid patent claiming that same invention, even though its claims be of different scope.

When the General Electric Company decided to change its position and claim the high vacuum electron discharge device for Langmuir, it failed to restrict all the claims of the Coolidge patent to *inventions* essentially distinguishable from what it later claimed for Langmuir. To illustrate the kind of restriction necessary, it may be noticed that the X-ray tube required a focusing shield, and it may be that Coolidge's provision of this element was an invention quite distinguishable from the invention of the high vacuum electron discharge tube. Many of the claims of the Coolidge patent refer to this focusing shield as, for example, claim 4.[9] If the Coolidge patent had been restricted to such claims, the case would have appeared much better for the General Electric Company in its effort to secure a broad patent for Langmuir instead of Coolidge. But by retaining claim 1 (quoted above) and claims 16 and 32 of the Coolidge patent, it claims the invention of the high vacuum electron discharge tube for Coolidge, and it cannot thereafter secure a valid patent on that same invention for Langmuir.

---

[a] Rec., Vol. 6, p. 1016.

The Langmuir patent is therefore invalid for *double patenting.*

> *Miller* v. *Eagle Manufacturing Co.*, 151 U. S. 186;
> *In re Dunbar*, 278 Fed. 334;
> *Thompson Spot Welder Co.* v. *Ford Motor Car Co.*, 268 Fed. 836;
> *Otis Elevator Co.* v. *Portland Co.*, 127 Fed. 557;
> *Palmer Pneumatic Tire Co.* v. *Lozier*, 90 Fed. 772;
> *Caldwell* v. *Firestone Tire and Rubber Co.*, 13 Fed. (2) 433;
> *American Bell Telephone Co.* v. *National Manufacturing Co.*, 109 Fed. 976;
> *Industrial Manufacturing Co.* v. *Willcox and Gibbs*, 112 Fed. 535;
> *Dey Time Register Co.* v. *Syracuse Time Recorder Co.*, 152 Fed. 440;
> *Pittsburgh Plate Glass Co.* v. *American Window Glass Co.*, 276 Fed. 187 (affirmed 276 Fed. 849).

---

[9] Rec., Vol. 6, p. 1026.

In *Miller* v. *Eagle Manufacturing Co., supra,* this Court laid down the broad principles relating to the question of double patenting, in the following language:

> "The result of the foregoing and other authorities is that no patent can issue for an invention actually covered by a former patent, *especially to the same patentee,* although the terms of the claims may differ; that the second patent, although containing a broader claim, more generical in its character than the specific claims contained in the prior patent, is also void; but that where the second patent covers matter described in the prior patent, essentially distinct and separable from the invention covered thereby, and claims made thereunder, its validity may be sustained.
>
> "In the last class of cases it must distinctly appear that the invention covered by the later patent was a separate invention, distinctly different and independent from that covered by the first patent; in other words, it must be something substantially different from that comprehended in the first patent. It must consist in something more than a mere distinction of the breadth and scope of the claims of each patent. If the case comes within the first or second of the above classes, the second patent is absolutely void".

The remaining cases above noted are all pertinent to the applicability of the doctrine of double patenting to the facts in the present case. Thus, in *In re Dunbar, supra,* the Court of Appeals for the District of Columbia held that "the same patentee" embraces a common assignee of two applicants.

The reasons for the doctrine of double patenting applied to a common assignee or patentee, as set forth in

Miller v. *Eagle, supra,* and developed more at length in *In re Dunbar, supra,* are matters of pure logic. Let us consider the specific case raised by the Coolidge and Langmuir patents. The Coolidge patent issued in 1916. Under that patent the General Electric Company secured a 17-year monopoly of the hot cathode pure electron discharge tube when used as an X-ray tube, an exceedingly important invention, according to Respondent's contention. In 1925, after it had enjoyed this monopoly for 9 years, the General Electric Company secured the grant of the Langmuir patent here in suit. This purports to give it a 17-year monopoly of the hot cathode pure electron discharge tube when used in any useful way, including its use for an X-ray tube. This is not a different invention. It is the same invention. The only difference is that in the later patent the exclusive right is stretched over a wider field of use that includes the field of the earlier patent, namely, the X-ray field. 17 years added to 9 years make 26 years, the entire term for which the General Electric Company seeks to monopolize the single invention of the hot cathode pure electron discharge tube. Its exclusive right to this invention should come to an end with the expiration of its first patent, the Coolidge patent of 1916, and the Langmuir patent should be adjudged invalid as an attempt at double patenting.

CONCLUSION.

It is respectfully submitted that the judgment of the Court below, based on the present majority opinion thereof, should be reversed and the decree of the Trial Court sustained.

Respectfully submitted,

THOMAS G. HAIGHT,
SAMUEL E. DARBY, JR.,
Counsel for Petitioner.

Of Counsel, as to "Point III" and the related part of "Point V" only (see the footnote on page 56),

CARL A. RICHMOND,
WILLIAM R. BALLARD.

LAWYERS PRESS, INC., 165 WILLIAM STREET, NEW YORK CITY, N. Y.

FILE COPY

FILE
MAY 1
CHARLES E

Supreme Court of the United States

October Term, 1930.

No. 630.

DeForest Radio Company,
Petitioner,

vs.

General Electric Company,
Respondent,

REPLY BRIEF FOR PETITIONER.

Thomas G. Haight,
Samuel E. Darby, Jr.,
Counsel for Petitioner.

Carl A. Richmond,
William R. Ballard,
Of Counsel as to the
Priority Issue only.

INDEX

PAGE

Respondent's Statement of the Case Is Misleading 2

The Asserted Dependence of DeForest and Fleming upon Gas 4

Amplifying Tubes 8

Respondent Now in Effect Withdraws Its Eleventh Hour Definition of the Invention Used to Obtain the Rehearing in the Court of Appeals 10

THE ARNOLD-LANGMUIR PRIORITY ISSUE 12

Misrepresentations of the Opinions of the Lower Tribunals 12

Disputed Questions of Fact 12

The Insinuation that the Telephone Company Appropriated the Invention from Langmuir 14

Arnold's Conception was Complete 16

Misrepresentations of Arnold's Disclosure of November 1, 1912 19

Pumping Audions in December, 1912, and January, 1913 21

Arnold's Philadelphia Audions 21

Langmuir's Admitted Lack of Perception in Relation to His Tube of August, 1912 23

Langmuir's Alleged "New Type of Discharge" 27

Langmuir's Work Recorded in His Notebook November 22, 1912 28

PAGE
Langmuir's "Now what I intend to do" 31
Langmuir and Alexanderson 31
White's Audion No. 2 32
The Rule of Morgan v. Daniels Not Applicable 33
Conclusion 34

Table of Cases.

Adamson v. Gilliland, 242 U. S. 350 13, 14
DeLaski v. Tire Co., 232 Fed. 884, 888 24
Morgan v. Daniels, 153 U. S. 120 33
Motion Picture Patents Co. v. Universal Film Co., 243 U. S. 502 34

Text Books.

Robinson on Patents, Vol. 1, Sec. 87 23

Supreme Court of the United States

October Term, 1930

No. 630

DEFOREST RADIO COMPANY,
Petitioner,
vs.
GENERAL ELECTRIC COMPANY,
Respondent.

REPLY BRIEF FOR PETITIONER.

Respondent's brief makes out its case of patentable invention for Langmuir by studiously suppressing the essential similarity in principle of operation between the modern vacuum tube and the earlier tubes of Fleming and DeForest, and by asserting, on the other hand, an untrue difference in principle of operation based upon matters of terminology or upon unsworn statements from patents, publications or advertising circulars—an asserted difference, moreover, which is positively denied by witnesses in this case, including Respondent's own expert, Hogan.

NOTE.—In this brief we refer to the copy of the opinions rendered heretofore which Respondent filed with its brief, using its same notation "Op. p.—."

Italics in quotations are ours, unless otherwise stated.

Respondent's Statement of the Case Is Misleading.

The attempt to suppress the essential similarity in principle between DeForest's original three-electrode tube and the tubes now claimed to infringe starts with Respondent's statement of the case. Without being able to criticize Petitioner's statement of the case, it has rewritten the statement of scientific principles involved, *to omit any reference to the all-important "space charge" effect.* On pages 8 and 9, which deal with the scentific principles applicable to both the new and old tubes (top of page 7), Respondent says that the variations in current in the output circuit of a three-electrode tube are due to "variations in the effective *potential of the plate*" (p. 8), where it should state that the variation in the output current is due to more or less *neutralization of the space charge effect,* explained in our brief, page 9; and it says further as to the effect of ionization,

> "The physical phenomenon is rather complicated but it is sufficient for the purposes of this case to know that when ionization is present in a tube, the gas acts as a sort of conductor increasing the current to a value beyond what it would be at the same voltage in the absence of ionization."

The effect of ionization is no more complicated than the rest of the things Respondent was here explaining. This is merely a convenient way of avoiding reference to space charge, which is the controlling characteristic in the operation of both the old and the new vacuum tubes. It is not true, as Respondent here states, that "the gas acts as a sort of conductor." In both DeForest's tube and the modern tube the current consists entirely of electrons. The gas is no more a conductor for the current in earlier DeForest tubes than it is in the highest vacuum tubes made today (in which there is always some gas). What Respondent should have said at this point is that when ionization occurs, the positive charges of the ions begin to neutralize the space charge caused by the crowd of negative electrons around the filament and that, because of this neutralization, more of them are free to pass across the tube to the plate; and that if the neutralization continues to increase, due to increased ionization, the space charge will entirely disappear.

The importance of this point in the case arises from the fact (noted on p. 10 of our brief) that *the characteristic operation of* **all** *three-electrode tubes*, and especially when used as amplifiers, *depends upon a varying neutralization of the space charge* in the tube *by the varying potential imposed upon the grid electrode.* This is the celebrated "grid effect" which made the three-electrode tube so important and useful in modern industries. It is the thing which enables the three-electrode tube to reproduce in its output circuit a perfect copy, in enlarged form, of any current variations imposed upon its input circuit. *If the gas content of the tube, and so the ionization, is great enough to destroy or to seriously impair the space charge, then the three-electrode tube ceases to function according to its characteristic principle of operation.*

It is this principle of operation which was fundamental and characteristic with the earlier DeForest tubes, just as it is the characteristic which makes the modern tube operative and valuable. *If the earlier DeForest tube had enough gas in it so that in operation the space charge was neutralized, it could not have operated in its characteristic and intended manner.* The amount of power which an early DeForest tube could have handled without destruction of the essential space charge depended upon the degree of the evacuation, it is true, but this is just as true of the tubes made in accordance with the patent in suit, which clearly states in its own specification that the degree of evacuation is to be proportioned to the voltage which it is intended to apply in use, that is, the power it is intended to handle (Rec., Vol. VI, p. 779).

The *characteristic* principle of operation of both the earlier DeForest tube and the modern tube is, therefore, *the control of an electron flow by the combined effect of grid and space charge.* This is the important and essential similarity which Respondent would conceal in its method of stating the principles involved.

The Asserted Dependence of DeForest and Fleming upon Gas.

Having thus omitted to state the essential characteristic of operation in three-electrode tubes,—both DeForest's early tube and the modern tube,—Respondent then proceeds to assert that the characteristic principle of DeForest's tube was due to gas effects, while the tube of the patent relies upon a pure electron flow.

In support of this, Respondent cites four instances where Fleming refers, in published papers, to "gaseous conduction" or the "conductivity of ionized gas" (p. 24).

These do not even tend to prove the point. They are instances of the use of a standard terminology to which we refer on page 45 of our main brief, and they are statements by one who, as there pointed out, insisted on the elimination of every possible remnant of gas. It cites next two statements of DeForest which are nothing but guesses made by DeForest at the early date of 1906 as to the theory of operation of his audion tubes. Neither DeForest nor anyone else in the world understood the underlying principles of these tubes at that time. It next refers to a DeForest application containing references to the ionized gas in audion tubes, which is on a par with the statements of Fleming already referred to. It next refers to a statement by Gernsback which it dignifies as part of a "critical study" of the audion. Gernsback had no standing in the art and most evidently knew little or nothing about the subject. He was merely accepting current terminology for vacuum tube operation. Next, Respondent refers to an advertising circular of the DeForest Company which seems to us is entirely disposed of by our observations on page 54 of our main brief. Next, it refers to a von Lieben *et al.* patent which it says covers a device "seriously considered by the Telephone Company for telephone relay uses". Its adoption was *not* seriously considered and there is no evidence that it was. It was merely exhibited by the inventors on their own motion. *It* was *indeed* a device depending upon a gas content, and quite different in this respect from the DeForest audion. Observations as to its operation have no more relevancy to the DeForest tube than observations as to the operation of a Hewitt mercury vapor lamp would have, (to which Respondent also refers further along).

Next, Respondent cites Whitney's mistaken understanding that some gas was necessary in order that electrons might be emitted from the filament. The record shows clearly that both Whitney and Langmuir were not abreast of the scientific knowledge on this and related facts. Others, such as Millikan, Richardson, Arnold, Wehnelt, J. J. Thomson, H. A. Wilson, and Lilienfeld, knew well that gas was not essential to the discharge. Next, Respondent cites the Arnold application in which it is merely stated that it had "been commonly *supposed*" that ionization was necessary for a vacuum tube to "operate efficiently". Next come two quotations from Langmuir's testimony, one asserting that Fleming and DeForest depended upon gas ionization, and the other asserting that the gas ionization in these devices, due to the fact that they were "poorly exhausted", modified and partly eliminated the space charge and otherwise interfered with their operation. Next, Respondent again quotes the Arnold patent application as in turn quoting the DeForest patents to the effect that gas ionization was involved in his tubes, and quoting the Fleming patent as indicating the same.

The character of this evidence is not impressive for the establishment of the scientific fact essential to Respondent's argument. Even standing alone, we think it would be far from sufficient for its purpose. *The fact is, however, that it is directly contradicted by Respondent's own expert Hogan, who testified in this case in open court.* His testimony, to which we have referred in our main brief (p. 51), was not, as suggested by Respondent (on p. 35), quoted from some other case without authority of the witness himself. This testimony was read to Hogan while he was on the witness stand and he fully confirmed and adopted it in this case as his testimony (Rec., Vol. I, pp. 113, 117, 118, 120), and it is, as we have already pointed out, to the effect that the early DeForest audion with which Hogan was very familiar did *not* operate upon any different principle from the high vacuum tubes then in use by the Telephone Company which, as Respondent itself asserts (brief, p. 35), are tubes within the scope of the patent in suit. *This is the direct and positive testimony of Respondent's own expert given in this case when he was subject to examination by both parties,* and must certainly far outweigh the desultory and fragmentary comments which we have reviewed above.

As to the Fleming valve, the testimony of Waterman is equally positive. Waterman was not called as a witness in this case but his testimony in the *Marconi* suit was stipulated into this case as substantive evidence (Rec., Vol. III, p. 1485), and when given was subject to cross examination by an adverse interest. We reviewed it on pages 49 and 50 of our main brief.

We confidently assert that the court cannot find on the evidence in this case that the early DeForest tubes were operable only because of ionization which occurred in them and that the modern tubes asserted to infringe operate upon an entirely different principle; but on the contrary must find that the *principle of operation of both the early DeForest tube and the modern tube is control of an electron stream by the combined effect of the grid and space charge.*

Indeed, a most conclusive proof that ionized gas was not the "conductor" of the current in the early Fleming and DeForest tubes is the fact that *when the gas is removed—*

when the highest vacuum that Langmuir advocates is obtained—*the current is still conducted across the tube.* Moreover, it was usual to use tubes below ionization voltages from the earliest days of the Fleming and DeForest tubes. If those tubes operated, as they did, when there was practically *no* gas ionization, how can it be seriously believed, as Respondent contends, that ionized gas constituted the "conductor" upon which the operation of the tubes depended. Quite obviously the fact is, as the *evidence* shows, the tubes have always depended upon electron flow, and have been useful solely because of that fact.

In this connection we must point out how unwarranted is the comparison (on p. 35 of Respondent's brief) of the testimony of Millikan in the *Hewitt* suit with the testimony of Hogan, above referred to. In the first place, the testimony of Millikan in the *Hewitt* suit was not made evidence in this suit, and second, the testimony referred to contrasted the *Hewitt mercury vapor lamp device* with the high vacuum tubes of the Telephone Company. The Hewitt mercury lamp device, as every one knows, operated by reason of a heavy mercury vapor boiling out of a pool of mercury and filling the tube during operation, and had nothing in common with the three-electrode tube either of DeForest or of the Telephone Company.

Amplifying Tubes.

Langmuir testified in this case that when ionization was sufficient to materially affect the operation, an *amplifier* tube was most sensitive at about 27 volts and that amplification practically disappeared in the neighborhood of 40 volts. Respondent objects (p. 55) to our reference to this testimony to indicate that DeForest's tubes, as used by him, and as demonstrated to the Western Electric Company in 1912, with voltages ranging from 35 to 60 and over, could not have been affected materially by gas ionization. It says this is unfair because Langmuir testified as to "a particular tube" and that the conclusions cannot be generalized. But Langmuir's testimony was not concerned with the action of one tube. *He was endeavoring to show a general principle*, namely that the presence of gas increased the amplifying action but *very strictly limited the range of voltage usable* if amplification was to be attained (Rec., Vol. 2, p. 1261) and he put in the testimony "to illustrate" the point. Nor did he depend upon one tube but refers to tests upon a number (Rec., Vol. 2, pp. 1264-66). In one case the maximum amplification was at 27 volts while with 30 volts the tube, he says, "is a very poor amplifier, poorer than if it had a good vacuum" (Rec., Vol. 2, p. 1264, bottom). Another tube which he refers to as a "third tube" showed a maximum amplifying power at 24 or 25 volts which fell "to practically nothing at 30 volts" (Rec., Vol. 2, p. 1266).

DeForest demonstrated his amplifier tube to the Western Electric Company at a voltage of approximately 40 (Interf. Rec., Vol. II, line 6, p. 2166) and he was using amplifier tubes in the Federal Telegraph Company's service with voltages considerably greater than 50 volts.

This testimony also shows therefore that the characteristic operation of the DeForest amplifiers was not the characteristic operation of an amplifier depending upon gas ionization. It is the testimony of Respondent's own witness,—the alleged inventor—and cannot be overcome by speculative references to supposed theories of operation found in publications or papers dating back to the time when people did not understand the underlying principles of the audion.

This testimony as to amplifier action is peculiarly important because it is essential to Respondent's present argument to show that the *amplifier* tubes of DeForest *depended upon* gas ionization. As to the detectors, everyone agrees that an ionization effect was, in general, desirable. Langmuir himself testified:

> "I think everybody recognizes that in detector tubes gas greatly increases the sensitiveness as a detector in those parts of the curve where the curvature is made abnormally large by the presence of gas" (Rec., Vol. 2, p. 1264).

Respondent Now in Effect Withdraws Its Eleventh Hour Definition of the Invention Used to Obtain the Rehearing in the Court of Appeals.

As we point out in our main brief (p. 41), where Respondent stated to the court below that Langmuir's invention consisted of taking out a gaseous conductor upon which DeForest and Fleming depended, its argument required that it assert this as a scientific fact and not as a mere mistaken supposition by early commentators because in the latter case it would be crediting Langmuir merely with furnishing an explanation of an existing thing and not with producing a new thing.

In its brief before this Court (p. 22) Respondent practically withdraws its eleventh hour definition which served it so well at the rehearing. This is not surprising because it is evident that it will not stand up in the face of the testimony of Langmuir himself to which we have referred in our main brief (p. 46). In withdrawing from this untenable position, however, Respondent attempts to do it so adroitly as not to lose any benefit it may have gained from its erroneous statement. It asserts now that its eleventh hour definition was not a new definition at all but was the same one which it had used throughout the litigation. This is obviously not so as appears from a mere comparison with the definitions quoted by Respondent at pages 19 to 21. The point of the earlier definitions is that the operation is by electron flow substantially unaffected by ionization, which brings the asserted difference between the old and the new tubes back to a difference in degree of ionization involved or of vacuum attained.

If Respondent were willing now to stand by its statement that the eleventh hour definition means merely the same thing as the earlier definitions just referred to, we would have no objection. But while saying this at one place it still refers continuously elsewhere in the brief to the "gas conductors", etc. of the earlier tubes. Apparently the purpose is to withdraw from its untenable position when it is directly attacked, while attempting to obtain the benefit of the asserted but unreal difference by mentioning it elsewhere as if it were real and admitted.

The Arnold-Langmuir Priority Issue.

Misrepresentations of the Opinions of the Lower Tribunals.

Respondent states at page 18 that, "The question of priority was decided by the Patent Office Tribunals in favor of Langmuir". This statement is repeated at page 58. It is not correct. The ultimate authority of the Patent Office, the Commissioner of Patents, decided priority wholly against Langmuir, and wrote a full opinion explaining precisely how he reached his decision (Op., pp. 83 to 90). We believe this Court will find his opinion to be better considered and more convincing than either opinion of the two tribunals of the Patent Office below him.

Another error is the statement at page 60 (also at p. 76), that the District of Columbia Court of Appeals was "following" the Board and thereby held that Langmuir conceived in August, 1912 and reduced to practice in November, 1912. On the contrary the Court of Appeals *attempted equally* to follow the two lower tribunals of the Patent Office (Op., p. 95, line 9) one of which assigned the dates above mentioned, and the other of which assigned April 15, 1913 for Langmuir's first date of invention (Op., p. 47, line 3).

Disputed Questions of Fact.

Respondent asserts (p. 84) "that this case turns on inferences or conclusions to be derived from substantially undisputed facts, and not upon findings of fact based on conflicting testimony", and that this Court's ruling in

Adamson v. *Gilliland* has no application to the case. This is not correct.

Langmuir testified that certain phenomena observed in his laboratory in August, 1912 indicated the presence of the invention. Respondent presents this testimony at length in its brief at pages 62 to 66. Petitioner's witness Becker testified that the phenomena must have occurred without the presence of the invention (Rec., Vol. 3, pp. 1791 *et seq.*). Respondent mentions Becker's testimony at the top of page 74 and context and goes on to say that "Langmuir's testimony in rebuttal (Vol. III, pp. 1916 to 1923) completely disposes of Becker's suggestion * * *." Here Langmuir tried to contradict Becker on the scientific facts. These facts were in dispute. A reading of the testimony of the witnesses shows Becker's superior knowledge and accuracy of statement, but this can scarcely put one in the position of Judge Morris who heard and saw these witnesses and decided in favor of Arnold.

Arnold testified, with corroboration by Jewett and Colpitts, that he fully disclosed the plan of the invention to them on November 1, 1912. In reply, Respondent quotes (p. 77) Langmuir's testimony *given not in court but in prepared affidavits for the earlier interference proceeding.* In these, Langmuir attempted to contradict Arnold. The Trial Court accepted the testimony of Arnold and his corroborating witnesses (Op., p. 122 and context).

It is interesting to notice that Respondent's references to the record for Arnold's testimony in its argument against him are almost all to the Interference Record, which it cites as "I. R." In fact its references are to Langmuir's attempted contradictions of Arnold. But Judge

Morris heard Arnold and saw him on these matters, and of course heard and saw Langmuir but did not permit him to testify as an advocate (Rec., Vol. 2, pp. 1117 to 1119, 1137, 1159, 1160, 1167, 1168, 1209, 1210, 1240, 1241) as he had done in his prepared affidavits. Judge Morris was the only tribunal that saw and heard these witnesses.

Respondent asserts (pp. 78 to 80) with urgent emphasis that Arnold did not know how to get the necessary vacuum for the invention, and that thus he lacked the "idea of means". This is simply to invite disbelief of the testimony of Dr. Millikan that he himself had instructed Arnold fully in an adequate "idea of means" (Rec., Vol. 1, pp. 442, Q9, to 449, Q22; also pp. 457, Q38, to 459, Q43). The District Court heard and saw Dr. Millikan. It had to appraise Millikan's testimony, to which Respondent's argument is in opposition.

Respondent says (p. 81, top) Arnold did not appreciate his audion 7-A. Arnold says he did appreciate it (Rec., Vol. 2, p. 759, Q743). It was for Judge Morris to weigh his testimony, which Respondent now disputes.

Obviously, therefore, the doctrine of the case of *Adamson* v. *Gilliland* is applicable, and is conclusive to the present case.

The Insinuation that the Telephone Company Appropriated the Invention from Langmuir.

This insinuation appears at pages 59, 80 and 83 of Respondent's brief.

Although both Langmuir and Arnold testified in regard to the occasion of the paper that Langmuir "orally summarized" Arnold never admitted that the invention was disclosed in any way, and Langmuir made no specific nor direct assertion to that effect. Against Respondent's insinuation that the Telephone Company learned first of the invention on this occasion, there are the following considerations:

(a) There is the explicit affirmative testimony of Arnold and his witnesses that Arnold made and disclosed the invention about a year earlier, and that in the meantime he and his associates pursued the activities naturally consequent on such disclosure as narrated in our main brief.

(b) The only written record of Langmuir's talk is an "abstract" prepared and published by him, which makes no disclosure of the invention whatever (Rec., Vol. 6, pp. 1361-2, Deft's. Ex. 326). Of all the many persons who heard Langmuir, none was called as a witness.

(c) Three days before the talk, Langmuir made oath to the application for the patent here in suit with disclosure and claims diametrically opposed to the fundamental condition that Respondent now insists is most essential for realizing the invention. It ought not to be supposed that Langmuir had reversed himself in those three days (Rec., Vol. 6, p. 659 *et seq.*, Deft's. Ex. 62; see especially the mention of "bombardment without heating", etc., pp. 665, 667, 668; the date of the oath is on p. 674; see claims numbered 1, 3 and 5 on pp. 672, 673).

(d) About five months before this Langmuir talk, the General Electric Company had filed a patent application claiming the invention here in issue for its employee Coolidge instead of its employee Langmuir, and in the said

Langmuir application executed three days before the talk, Langmuir explicitly identified the Coolidge application and acknowledged Coolidge's priority. It ought not to be supposed that in his talk Langmuir disclosed what he then regarded as Coolidge's invention (Rec., Vol. 6, p. 664, Deft's. Ex. 62, p. 941 *et seq.*, Deft's Ex. 67; Respondent admitted in its main brief below, p. 241, that the original Langmuir specification acknowledged Coolidge's priority).

On page 80 of Respondent's brief it is stated "Arnold never succeeded in making any good tubes until after Langmuir's Physical Review paper was published." This statement is contradicted by the evidence as to tubes made by Arnold and to which we have referred on pages 72 to 77 of our main brief. Arnold had tubes in commercial operation in the Telephone Company's plant for a month or two prior to the publishing of the paper referred to.

Arnold's Conception Was Complete.

Respondent's attack on Arnold's invention (pp. 78 to 83) consists chiefly in the assertion that "Arnold had no adequate idea of means." The context shows that what Respondent means by this is that Arnold did not have an adequate idea of means for *manufacturing* his tubes, especially for getting a good enough vacuum.

There are two answers to this: first, it is not true, and second, if true, it would not mean that Arnold had not a completed conception. We have pointed out (Main Brief, p. 65) that Dr. Millikan very positively testified that he had, years before, taught Arnold all of the requirements for high evacuation which are taught by the patent in suit.

And he testified further that the means he had thus taught Arnold would be perfectly adequate to turn a DeForest tube into a tube which would stand 100 or 200 or more volts and give "regular reproducible operation" free from "harmful ionization". We think it is ridiculous, therefore, to say that Arnold had no knowledge of the mechanism for producing high vacua.

But in using this argument Respondent shows a lack of familiarity with the law applicable to the situation. The patent law requires, for a complete conception of an invention, that it include a *definite idea of means for accomplishing the intended result.* This is apparent from the quotation from Robinson (p. 23, *infra*) stating the nature of the inventive act, and is amply supported by authority. This rule of law does *not*, however, mean that the inventor of a device,—having conceived a useful object to be attained and also a useful mechanism for attaining that object, must also conceive methods or apparatus for manufacturing that device. Methods of manufacture or machines for manufacturing may be inventions in themselves but they are inventions quite apart from the device which it is intended to manufacture. Arnold's conception was of a device *for amplifying speech currents.* He conceived the purpose to be attained and he conceived means for attaining it, namely a DeForest audion in which the vacuum was improved to the point where gas did not affect the operation at the required voltages. That is a complete conception of the alleged invention here in question, including a "complete and adequate idea of means" *for amplifying voice currents.* We have shown (Main Brief, pp. 21 to 25) that all of the *means for getting a vacuum* which are taught by the patent in suit are also taught by prior patents and publications, and as already noted, Arnold himself knew of these things. But manifestly, these methods of manufacture are no part of the alleged invention here in controversy.

On November 1, 1912, Arnold proposed to get his high vacuum by the use of a mercury pump, to which he had been accustomed, supplemented by liquid air and charcoal to exclude mercury vapor. He soon learned that liquid air was difficult to obtain at that time, and he changed his plan and decided to use a Gaede molecular pump. In the last sentence of the first full paragraph on page 79, it is insinuated that there was something reprehensible in this change of plan. However, this Gaede molecular pump to which Arnold changed his plan, and which he procured and put in operation as soon as possible, is precisely the means recommended by Langmuir in his patent and at many other places, for getting the requisite vacuum.

At the middle of page 79 Respondent says that nowhere in the records until October, 1913, "did Arnold make any reference to this *new* idea of means". This statement is not correct. Defendant's Exhibit 248 (former 11) is a copy of the order for the new Gaede molecular pump, dated January 23rd and 24th, 1913. Defendant's Exhibit 250 (former 13), dated April 23, 1913, notes the arrival of the "new molecular pump", and Defendant's Exhibit 255 (former 18), page 105, with date April 25, 1913, notes "audion 20.2 re-evacuated with Gaede molecular pump" and goes on with a record of its successful tests thereafter for which the data were mentioned at the top of page 74 of our main brief. There is another explicit and favorable record of use of the same "molecular pump" at pages 114, 115 of this same exhibit.

Instead of facing the facts, respondent tries (last paragraph on p. 79) to convict the Telephone Company of inconsistency in applying for a patent on a specific use of the evacuation process that Arnold had learned from Dr. Millikan. This application was a mistake in its first claims as explained in the testimony of Folk (Vol. 3, pp. 1858-1862) and Arnold (Vol. 2, p. 785). When the mistake was apprehended the corresponding claims were cancelled. Respondent did not hesitate to put Coolidge on the stand to testify that certain claims made by him were a mistake (Rec., Vol. 3, pp. 1524-1526).

Misrepresentations of Arnold's Disclosure of November 1, 1912.

On pages 76 and 77 Respondent seeks to make it appear that Arnold was interested in improving the DeForest audion only far enough to get rid of "blue haze". This seems to us a rather ridiculous attempt. What Arnold admittedly proposed to Jewett and Colpitts was to improve the vacuum in the DeForest audion so that it would stand sufficient voltage to serve as a practical telephone amplifier. Blue haze was sometimes (though not frequently) referred to as an indication that gas effects were present when they put too much voltage on DeForest's tube, but it obviously was referred to as a symptom and not as the disease which it was intended to cure. The witnesses testified repeatedly without mention of blue haze as a criterion. Arnold said:

> "I explained to Mr. Colpitts that the *erratic behavior* of these audions was no doubt due to the re-

> sidual gas in them. I had become very familiar with the effects of gas * * * I knew there would be a great gain in steadiness of behavior if *all gas* could be eliminated * * *" (Interf. Rec., pp. 2166, 2167).

Jewett testified that Arnold's proposed improvement was

> "a tube like these DeForest audions but with greater electron emission and so much better evacuated that *erratic behavior* due to positive ionization would be eliminated * * *" (Interf. Rec., p. 2219).

and Colpitts testified:

> "This view of the proper audion operation *as being substantially unaffected by positive ionization* was held all along by Dr. Arnold and myself after our discussion on November 1, 1912" (Interf. Rec., p. 2228).

For Arnold and Langmuir alike, blue glow is a test *sometimes* used. Langmuir's witness, Dushman, relied on it almost exclusively (Interf. Rec., p. 2136, line 3 and line 5 from bottom, p. 2137, line 10 from bottom and p. 2138, line 9). The whole testimony on the subject shows that Arnold placed his main and overwhelming reliance on the third electrode test (Interf. Rec., pp. 2181 *et seq.*), which is fully endorsed by Dr. Millikan (Rec., Vol I, p. 454, Q31). For example, on November 29, 1912, Arnold made an elaborate experiment recorded in Defendant's Exhibit 244 (former 7), pages 32 to 35, that was fundamentally based on this approved test and thereby he demonstrated he had a pure electron discharge up to 80 volts on that occasion.

Pumping Audions in December, 1912, and January, 1913.

The re-pumping of DeForest audions in December, 1912, as described in Respondent's brief in the first complete paragraph on page 80, is a misrepresentation in two respects: (1) It was not an effort to realize Arnold's invention, but merely to discover whether the audions that came from the hand of DeForest had as good a vacuum as could be secured by an unaided mercury pump. (2) Arnold's testimony quoted in the third complete paragraph on page 80 of Respondent's brief, refers to an *entirely different matter.* This refers to some audions that Arnold had directed Trimble to make in order to acquire the necessary technique with filament cathodes As to these, the testimony is very complete (Interf. Rec., pp. 2190 to 2192, 2246, 2247; Rec., Vol. 2, pp. 661 to 664), and shows that after some failures, Trimble learned how to manage the filaments and made some audions that were very good, except they were not sufficiently evacuated. When the new molecular pump that had been ordered from Germany arrived, it was used to re-evacuate these same Trimble audions and they were proved by test to be high vacuum audions (our Main Brief, p. 73).

Arnold's Philadelphia Audions.

Selecting part of the testimony instead of the whole, Respondent (p. 82, bottom) finds "30 to 50 volts" mentioned in remote connection with the audions used at Philadelphia in the latter part of 1913. These figures appear not in "written instructions for the use of these tubes", as Respondent asserts, but in an elementary presentation of their theory of operation (Deft's. Ex. 260, former 23). They relate to a certain one-way amplifier which was never used at Philadelphia, all the amplifiers for that use being rigged up in two-way repeater systems. What the whole testimony shows, instead of a selected part, is that Dr. Kelly actually produced two tubes that were used at Philadelphia, and that he tested them by methods approved by Dr. Millikan; he found they had extremely high vacua and would go to voltages as high as 100 volts. Instead of a limit of 0.005 watts as Respondent tries to imply at the middle of page 83, though it does not assert it exactly, Kelly tested these tubes to values 8 and 11 times as high as 0.005 watts (Rec., Vol. 2, p. 812, Q6 *et seq.*, and p. 830, Q42 *et seq.*).

Respondent scorns "30 to 50 volts" when it is the voltage of an Arnold tube, but often points with pride to voltages within the same range for Langmuir tubes. In the interference proceedings, with the utmost ostentation, Langmuir produced a tube which he made in 1914 and demonstrated it as an exemplification of his invention. He went to 50 volts only, pointing out that this was the limit for that tube (Interf. Rec., pp. 1483 to 1488, 1591 to 1595, particularly paragraph 10 on pp. 1594 and 1595). Of the many tubes made by his company during the war, and which he asserts were examples of his invention, over one-half were type G pliotrons (Interf. Rec., p. 1178, compare p. 528). For these, Langmuir himself stated, "The normal operating anode voltages range from 18 to 44 volts" (Interf. Rec., p. 1181).

Langmuir's Admitted Lack of Perception in Relation to His Tube of August, 1912.

On page 66 Respondent describes the deficiency in Langmuir's August work with his tube as a failure to "understand the theory of its action" and the same idea is advanced on pages 70 and 71. *This was not the trouble with Langmuir's August work.* His trouble was he had not *made* any invention, at all.

An invention in the sense of the patent law, as Robinson on Patents points out, involves "(1) the idea of an end to be accomplished; (2) the idea of a means by which that end can be attained."* In his August work, Langmuir was attempting to discover some principles of natural law (the rate at which gas in a tube "cleaned up" under the action of the "Edison current"). From his own admissions it is clear that he had no idea either of a practical purpose to be accomplished in the useful arts, nor of any means for accomplishing such a purpose. This will be perfectly manifest from the testimony on the point which is referred to in our main brief, pages 83 and 88.

We quite agree with Respondent that it is not necessary for an inventor to understand the scientific theory of his invention, but that is quite a different thing from having no idea at all either of a useful purpose to be accomplished or of a mechanism for accomplishing it. Langmuir had before him a physical tube by which he was attempting to formulate some physical laws, but the evidence is clear that it did not even occur to him then that he had a pure electron discharge (as a matter of fact he did *not* have one), and it is not even claimed that he thought of any useful purpose the tube would serve.

---

* Robinson on Patents, Vol. I, § 87.

Exactly here is where the attempted analogy to the "feed-back" case referred to by petitioner on page 73, falls down. In the "feed-back" case DeForest had a physical thing which he was using to produce a commercially useful product, viz., alternating current, and he was doing it by a device never before used for that purpose. Having thus accomplished a useful end by a new device, it was, of course, not necessary that DeForest understand his theory of operation. Respondent states that "there was not a word of evidence in that case that DeForest then appreciated any utility for the thing". This is not true. The testimony of DeForest, Van Etten and Logwood in that case was that they all appreciated the utility of the device. The law, of course, does not require an inventor to appreciate the full, or even the greatest utility, of his invention. But it does require him to have in mind the accomplishment of some purpose useful in the arts. In this connection Respondent seems to entirely misapprehend the effect of the cases cited in our brief (pp. 81-83) and discussed by it on page 71. *The point of these cases is that we cannot find invention except as it arises in the mind of an inventor* (or discoverer). The fact that a physical thing may exist either in nature or through human agency is of no benefit to mankind and of no consequence in establishing the existence of an invention *until it is perceived by somebody to have a useful application* and until the method of applying it to the accomplishment of the useful purpose is recognized. As Judge LEARNED HAND aptly puts it in *DeLaski v. Tire Co.,* 232 Fed. 884-888:

> "Yet invention necessarily involves a conscious element. It is the imaginative projection of an integral ideal of certain selected natural objects. The fortuitous juxtaposition of the elements without any conscious recognition of some pragmatic relation is sterile and valueless."

The attempt on page 72 to meet this difficulty by asserting that Langmuir's August tube *could* have been used as a rectifier fails, first because it is not shown that either Langmuir or anybody else realized that it was useful as a rectifier, and second, because if we *assume* it was useful as a rectifier, there still is no evidence that it was any different sort of a rectifier from that already employed and patented by Fleming. To make it an invention in the rectifier art by Langmuir it would have to appear that it was a rectifier different from Fleming's *and that Langmuir recognized that it was.* There is no testimony that either of these things was true.

The statement on page 74 that Langmuir did rectify alternating current with such a tube in November, is quite misleading. Langmuir says plainly that he applied alternating current to his November tube merely to see what effect it would have upon the electron emission of the filament, and to get a voltage higher than was available with his direct current source (Rec., Vol. 2, p. 1165), not for the purpose of rectifying alternating currents or to see whether that tube rectified any differently from the Fleming tube. He still was interested merely in discovering scientific laws and not at all in producing a new and useful device.

Moreover, Becker's analysis of Langmuir's data established that the alleged rectifier was indeed a gassy tube. Langmuir pronounced a like tube to be a gassy tube when it had an exponent as great as 1.71 for its current-voltage relation (Pltf's. Ex. 21, p. 407), and yet this tube had an exponent of 1.73 (Pltf's. Ex. 100, "Plots", 7th sheet, "R. S. 1353-5"). By so much more was this a gassy tube. On different occasions with different voltages it gave currents that were greater with less voltage (exactly contrary to the behavior of a high vacuum tube), and indeed we find in the contemporary record the entry "rise in pr. [pressure] due to heating of anode" (Pltf's. Ex. 100, pp. S. 1353 and context). Of course "pressure" means *gas*.

Petitioner's witness, Becker, made a tube substantially like Sweetser's tube of August, 1912, and duplicated the experiments which Respondent describes at length on pp. 63 to 66 of its brief. That Becker's tube was substantially a duplicate of Sweetser's tube was admitted by the Respondent at page 247 of its main brief in the District Court. Becker went on and proved (Rec., Vol. 3, pp. 1801, *et seq.*) that when the phenomena described by Respondent occurred, there was a very substantial quantity of gas in the tube, so much that the current was twice its pure electron discharge value. Becker's tube presents a dilemma for Respondent. Plainly it does not embody the invention, and hence the Sweetser tube of which it is a duplicate could not have embodied the invention. Or, if Respondent should choose to repudiate its admission that the Becker tube is a duplicate, then no one knows how to build a duplicate of the Sweetser tube, and therefore, the alleged invention thereof is lost.

Respondent's statement at the bottom of page 73, that Becker admitted Langmuir had "a new type of discharge" is a perversion of his testimony. A reference to the record will show that Becker was simply describing a succession of events, and when he said "a new type of discharge" he merely meant "new" as compared with what immediately preceded. Indeed a little earlier on the same page Becker stated "the phenomenon was not new". And as to Becker's admission that the current was limited by space charge, he explained that he meant a partial space charge, and Langmuir himself has admitted that such partial space charges were old in the prior art. "Of course, even in gaseous discharges, the current, as has been recognized for the last 20 years, is often limited by space charge, * * *" (Interf. Rec., p. 1475).

The only purported study of the Langmuir-Sweetser August, 1912 work that has ever been recorded by any tribunal with a result favorable to Langmuir, was by the Board of Examiners in Chief in the Patent Office. Subsequently thereto, two very careful studies were made, both with results *un*favorable to Langmuir, one by the Commissioner of Patents (Op., pp. 83 to 85) and the other by Judge MORRIS in the Delaware District Court (Op., pp. 123 to 124).

Langmuir's Alleged "New Type of Discharge".

At the bottom of page 77, Respondent refers to a "new type of discharge", and on page 5 it says that this "distinguishes" the invention, thereby claiming that Langmuir's invention involves a new type of discharge as contrasted with that found in the DeForest tube even when operating at voltages such as used when it served beautifully to amplify weak speech currents in the demonstration before Jewett, Colpitts and Arnold. We have already pointed out (Main Brief, pp. 26 to 28) that there is no new type of discharge involved in the tube of the patent in suit. The fact that the DeForest audion worked properly to amplify voice currents only when used with voltages approximating 40 does not mean that the discharge was of a different type from that referred to in the patent in suit. On the contrary, the patent in suit definitely says that the *tubes of the patent are exhausted with respect to the particular voltage with which they are to be used* and makes it perfectly clear that, if a tube is made in accordance with the patent to stand a voltage of 50, then 50 volts is the critical value for that tube, and that if used with higher voltages harmful gas effects may be expected to appear, notwithstanding that the tube entirely complies with the requirements of the patent and falls within the claims of the patent (*e. g.*, claim 26).

Langmuir's Work Recorded in His Notebook November 22, 1912.

With reference to this work, Respondent states at page 67, line 9 from bottom, that "Langmuir immediately disclosed these results to his associates", and refers to page 2123 of the Interference Record. We ask the Court to turn to this page and see whether it finds therein any disclosure of the invention. So far is the record on which Respondent relies from such a disclosure, that its conclusion is as follows:

> "A plausible hypothesis to account for some of these effects, is that a small amount of some gas

> such as argon, always remains in the lamp'' (Interf. Rec., p. 2124).

In other words, what the disclosure amounts to is that Langmuir had gas effects instead of a pure electron discharge.

When pressed on cross examination, Langmuir named five persons with whom he discussed this "important" work (Rec., Vol. 2, pp. 1368, *et seq.*). Aside from Coolidge, whom we have discussed at page 89 of our main brief, not one of these gave any testimony to a disclosure of the invention.

The notebook entry of November 22, 1912 to which Respondent refers on page 67, may state a "theory of Edison current'' that was "new'' to Langmuir at the time, but every word of it except the part that Langmuir admits to be erroneous, is found more fully and clearly stated in the previously published papers by Lilienfeld and Child.

The attempt to get Richardson's endorsement at the bottom of page 68, is a perversion of testimony. In the words that follow immediately after the quotation from Richardson, "I was naturally very pleased * * *", Richardson goes on and explains that the "current limitation" *was due to electrostatic charges on the tube walls.* Respondent does not like this explanation and therefore cuts off this part of Richardson's testimony, and supplies Counsel's version, "The 'current limitation', of course, was due to space charge''. Then counsel turns to Richardson's book which credited Langmuir with the discovery of the space charge effect. But Respondent neglects to mention that Richardson himself pointed out (Interf. Rec., pp. 318, *et seq.*) that this was a mistake, that at the time he wrote it in his book he was ignorant of the published papers of Lilienfeld and Child, who had discovered and published this effect before Langmuir.

At the top of page 62 and more especially at the middle of page 66, Respondent asserts that "By the accepted theory of the time, in such a high vacuum there should have been no current at all". Thus according to Respondent, it remained for Langmuir to prove that you could have a current in a high vacuum. This whole subject has been carefully considered by petitioner's expert witness, Dr. Robert A. Millikan, formerly of the Ryerson Physical Laboratory of the University of Chicago and now of the California Institute of Technology (Interf. Rec., p. 886 *et seq.*). Dr. Millikan points out that his own opinion and the published opinions of the highest authorities in physics, such as Wehnelt, H. A. Wilson, and Sir J. J. Thompson, were all in favor of the view that electrons would be emitted and would pass freely in a substantially perfect vacuum.

Inasmuch as Arnold always believed in this now accepted theory of electron emission and current flow in a vacuum, he was in far better position to make the present invention than was Langmuir, who had grave doubts on the matter until some time in the year 1913.

Respondent's assertion quoted above rests on only a very few publications by obscure men, and on *alleged hearsay, reported by Langmuir, subject to due objection.* For example, notice the reliance on Wien at the bottom of page 27 of Respondent's brief, and then notice (Rec., Vol. 2, p. 1227 and Vol. 3, p. 1940) that Langmuir's report of this hearsay was refused admission to the record, and that

Respondent now attempts to rely on this excluded testimony without having even assigned its exclusion as error, as required by Rule 11 of the Third Circuit Court of Appeals. Exclusion of this hearsay by the District Court has *never been overruled.*

Langmuir's "Now what I intend to do".

Respondent labors through a full page (p. 75) to prove that its quotation at the bottom of the preceding page "makes it perfectly clear" that when Langmuir wrote on March 21, 1913 "Now what I intend to do * * *" (our brief, p. 91), he meant that he intended to make an audion *with a plate anode.* He did not say so; he did not even mention a plate anode. If he had meant an audion *with a plate anode,* of course he would have said so. He did not even testify to that effect in the District Court, though we had previously asserted the same position that we assert now, namely that his words as quoted on page 91 of our brief mean exactly what they said. Respondent's effort to qualify them by its quotation on page 74 of "What follows" (so Respondent alleges) is considerably weakened by noticing that it omits six lines that come between.

Langmuir and Alexanderson.

The correct version of the alleged disclosure by Langmuir to Alexanderson is not as given on page 69 of Respondent's brief. On the contrary the proposition of "a hot cathode high vacuum electron discharge apparatus of the three electrode type" was made by *Alexanderson to Langmuir, so Langmuir admitted* (Rec., Vol. 3, p. 1425). And Alexanderson made admissions to the same effect (Rec., Vol. 3, p. 1465 and context). So far is Alexanderson's testimony from corroborating the alleged disclosure by Langmuir.

White's Audion No. 2.

Respondent says "The evidence is positive that this audion operated by pure electron discharge", referring to Langmuir's involved reasoning in 1926. But the contemporary records in 1913 were far different. White wrote "it was necessary to run filaments for quite a time to get results consistent with previous day's results". Rather a bad showing on reproducibility. White now conjectures that the fault was due to warping of the grid by the heat.

Dushman recorded a complete failure in his effort to make use of this audion No. 2. See his closing entry "no effect" on page 19 of his notebook, Plaintiff's Exhibit 127.

Langmuir wrote at the same time in reference to this work by Dushman:

> "It is apparent to me that negative electricity leaks off the grid too easily. This is due either to the leads from the grid and the plate or filament coming out too close to each other or to *positive ionization in the bulb.* In the next relays we will use great care to avoid both of these effects. It may be that *a little hydrogen may cut down positive ionization* by removing oxygen for oxygen certainly greatly increases positive ionization. *More probably the best results will be obtained by using the highest possible vacuum.* For experimental purposes it may be well to immerse the audion or relay in liquid air *to improve the vacuum* and improve the insulation" (Pltf's. Ex. 131, pp. 60, 61).

The Rule of *Morgan* v. *Daniels* Not Applicable.

On page 60 of its brief, Respondent argues that the usual presumption accorded by the rule of *Morgan* v. *Daniels*, 153 U. S. 120, to a decision of the Court of Appeals of the District of Columbia on the fact issue of priority of invention applies by analogy to the case at bar. The basis for this argument is that the Telephone Company has assisted the defendant in the presentation of the defense of prior invention. It needs but a moment's reflection to perceive that the rule of *Morgan* v. *Daniels* has no applicability. It is a modified *res adjudicata* doctrine and is predicated upon the essential prerequisite of *identity of the party* against whom the decision was given in the previous litigation. The DeForest Company, the only defendant in this action, was not a party to the interference proceeding between Arnold and Langmuir. Therefore, there is no identity of parties in this case upon which to hang *Morgan* v. *Daniels*. Surely, the general rule is in no way affected because the defendant has accepted the assistance of a party to the previous litigation.

Moreover, there is important new evidence, taken in the Court below, which would in any event exclude the case from the rule in *Morgan* v. *Daniels*. We direct attention to one or [illegible]o examples.

It will be remembered that the Court of Appeals of the District of Columbia relied on the opinions of the Examiner of Interferences and the Board of Examiners-in-Chief of the Patent Office. The Board said of Arnold's disclosure of a plan for improvement of the DeForest audion on November 1, 1912,

> "According to the testimony, Arnold at once perceived just where the troubles lay, and then and there disclosed the invention in issue to Colpitts and Jewett" (Interf. Rec., p. 2505).

In support of the foregoing statement, the Board went on and gave the details of the structure of the tube as conceived and disclosed by Arnold; then the Board said,

> "And if it clearly appears that he knew how to produce such a tube we would consider him entitled to November 1, 1912 for conception of the invention in issue. *But we are not satisfied that he had such knowledge* * * *" (Interf. Rec., p. 2506).

Before Judge MORRIS, abundant *new evidence was adduced that Arnold had such knowledge*, including his own testimony (Rec., Vol. 1, pp. 567 *et seq.*, Qs. 17 to 21, 31 to 34) and the testimony of his teacher, Dr. Millikan (Vol. 1, pp. 442 *et seq.*). Another line of new evidence in the District Court was Becker's testimony which proved that neither in August, 1912 nor in November, 1912 did Langmuir have a pure electron discharge.

CONCLUSION.

Although patent grants were created as an award to inventors "to promote the progress of science and useful arts" as Respondent urges in the conclusion of its brief, they were not created for the primary purpose of building up private fortunes for the owners of patents, as this Court forcefully pointed out in *Motion Picture Patents Co.* v. *Universal Film Co.*, 243 U. S. 502, at page 510. As the Court stated in that case, the *primary* object of the patent laws is to benefit the public or community at large. It is certainly as important to the public to prevent an unwarranted monopoly in a universally used and indispensable commodity—one on which virtually the entire population of the nation depends for communication, amusement and medical treatment—as it is to enrich the General Electric Company for establishing what it characterizes as a "wonderful" research laboratory, to *rediscover* what scientists had discovered and published to the world years before. The fundamental basis of the award of a patent was and is that an *invention* be made. It was for *invention* that the patent monopoly was to be and is granted to the *inventor*. The invention of Langmuir, for which he originally asked a patent, was the method of gas-freeing metal bodies *without heat*—a scientific absurdity and an admitted impossibility. The patent issued for an entirely different thing—the vacuum tube *per se.* The *application* disclosed and claimed Langmuir's "invention". The *patent* was built up by a patent solicitor by constant and innumerable modifications, cancellations and additions extending over a period of eleven years.

This is not the sort of a patent which "The framers of our Constitution in their great wisdom" intended to be granted.

Respectfully submitted,

Thomas G. Haight,
Samuel E. Darby, Jr.,
Counsel for Petitioner.

Carl A. Richmond,
William R. Ballard,
Of Counsel as to the
Priority Issue only.

FILED

JAN 30 1931

CHARLES ELMORE CRO

CLE

FILE COPY

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DeFOREST RADIO COMPANY

Petitioner

v.

GENERAL ELECTRIC COMPANY

Respondent

BRIEF FOR RESPONDENT ON PETITION FOR WRIT OF CERTIORARI

RALPH B. EVANS
ALBERT G. DAVIS
PAXSON DEETER
HUBERT HOWSON
Counsel for Respondent

APPEAL PRINTING CO., 30 VANDAM ST., NEW YORK CITY

References herein in the form "Vol. ......, p. ......" are to the printed record in the Circuit Court of Appeals for the Third Circuit.

References in the form of "I. R., p. ......" are to the record in the Court of Appeals of the District of Columbia in the interference between Langmuir and Arnold, which record has, by stipulation, become a part of the record in the present case (Vol. II, p. 927).

References to pages of the decisions of the District Court and of the Circuit Court of Appeals in this case and of the Court of Appeals of the District of Columbia in the Langmuir-Arnold interference are to the two pamphlets, one buff-colored and one green, containing those decisions, printed for the use of this Court by the respective parties.

Italics in quotations in this brief are not necessarily in the originals.

INDEX

PAGE

Opinions of the Courts Below 1

Jurisdiction 2

  Petitioner's Five Points 3

    1. Because the decision was by a divided court in a case of great importance 3
    2. Adamson *v.* Gilliland 4
    3. Judge Davis' Reversal of Opinion 5
    4. Degree of Vacuum 5
    5. Judge Woolley's Suggestion 6

Statement of the Case 6

Argument 10

  The Dissenting Opinion 11

    Opinion of the Law Examiner 11
    Prior Art Publications and Patents 12
    The Alleged DeForest Prior Use 14
    Judge Woolley's Mistaken Notion about Ionization 18
    Judge Woolley's Criticism of Plaintiff's Definition of the Invention 20
    The Theory of Gaseous Conduction in the Prior Art 21
    Judge Woolley's Comments on the History of the Patent Application 25
    The Issue of Priority 27

  The Petition's Attack on the Opinion of the Court 28

Brief of Amici Curiae 29

TABLE OF CASES.

PAGE

Adamson *v.* Gilliland, 242 U. S. 350 4
Anaconda *v.* Carson, 278 U. S. 635; 26 Fed. (2d) 651 .. 3
Brittania, The, 153 U. S. 130 5
Chemical Foundation *v.* General Electric Co., S. D. N. Y. (unreported) 29
DeForest Co. *v.* General Electric Co., on Coolidge Patent, 278 U. S. 656; 28 Fed. (2d) 641 6
Eibel Process Co. *v.* Minnesota Paper Co., 261 U. S. 45 5
Forsyth *v.* Hammond, 166 U. S. 506 2
Franc-Strohmenger *v.* Forchheimer, 277 U. S. 597; 280 U. S. 542; 20 Fed. (2d) 553; 27 Fed. (2d) 785; 39 Fed. (2d) 899 3
General Electric Co. *v.* DeForest Radio Co. (the present case in the District Court), 6 Fed. (2d) 704 ... 1
Harkin *v.* Brundage, 276 U. S. 36 5
Keller and Lillie *v.* Adams-Campbell Co., 264 U. S. 314 2
Magnum Import Co. *v.* Cody, 262 U. S. 159 2
Marconi Co. *v.* DeForest Co., 243 Fed. 560 13
Woods, In re, 143 U. S. 202 2
Wetzler *v.* Tolfree, 278 U. S. 628; 25 Fed. (2d) 553 ... 2

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930.

DEFOREST RADIO COMPANY, *Petitioner*, *v.* GENERAL ELECTRIC COMPANY, *Respondent.*	No. 630. Langmuir Patent 1,558,436.

ON PETITION FOR WRIT OF CERTIORARI

TO THE CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT.

BRIEF ON BEHALF OF RESPONDENT.

OPINIONS OF THE COURTS BELOW.

The opinion of the Court of Appeals of the District of Columbia awarding priority to Langmuir in the Patent Office interference between Langmuir and Arnold of the American Telephone & Telegraph Company is reported at 6 Fed. (2d) page 704. The opinion of the trial court holding invalid the Langmuir patent is at 23 Fed. (2d) 698. The memorandum decision of the Circuit Court of Appeals for the Third Circuit affirming the decision below, Judge BUFFINGTON dissenting, is not reported. The opinion of the same Court on rehearing, sustaining the patent, by Judges BUFFINGTON and DAVIS, Judge WOOLLEY dissenting, which is the opinion the petitioner seeks to have reviewed, also has not been reported. For the convenience of the Court we have printed in a separate buff-colored pamphlet the opinion of the Court of Appeals of the District of Columbia, the memorandum of the Court of Appeals for the Third Circuit and the opinion of the Court of Appeals for the Third Circuit.

JURISDICTION.

The policy which this Court has followed with respect to the exercise of its unquestioned right to review by certiorari any patent case decided by any one of the nine Circuit Courts of Appeal, and the "necessary limitations upon our issue of the writ," as this Court put it in *Magnum Import Co. v. Cody*, 262 U. S. 159, 163, are expressed in Rule 38, and in *Keller and Lillie* v. *Adams-Campbell Co.*, 264 U. S. 314, *Forsyth* v. *Hammond*, 166 U. S. 506, 513-515 and *In re Woods*, 143 U. S. 202, 205, 206.

The present case is "an ordinary patent case with the usual issues," such as this Court said in the *Keller and Dillie* case it would "not bring here by certiorari unless it be necessary to reconcile decisions of Circuit Courts of Appeal on the same patent."

The decision of the Court of Appeals for the Third Circuit in the present case is in conflict with no other Circuit Court of Appeals. It is in harmony with the decisions of the Patent Office as to patentability in a strenuously contested proceeding. It directly follows the decision of the Court of Appeals of the District of Columbia on the issue of priority.

Petitioner's Five Points.

The petitioner urges five reasons why this Court should rehear the case:

1. Because the decision was by a divided court in a case of far-reaching economic, industrial and public importance.

The argument that certiorari should be granted because the Court of Appeals has by a two-to-one decision reversed the trial court has already been considered by this Court. Such was the situation in *Wetzler* v. *Tolfree*, where Judges Woolley and Davis reversed Judge Clark, Judge Buffington dissenting (278 U. S. 628). Such was also the case in *Anaconda* v. *Carson* (278 U. S. 635). In both of these cases certiorari was refused. Such also was the case in *Franc-Strohmenger* v. *Forchheimer* (277 U. S. 597), where the Court refused certiorari until a second Court of Appeals reached a different conclusion, when certiorari was granted; 280 U. S. 542 (see 25 Fed. [2d] 553; 26 Fed. [2d] 651; 20 Fed. [2d] 553; 27 Fed. [2d] 785, and 39 Fed. [2d] 899).

The case is important only in the sense that any suit on a patent on a great invention is important, whether the decision be for or against the patent. The present invention is one of the great contributions to the public good which have been made possible by the research of great scientists like Langmuir, Coolidge, Alexanderson and others, carried on in a thoroughly equipped research laboratory, organized and maintained by plaintiff at its sole expense.

The petitioner complains that the decision will give to the plaintiff a monopoly which will dominate the industry. But as Judge Woolley has pointed out, the growth of the radio industry has not been wholly dependent upon any single invention. On the other hand, it is inventions like this one which have made it possible for the industry to grow. Moreover, the Telephone Company and many radio tube manufacturers are licensed under the patent. In any case it is difficult to see how the public interest would be served by granting a new monopoly, running seventeen years longer instead of twelve years longer, to the American Telephone & Telegraph Company, on the theory that Arnold and not Langmuir made the invention. But this is just what the American Telephone & Telegraph Company contended for by its counsel in the courts below (Vol. I, p. 399), and is now contending for in a suit under R. S. 4915, pending in the Southern District of New York (Vol. III, p. 1786), and the alleged priority of Arnold over Langmuir is one of the main points discussed in the petition.

The petitioner complains that unless the decision is reversed it will be compelled to discontinue the manufacture of the same devices that it has manufactured and sold since 1906. This is of course absurd. The decision does not purport to prevent petitioner from manufacturing the type of tubes which it manufactured and sold in 1906. Petitioner has abandoned the manufacture of such tubes in favor of tubes which it admits infringe the patent (Vol. I, p. 39).

2. Because the decision is in conflict with the rule stated by this Court in *Adamson v. Gilliland* (242 U. S. 350).

Neither the issue of priority nor the issue of prior use turned on any disputed questions of fact, but upon the proper inferences or conclusions to be derived from facts which are substantially undisputed. Such being the case, the conclusions of the trial court are not binding upon the Appellate Court. (*The Britannia*, 153 U. S. 130; *Harkin* v. *Brundage*, 276 U. S. 36.)

Moreover, on the issue of priority the findings of the Patent Office Tribunals and of the Court of Appeals of the District of Columbia in favor of Langmuir as against Arnold are certainly entitled to as much weight as the findings of the trial court.

On the issue of prior use, the testimony was not taken before the Court, so that the rule of *Adamson* v. *Gilliland* would not apply in any event.

3. Because of Judge Davis' reversal of opinion.

That a judge may, as he should, change his opinion, if on reconsideration he concludes he is wrong, is the purpose of the rules which provide for granting rearguments. Judge Buffington having written the opinion of the Court, it is fair to assume that the reasons he expresses are the reasons which led Judge Davis also to conclude that the patent is valid. As to the change from the first to the second argument, the opinion says:

> "As usual in litigation over a patent of great commercial value, the vast mass of expert speculation, the protracted argument covering days and with briefs that in the aggregate covered several hundred pages, the case, on reargument, narrowed to the simple question of the patent paternity of what is known commercially as the Langmuir tube."

4. Because the patent covers nothing more than a degree of vacuum.

This point is fully covered in the opinion of the Court. In support of the Court's conclusion we refer to the opinion of this Court in *Eibel Process Co.* v. *Minnesota Paper Co.*, 261 U. S. 45.

5. Because Judge Woolley suggested that this Court should review the case.

It is indeed a novel proposition that this Court should review a case at the request of one judge, just because he differs with the rest of the Court.

Any suggestion that the writ should be granted because there was a dissent in the Court of Appeals would seem to be disposed of by this Court's refusal to grant the writ in many such cases, for example, in a suit between the present parties when the same Court of Appeals held invalid the product claims of plaintiff's important Coolidge patent for the drawn tungsten wire, Judge BUFFINGTON dissenting (278 U. S. 656; 28 Fed. [2d] 641).

STATEMENT OF THE CASE.

This is a suit for infringement of patent 1,558,436 granted to General Electric Company as assignee of Irving Langmuir.

Defendant admits infringement of every claim of the patent (Vol. I, p. 39). It asserts, however, that the invention is unpatentable in view of the prior art and because of prior use by defendant itself; or, if patentable, that Arnold of the Telephone Company, and not Langmuir, was the first inventor.

The invention is an improvement in electrical discharge devices, of the type commonly known as radio tubes, in which current flows through evacuated space from a hot cathode or filament to a cold anode or plate. A tube of this type is called a "hot-cathode tube."

The first practical radio tube was the Fleming valve, a two-electrode tube.

DeForest improved upon the Fleming valve by adding a third electrode called the grid. This was the DeForest audion.

Both the Fleming valve and the DeForest audion were "gaseous" tubes; that is, the flow of current from the filament to the plate depended upon the conductivity of the small amount of gas remaining in the tube.

The conductivity varied with the density of the gas, and the density varied in different tubes and in the same tube under different conditions, due in part to the gradual evolution of gas from the various parts of the tube, particularly from the plate. As the Court said (p. 10 of the buff pamphlet) quoting from Langmuir's testimony at Volume II, page 1242:

> "in the devices of the old art, in the DeForest audion, the pressure was continually changing. It sometimes increased and it sometimes decreased. Both things went on and there was an evolution of gas, water vapor would come off the bulb and be decomposed by the filament and it would generate gas. Gases would come out of the electrodes. Positive ions would bombard the walls and the electrodes and would drive gas off."

The consequence was that the current which a given voltage would produce in such a tube was not fixed and constant, but depended on the amount of gas present in the tube, and therefore varied in different tubes, and in the same tube at different times. Such tubes therefore required critical adjustment of the "B" battery voltage. As Gernsback said in 1911 (I. R., p. 1505):

> "It is undoubtedly true that the audion, when in its best condition, is highly sensitive and that it is therefore well suited for wireless telephony. But unfortunately *the sensitive condition is extremely difficult to find and still more difficult to maintain.* Some audion tubes show an extraordinary sensitiveness at first, but quickly grow dull when in use.

> Other lamps are nearly worthless from the beginning and *none remain sensitive very long.*"

The art realized that this erratic behavior was in some way connected with the action of the gas, but they regarded it as an unavoidable thing in such a device. Both Fleming and DeForest and the art generally believed that if there was not enough gas in the tube to act as a conductor no current would flow, and experience confirmed this belief.

Langmuir defied the teaching and experience of the art. He made a tube in which the current flowed without gas.

The preparation of such a tube involved problems new in the art. It was not simply a matter of pumping a very high vacuum, which would be destroyed by the evolution of gas as soon as the tube was operated; the new and difficult problem was to get all the gas out of the parts of the tube so that there would be no further evolution of gas during the operation of the tube.

And when Langmuir had constructed such a tube, he found, contrary to the general belief, and for the first time demonstrated, that current would flow in what we may term a pure vacuum.

Moreover, the current, being unaffected by the gas, was steady and reproducible at any particular voltage.

Langmuir filed his patent application on October 16, 1913; two days later he presented before the American Physical Society a paper which was published in the December, 1913, issue of the Physical Review. It contains a full disclosure and explanation of his invention (I. R., pp. 1595-1596; Vol. II, p. 1234, Q194).

Shortly thereafter Langmuir's tubes came into commercial use; because of their stability, reproducibility and power they are used on a large scale in radio, in wire telephony and in other important applications.

In 1919 defendant issued a bulletin (Vol. IV, p. 158), in which it announced its discontinuance of the manufacture of the old audion and its adoption of the modern tube. In this bulletin it said:

> "The old style type T was an ionic or gaseous tube very unstable in operation and requiring a variable 'B' battery. It had the decided disadvantage that after continued use the tube would get 'hard' and require more 'B' battery until it reached such a state as to be inoperative. The new 'VT' tube, like the DeForest standard tubes to-day, is purely an electronic tube exhausted to a very high vacuum, so that it is nongaseous and will stand very high plate potentials. * * * The 'B' battery moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work."

On the next page of the same bulletin it said:

> "The gaseous type tubes are, however, no longer being manufactured."

The tubes which were relied upon to prove the defence of prior use were some of the "old style" "ionic or gaseous" tubes, referred to in the bulletin quoted above.

The issues of patentability and priority were fought out and decided in the Patent Office. Arnold filed an application on November 2, 1915, which was thrown into interference with the Langmuir application. Arnold at once moved to dissolve the interference on the ground that the invention was not patentable in view of the prior art. Every conceivable prior art reference was cited and nearly two thousand pages of testimony were taken on the motion. After careful consideration, the Patent Office concluded that the invention was novel and entitled to patent protection (I. R. pp. 2468-2470).

Thereupon the interference was proceeded with, the case being carried to the Court of Appeals of the District of Columbia, and resulting in a finding by that Court that Langmuir was the first inventor.

The defence of priority in the present case was conducted by the Telephone Company, which appeared by its own counsel and with its own witnesses (Vol. I, p. 399).

The case was heard before Judge MORRIS. The trial consumed more than four weeks. The record covers 3,678 pages, not including the Interference Record, which was stipulated in, and which covers 2,522 pages. In addition there was a great mass of documentary evidence and printed matter offered as physical exhibits.

Judge MORRIS decided for the defendant on every point, including the defences of prior use and priority.

The case was heard on appeal in the Circuit Court of Appeals for the Third Circuit by Judges BUFFINGTON, WOOLLEY and DAVIS. The Court originally sustained Judge MORRIS in a short *per curiam* memorandum, Judge BUFFINGTON dissenting. A motion for reargument was allowed. The case was fully reargued, and the Court sustained the patent in an opinion by Judge BUFFINGTON, Judge WOOLLEY filing a dissenting opinion.

ARGUMENT.

As Judge WOOLLEY'S dissenting opinion was written "with the hope that it will arrest the attention of the reviewing Court," and as the petitioner has adopted it as its brief on the merits of the case, we shall regard and answer it as such. We shall then dispose of the petitioner's single criticism of the majority opinion. In conclusion we shall say what we have to say about the brief filed by the Federal Telegraph and Telephone Company and others as *amici curiae.*

The Dissenting Opinion.

Briefly stated Judge Woolley's position is that the invention is nothing more than a high-vacuum, or non-gaseous tube, and that a non-gaseous tube was old in the art. His conclusion is predicated upon three things:

First.—An incomplete quotation from the opinion of the Law Examiner (p. 43 of the green pamphlet).

Second.—The prior art publications and patents (p. 44).

Third.—The evidence as to alleged prior use by DeForest (p. 44).

The Opinion of the Law Examiner.

Judge Woolley was so far misled by defendant's brief as to stop his quotation at such a point as to convey an incorrect impression of the Law Examiner's decision. The Law Examiner went on to say (I. R., p. 2468):

> "It is well settled, however, that the patentability of a combination is independent of the novelty of any of its constituent elements (Leeds *v.* Catlin, C. D., 1909, 549). *There remains for determination the question of the patentability of the combination as a whole.*
>
> * * * * * *
>
> "We may lay aside those alleged anticipating disclosures, such as Lenard, Gehrts and Dember, which pertain to photo electric devices using small currents of the order of 10^{9} amperes or less. No effort was made at the hearing to include these within the scope of the count or the claims re-

tained and they are avoided by evident limitations, for example, space charge does not govern the flow of current in these devices. *It is not seen that any of the remaining references made fully available to the public by proper disclosure the device now claimed in the issue as reformed, or that the proposed combinations of references, with results not suggested by any one of them, were obvious.* The fact seems incontrovertible that a substantial and valuable contribution to the art has been made and that, within the limits explicitly stated or necessarily implied in the claims retained, it is entitled to patent protection."

The Prior Art Publications and Patents.

The Law Examiner was unquestionably right; of the various references, on which Judge Woolley says "I stand" (p. 44 of the green pamphlet) some going back to 1881, long before radio was dreamed of, not one discloses Langmuir's tube, and not one suggests the results which Langmuir's tube accomplishes.

Doane, Malignani, Edison, Dwyer and Thatcher disclose old-style carbon-filament incandescent lamps and methods for evacuating them, which methods all produced vacua substantially the same as that in the old DeForest audion, which, as DeForest himself said, was the vacuum of the incandescent lamp (I. R., p. 1493). These citations are discussed in the record; see for example Vol. I, p. 250, XQs346-347; Vol. III, pp. 1571-1572; p. 1675, p. 1676; Vol. I, p. 225, XQs213-214; p. 221, XQs176-177; p. 232, XQ244; p. 231, XQ242; p. 360, Q1013; Vol. III, pp. 1689-1690. Of course they do not disclose "hot-cathode" tubes, or radio tubes, or anything of the sort.

Duncan discloses a tube, but not a hot-cathode tube; it is an old-fashioned gassy X-ray tube, with a cold cathode, which had a gas pressure about the same as that in the old incandescent lamp or in the audion, and which worked only because of the gas which it contained (Vol. III, p. 1673).

Fleming discloses the old Fleming valve, which defendant's expert Chaffee admitted was a gassy tube (Vol. I, pp. 262, 263, XQs430-431) and which had the same vacuum as the old incandescent lamp and the old audion, as the Court of Appeals for the Second Circuit found in *Marconi v. DeForest*, 243 Fed. 560 (see also I. R., p. 1309).

The Lilienfeld articles relied upon were discussed by the Law Examiner at I. R., page 2469. They describe certain scientific experiments made in an attempt to prove an absurdly erroneous theory in physics (Vol. III, p. 1702; Vol. I, p. 334, XQs851-857; I. R., p. 318). The single tube used in those experiments had no conceivable practical application, and carried its current by an action entirely different from that of a radio tube (I. R., pp. 1066-1071). When, a little later, Lilienfeld tried to make an X-ray tube with a hot cathode, he was unable to maintain the necessary vacuum, and contented himself, until Langmuir's work was published, with a tube which admittedly would not work unless it had gas in it (Vol. I, p. 280, XQs522-525).

The Bessel-Hagen article, published in the year 1881, describes some experiments made with a tube in which the gas pressure increased the moment the current was passed through the tube, to a value considerably higher than that in the DeForest audion (Vol. III, pp. 1669-1670; Vol. I, p. 342).

"Leonard" is undoubtedly the Lenard referred to by the Law Examiner in his conclusion which we have quoted above.

Von Beyer's pressure went up to the pressure in the audion when he lighted his filament (I. R., p. 2005).

Child worked only with tubes gassier than those of DeForest (Vol. III, p. 1695).

The Soddy patent, Defendant's Exhibit No. 17, is for a vacuum pump which has no relation to Langmuir's invention. The Soddy article, Defendant's Exhibit No. 18, discloses an experiment by which Soddy proved to his own satisfaction that *when a hot-cathode tube was thoroughly exhausted no current at all would pass through it* (Vol. III, p. 1580).

The Alleged DeForest Prior Use.

Judge Woolley says (p. 46 of the green pamphlet) that DeForest "put into commercial practice for nearly three years before Langmuir, the very electron discharge of Langmuir's claimed invention." This is an amazing statement in view of the fact that DeForest was not called to testify in this case, and of the further fact that when DeForest subsequently offered his device to the Telephone Company as a telephone amplifier, the best he had to offer was a gaseous tube, which as he recognized and admitted (Vol. I, pp. 497-8), and as Arnold testified (Vol. II, p. 721), was "of practically no value in the telephone plant."

Judge Woolley's conclusion is based upon the erroneous assumption that simply because certain audions may have operated at 54 or 67½ volts (as to which there is no proof), they must have operated without substantial ionization. He so finds, notwithstanding the facts that:

a. No witness has been willing to so testify;

b. The evidence, in so far as it shows anything about the operation of these tubes, shows clearly that they operated by gas ionization (Vol. II, p. 1008; Vol. III, p. 1616);

c. Both Langmuir (Vol. II, p. 1285) and Hogan (Vol. III, p. 1614) testified positively and without contradiction that the process of evacuation used with these tubes could not possibly have produced a vacuum sufficiently high to avoid substantial ionization, or anything better than the vacuum of an ordinary DeForest audion.

d. During the taking of depositions defendant had a tube exhausted by the same process, for the purpose of offering it in evidence, *but it was never offered and plaintiff was never afforded an opportunity to test it* (Vol. II, pp. 1060-1063 and p. 1042).

Judge Woolley's error here, as elsewhere, is due to his complete misunderstanding of the difference in principle of operation between a gaseous and a non-gaseous tube. This is apparent from his statement (p. 42) that

> "The invention is an electron discharge tube which is *capable* of being operated below saturation and above ionization voltages."

This, of course, is not the invention. The old audion was "capable of being operated below saturation and above ionization voltages." It was in fact always so operated (I. R., p. 99), and depended, both as a detector and as an amplifier, upon the sharp rise of current due to ionization occurring at voltages above the ionization voltage (I. R., p. 2007, 2008; Vol. II, p. 1261). The Langmuir tube operates in the same range, *i. e.*, below saturation and above ionization voltages, *but it operates without substantial ionization effects*, and this is what the patent says.

Judge Woolley has unquestionably been confused by the ambiguous statement of defendant's counsel, which is repeated in petitioner's brief (p. 19), that "the patent purports to cover any vacuum tube which can function *properly* when using 40 volts or more."

The old audion often functioned *"properly"* when using 40 volts or more, but whatever the voltage it always functioned by gas ionization. Defendant recommended for use with its old gaseous audions a *variable* "B" battery of 30 to 36 cells, which is 45 to 54 volts (Vol. IV, p. 135), and the instructions were to adjust the voltage to the point just below that at which blue glow occurred (Vol. IV, p. 140), which, as Langmuir explained, was in order to obtain the strongest ionization effects (I. R., p. 2007).

The Langmuir tube also functions *"properly"* when using 40 volts or more, but it functions without substantial ionization effects. Claim 26 of the patent, which is the claim to which petitioner refers, defines the tube as "capable of passing a sustained discharge of one tenth of a milliampere at 40 volts, *without developing any substantial positive ionization effects."*

Counsel's statement "the patent purports to cover any vacuum tube which can function properly when using 40 volts or more" is true only when the word *"properly"* is understood to mean "without substantial ionization effects." It was this ambiguous use of the word "properly" which confused Judge WOOLLEY, and led him to conclude that any tube which functioned usefully at 40 volts or more, regardless of how it functioned, was a Langmuir tube.

The test is not whether a tube will operate usefully at any particular voltage, but *how* it operates. As to this there is one very simple but accurate test and that is to find out whether the current is constant at a given voltage under all conditions of the tube; whether the tube requires the critical adjustment of the B-battery voltage referred to in defendant's circular, as necessary with the old style gaseous tube, or whether "a *fixed* B-battery may be used," as defendant's 1919 bulletin tells us is the case with the purely electronic tube.

Applying this simple test, we have positive evidence that Hewlett's tubes, for instance, whether they were operated as Judge Woolley says, at 67½ volts, or as Hewlett himself said, at some lower voltage, were operating upon the principle of gaseous conduction. Hewlett testified (Vol. II, p. 1008):

> "The voltage depended upon the degree of exhaustion of the particular tube I had in use and I would say it ranged around about sixty volts, but I had a glass beaker with a thermometer and the tube in the oil of this beaker and by lighting a small alcohol lamp under this beaker I could somewhat control the amount of B-battery used for best results.
>
> "Q17. What was the effect of heating the vacuum tube in the manner you describe?
>
> "A. Heating the tube lowered the amount of B-battery used on the tube."

Referring to Hewlett's testimony, plaintiff's expert, Hogan said (Vol. III, p. 1618):

> "That is exactly like the tube heating that was commonly used by radio operators in the early years of the audion. The heat applied to the glass walls results in disengaging gas within the tube and therefore increasing the gas pressure in the tube and reducing the voltage at which a blue glow can be had, and also the operating voltage of the tube."

In other words, these tubes which Judge Woolley now finds to be "the very electron discharge of Langmuir's claimed invention" are the identical old-art gaseous audions, which defendant in its 1919 bulletin (*supra*, p. 9) tells us "had the decided disadvantage that after continued use the tube would become 'hard' and require more B-battery *until it reached such a state as to be inoperative.*"

Judge Woolley's Mistaken Notion about Ionization.

The chief trouble with the dissenting opinion is that it proceeds from a fundamentally wrong conception of what ionization is, and the part which it plays in the flow of current in a gaseous tube.

Judge WOOLLEY said (green pamphlet, p. 42):

> "The ions (with their positive charges of electricity) fight against the electrons (with their negative charges) in the normal flow of the latter from the cathode to the anode, resulting at high voltages, in a blue glow which is the indication of bad action, a thing to be avoided."

At page 49 he speaks of gas as "an enemy to conduction."

Judge WOOLLEY is all wrong; yet this error is the basis of his findings against the patent, both on the question of novelty and priority. A similar error was the basis of the similar findings of Judge MORRIS.

The ions *do not* fight against the electrons; on the contrary they keep the electrons from fighting against themselves, and thus increase the flow of current across the tube (I. R., p. 1237). Gas is not an *enemy* of conduction. It is a *friend* of conduction, but an erratic and unreliable friend.

Ionization begins at a certain voltage, usually about 20 volts, but varying somewhat with different gases. When the voltage reaches that point the gas between the filament and plate begins to ionize or disintegrate and to form a sort of electrical conductor for the current. As the voltage increases, the amount of ionization increases; as the ionization increases, the conductivity of the gas increases and thus the flow of current is increased out of proportion to the increase in voltage. The amount of this increase at any given voltage depends upon the amount of gas in the tube. This is why a tube which is operating on the principle of gas ionization is critical and unstable.

When the ionization becomes very pronounced it causes a blue glow in the tube. This occurs at different voltages in different tubes and in the same tube at different voltages, according to the varying density of the gas. In this condition the tube is generally inoperative. In the range above ionization and below blue glow the current is influenced by ionization, and it was in this range that the audion was always operated, preferably at the voltage just below the point at which blue glow appeared, so as to get the maximum useful effect of ionization.

What DeForest wanted, therefore, was a tube in which he could get the maximum useful effect of ionization with a reasonable operating voltage range. In 1906 he said, for example, "If the exhausting process is carried too far, the audion loses its sensitiveness" (I. R., p. 1496). In 1913, in a paper on his *amplifying* audions, he spoke of the air in the bulb being "exhausted to the *most effective* pressure" (I. R., p. 1498).

In his letter to the McCandless Company, DeForest said (Vol. VI, p. 1061):

> "Out of the last lot of 24 audion bulbs which you manufactured for us there are only 4 that came up to proper sensitiveness test. Apparently the vacuum in the other bulbs is too low, because in these latter bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive."

Judge WOOLLEY finds that this letter showed that DeForest appreciated the necessity of a high vacuum. Of course it showed nothing of the sort. What it did show was that DeForest realized that when the vacuum was so low that the tubes blue glowed at voltages below that at which they were intended to operate, they were no good. He wanted a better vacuum than that, certainly; but all he wanted, or thought he could use, was the vacuum of a good audion; the "most effective pressure."

Judge Woolley's Criticism of Plaintiff's Definition of the Invention.

Judge WOOLLEY's misunderstanding of the effect of ionization, discussed above, accounts for his statement that our definition of the invention is inconsistent with the claims of the patent, and his further statement that "in interpreting and sustaining the patent broadly for a non-gaseous tube, the Court has given the plaintiff more than it ever dared to claim." We think that Judge WOOLLEY has misinterpreted the opinion of the Court. At page 38 of his opinion (green pamphlet), he quotes and criticizes our definition of the invention, and at page 40 he says:

> "The Court did not adopt the plaintiff's definition of coordinating elements with functional relations."

The fact is that this is precisely the Court's own definition, as clearly appears from page 17 of the buff pamphlet, where Judge BUFFINGTON says:

> "But a vacuum, or indeed change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so co-ordinate and interwork that current flow is not affected by gas."

We have endeavored to define the invention in such a way that the Court would understand it, sometimes using the technical language of the patent, sometimes attempting to paraphrase it in language which might be more intelligible to the Court. We have never intentionally or consciously attempted to define it as anything different from what the patent discloses. The expression "non-gaseous tube" is a convenient way of describing a tube in which gas is not present in sufficient quantity to affect the operation of the tube. It is exactly the phrase which the defendant used in its 1919 circular to distinguish its prior-art tubes from the new "purely electronic tube" which is the tube of the patent. To say that in the old-style gaseous tube the gas acted as a conductor, is a convenient way of expressing the fact which Langmuir stated when he said that positive ions took part in the conduction of current. To say that the invention consisted in taking out the gas conductor and substituting nothing in its place is a striking, but entirely fair, statement of the fact.

The Theory of Gaseous Conduction in the Prior Art.

Judge Woolley takes issue with our statement that the prior art not only depended upon gaseous conduction, but thought it was the only way in which the tube would work. He concedes that if we were correct in our statement, there would be no doubt about what Langmuir did and no doubt that it was invention.

In our brief below on rehearing, we filled several pages with statements quoted from scientific publications by Fleming, DeForest and others, showing that our statement represented the generally accepted belief of the art. Some of them are quoted in the opinion of the Court. Judge Woolley dismisses all these with the brief comment that they are "carefully selected"; but neither defendant nor Judge WOOLLEY have quoted any statements to the contrary. Judge WOOLLEY says that we make no distinction between detector and amplifier, the inference being that the art recognized some distinction, but the uncontradicted evidence is to the contrary. Hogan testified that there was no difference between the gas pressure in an audion detector and amplifier (Vol. III, p. 1620), and as we have seen, the audion, whether as a detector or amplifier, depended for its operation upon the action of gas.

At page 50 of his opinion, Judge WOOLLEY quotes Langmuir as repudiating this theory of gas conduction. Here again he is wrong, as he would have seen if he had had before him and read Langmuir's entire statement, instead of relying on the incomplete excerpt quoted in the petitioner's brief below.

In the original specification Langmuir had said, describing the action in the old-style gassy tubes, "the positive ions take part in the conduction of current, giving at first erratic readings on measuring instruments connected in circuit." Judge WOOLLEY says that this is what the plaintiff now contends, but that Langmuir himself repudiates it.

The statement was subsequently cancelled from the specification and the following substituted:

> "Under these circumstances the phenomena of *conduction* across the tubes are the result of the action and interaction of the electrons and the ions. These phenomena are in general erratic and non-reproducible."

In cross examination, Langmuir was asked whether the original statement would have been true if it meant that "the positive ions take part in the conduction of current *by acting as conductors or carriers of current.*" His answer was in effect that the statement would not be scientifically accurate. From this Judge Woolley concludes that Langmuir repudiated the theory of gaseous conduction in prior-art tubes, but if he had read the whole of Langmuir's statement he would have seen that such was not the case, because Langmuir had just said (I. R. 1774, XQ67):

> "The sentence 'The positive ions take part in the conduction of current' is a perfectly natural way of expressing the fact that the presence of positive ions greatly increases the current under certain conditions. *In fact, since the current is increased as the result of the presence of positive ions, it is absolutely true that the positive ions 'take part' in the conduction of current.* It does not necessarily follow from this statement that the current is carried by the positive ions. The statement is simply a rather loose way of stating that the current is dependent on the positive ionization."

It is evident from this that the change was merely one of phraseology and not of substance, and that Langmuir never repudiated the theory of gas conduction in prior art tubes.

Judge Woolley was also clearly wrong in saying that Langmuir did not in his specification refer to the audion as a device operating by gaseous conduction. At line 77 of the specification Langmuir says:

> "The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device with three electrodes known as the audion. This device has been used as a receiver for radio

> telegraphy and *depends in its operation upon the rapid change of the discharge current when ionization begins.*"

Judge Woolley quotes Langmuir's references to Lilienfeld, Von Beyer, Wehnelt and Richardson.

We have already referred to Lilienfeld and Von Beyer. We may here add what the Law Examiner said regarding Lilienfeld (I. R., p. 2469; see I. R., pp. 901 and 273);

> "The Lilienfeld device with its long, constricted tube is obviously impractical for any commercial purpose. The walls would tend to melt under electron bombardment and would become so hot as to furnish vapors under their own vapor pressure."

Judge Buffington refers in his opinion (p. 12 of the buff pamphlet) to the fact that Wehnelt, in a paper which he and Leibrich published in 1914, said that *ionization persisted in the best vacuum they could get* (I. R. p. 1427).

Judge Woolley quotes Langmuir to the effect that Richardson had expressed the opinion that even in the highest vacuum thermionic currents could still be obtained. True, but this was pure theory; Richardson had never demonstrated it, and did not know how to, and actual experiments made by others seemed to disprove it, until Richardson himself began to doubt it (I. R. p. 1512). And when in November, 1912, Langmuir showed Richardson a tube in which current did flow in a vacuum, and explained to him the relation between the current and the voltage, Richardson was at first puzzled and then relieved (I. R. p. 510). And in the book, which he published later, Richardson refers to the phenomenon as:

> "an interesting effect which was discovered and explained by Langmuir" (Vol. IV, p. 339).

Judge Woolley's Comments on the History of the Patent Application.

The petitioner seeks to give the impression that the patent as it issued covered *an invention entirely different from that originally claimed when it was filed.* Judge Woolley says something to the same effect, the obvious inference being that the invention underwent some change during the progress of the application through the Patent Office. He says in so many words that Langmuir "was far from certain what he had invented."

This is not a fair statement.

On October 18, 1913, two days after he filed his application, Langmuir read a paper before the American Physical Society in New York. It was published in the December issue of the Physical Review. No one can say that it does not contain a full, clear and accurate disclosure of the invention.

On December 28, 1913, before the Patent Office had taken any action on his application, he filed an amendment, adding four claims covering the tubes *per se.* One of these claims reads (Vol. VI, p. 676):

> "A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

Claim 11 of the patent as issued reads:

> "A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current pro-

> duces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

Certainly there is no substantial difference between the two claims.

A comparison of the original specification filed October 16, 1913 (Vol. VI, p. 662), with the specification of the patent as issued, shows that the essential portion, which is of course, as always, the description of the device itself and of the method of producing and of using it, is contained in the patent *in almost exactly the words of the original specification,* the only substantial exception being the elimination of one alternative suggestion relating to the process of evacuation which Langmuir then thought was a good one, but which he later found to be incorrect (Vol. II, p. 1276).

Langmuir understood well enough what his invention was. His patent solicitor seems to have had trouble in drawing claims which would accurately define the invention. That is an entirely different matter. It was not such an easy task as Judge WOOLLEY seems to imagine. He suggests that if Langmuir had invented the thing for which the Court gives him credit, he could have claimed it in a half dozen words, and suggests: "A non-gaseous discharge tube," or "an electrical discharge device with a high vacuum tube."

But these would not be good claims. "Non-gaseous" and "high vacuum" are relative terms; while sufficiently accurate to describe the invention in a general way, as we have used them in this brief, they are not sufficiently definite for a patent claim. As an absolute vacuum is an impossibility, the question would at once arise, how high a vacuum? As Langmuir says in his specification:

> "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron or even lower, *but no definite limits can be assigned.* The residual gas pressure should be below the value at which ionization by collision will take place *at the given working voltage and current.*"

In drawing the claims it was, therefore, necessary to define the invention in terms which would include all of the factors necessary to the operation of a tube by pure electron discharge, and if the Court will read the claims it will see that they are all directed to this end.

The Issue of Priority.

The Court of Appeals of the District of Columbia, affirming the decision of the Board of Examiners in Chief, held that Langmuir had conceived as early as September 1, 1912, and had reduced to practice by November 19th in the same year, and that Arnold had conceived and reduced to practice on April 25, 1913 (buff pamphlet, p. 22).

We have already said that the defense on the question of priority in this case was conducted by the Telephone Company by its own counsel and with its own witnesses, and that the Telephone Company has filed a suit in the United States District Court for the Southern District of New York under R. S. 4915, which suit is now pending awaiting final determination of this case.

Judge Woolley would reverse the findings of the Patent Tribunals and the decision of the Court of Appeals of the District of Columbia upon what he says is evidence substantially greater than the evidence in the Interference proceedings. He does not point out wherein the evidence in this case is any more favorable to Arnold's contention than the evidence before the Patent Tribunals. The fact is quite the reverse.

The Petitioner's Attack on the Opinion of the Court.

The Court, correctly understanding the invention, appreciated that the essential difference between the tubes of the patent and the tubes of the prior art is the difference in principle of operation.

The petitioner challenges this conclusion, and asserts on the contrary that the principle of operation is the same; as the proposition was stated in petitioner's brief in the Court below, that "every electron discharge device functions the same, irrespective of the degree of vacuum."

The petitioner can find nothing in the record to support its contention, except the statement made by plaintiff's expert, Hogan, in testimony given in 1916 (Vol. III, p. 1681), in a case between different parties, involving different devices, which testimony petitioner cites without reference to its context. We might with equal propriety refer to the testimony of the petitioner's expert, Millikan, who testified in the same case regarding the Telephone Company's amplifiers, which were Langmuir tubes, that "they work upon an entirely different principle" (Vol. I, p. 118), which he explained was due to the fact that "they are evacuated to such a degree that the residual gases play no part in the operation" (p. 119).

Langmuir clearly explained this difference in principle of operation. His testimony is too long to quote, but it commences at Volume II, page 1236. *Not a single witness has challenged the correctness of his statement.*

The difference in principle of operation is illustrated in a practical way by a comparison of a gaseous and non-gaseous tube operating in the same receiver. The defendant's 1919 bulletin furnishes exactly this comparison. After explaining the difference between the "old style" "ionic" or "gaseous tube" and the new purely "electronic" tube, the bulletin goes on to say (Vol. IV, p. 159) that the old-type gaseous tube may be used in place of the new high-vacuum tube, but in such case "a *variable* B-battery of from 20 to 50 volts is required" whereas with the new tube the instructions call for "a *fixed* battery of from 20 to 60 volts."

Here we have two tubes designed for use within the same range of voltage, one a gaseous tube, requiring a variable battery, the other a Langmuir tube operating with a fixed battery. The difference is due entirely to the difference in principle of operation. The gaseous tube, operating upon the principle of the conductivity of ionized gas, requires a variable battery to compensate for the varying conductivity of the gas; the non-gaseous tube, operating upon the principle of pure electron discharge, unaffected by gas ionization, works with a fixed battery at a predetermined and constant voltage.

BRIEF OF *AMICI CURIAE.*

The two numbered points in the brief filed by the Federal Telegraph Company and others are substantially identical with Points 2 and 4 on pages 16 and 21 of petitioner's brief and have been discussed above.

Most of the allegations of fact made in the brief are outside the record; some of them are clearly inaccurate; for example, the allegation on page three, that "the degree of vacuum shown in the Lilienfeld patents" referred to "is the same as that claimed in the Langmuir patent in suit." The fact is that the operation of the Lilienfeld X-ray tube, which his patents purport to cover, is inherently dependent upon the ionization of the gas left in the tubes, as defendant's expert Chaffee admitted (Vol. I, p. 280, XQs522-525). In *Chemical Foundation* v. *General Electric Company*, S. D. N. Y., not yet reported, Judge THACHER held that the "operation of the Lilienfeld device is shown to be dependent upon ionization."

The Chemical Foundation's interest in this matter results from its owning the Lilienfeld patents.

We presume that this Court is not particularly interested in the relations between the General Electric Company and the Federal Telegraph Company. We wish, however, to point out, among the many misstatements of fact in the brief, the statement on page 7 that the communication systems of the Army and Navy would be subject to the domination of this patent. The American Telephone & Telegraph Company, Western Electric Company, General Electric Company, Westinghouse Electric & Manufacturing Company and the Radio Corporation of America have granted full licenses among themselves to manufacture for and sell to the Government for Government use under all their radio patents, including the Langmuir patent in suit (see, for example, Vol. IV, pp. 286 and 283).

The brief complains that the Court of Appeals did not "define the scope" of the patent which it holds valid. The scope of the patent is defined, as usual, in the claims. No question of scope was before the Court, since infringement of all of the claims was admitted. The Court therefore did not consider scope further than was necessary to its discussion of validity.

Respectfully submitted,

RALPH B. EVANS,
ALBERT G. DAVIS,
PAXSON DEETER,
HUBERT HOWSON,
Counsel for Respondent.

January, 1931.

INDEX

PAGE
Opinions of the Courts Below 1
Statement of the Case 2
  Subject Matter Involved 2
  What the Patent Purports to Cover 5
  Scientific Principles Involved 6
  Principle of Operation of a Radio Tube 7
  Saturation 8
  Ionization 9
  Blue Glow 10
  Pure Electron Discharge 11
  Methods of Getting High Vacuum 13
  History of the Langmuir Application 13
  Arnold Interference 16

Summary of Argument 16

Argument 19

  Point I.—Definition of the Invention 19
    Contemporary Theory Regarding Conduction in a Hot Cathode Tube 23
    Evidence of Gas Conduction in the Fleming Valve and DeForest Audion 28
    Langmuir's Testimony Cited by Petitioner 31
    Petitioner's References to Prior Art on Conduction of Electricity by Gas 33

  Point II.—The Invention Is Not Merely a DeForest Audion Capable of Operating at Higher Voltages 38
    Prior Art Devices 39

PAGE
DeForest Audion 39
Fleming Valve 43
Lilienfeld Experimental Tube 45
The Vacuum of the Patent 48
High Vacuum in Prior Art 48
Novelty of Pure Electron Discharge 50

POINT III.—The Defense of Prior Use 52
Facts as to Detector and Amplifier Operation 53
DeForest's Letter to the McCandless Company 54
Langmuir's Testimony 55
Tungsten Cathodes 56
Evidence Regarding California Tubes 56

POINT IV.—Question of Priority (Arnold Defense) 58
The Critical Dates 60
Langmuir's Work Prior to July, 1912 61
The July and August, 1912, Work 62
In November, 1912, Langmuir Worked Out the Theory of the Action of His Tube 66
Langmuir's Invention Was Made in August, 1912 69
Petitioner's Criticism of Langmuir's Work 70
Arnold's Work 76
Arnold's Alleged Conception 76
Arnold's Idea of Means 78
Arnold's Later Work 80

POINT V.—The Rule of *Adamson* v. *Gilliland* 84

POINT VI.—Defense of Double Patenting 84

CONCLUSION 88

TABLE OF CASES

PAGE

Adamson *v.* Gilliland, 242 U. S. 350 84
Arnold *v.* Langmuir, 6 Fed. (2d) 704 1

Britannia, The, 153 U. S. 130 84

Corona Tire Co. *v.* Dovan Chemical Corp., 276 U. S. 358, 375 84

Dayton Fan & Motor Co. *v.* Westinghouse, 118 Fed. 562 87
Diamond Rubber Co. *v.* Consolidated Rubber Tire Co., 220 U. S. 428 89

Feed-Back Cases, 278 U. S. 562 ....60, 73

General Electric Co. *v.* DeForest Radio Co., 23 Fed. (2d) 698 1
General Electric Co. *v.* DeForest Radio Co., 44 Fed. (2d) 931 2
General Electric Co. *v.* Nitro-Tungsten, 261 Fed. 606 61

Harkin *v.* Brundage, 276 U. S. 36 83
Hewitt *v.* American Tel. & Tel. Co., 272 Fed. 194 and 392 35

Marconi *v.* DeForest, 243 Fed. 560 ....3, 36, 45
Marconi *v.* DeForest, 236 Fed. 942 34
Morgan *v.* Daniels, 153 U. S. 120 60

Pittsburgh *v.* Cowles, 55 Fed. 301 71

Telephone Cases, 126 U. S. 567 52
Thomson-Houston *v.* Ohio Brass Co., 80 Fed. 712 87
Tilghman *v.* Proctor, 102 U. S. 707 71

U. S. *v.* Bell Telephone Co., 167 U. S. 224 15
U. S. *v.* General Electric Co., 272 U. S. 480 61

Van Heusen Products *v.* Earl & Wilson, 300 Fed. 922 87
Victor *v.* Brunswick, 273 U. S. 670 60

Washburn *v.* Gould, Fed. Cases 17, 214 70
Westinghouse *v.* DeForest, 21 Fed. (2d) 918 ....51, 73
Westinghouse *v.* DeForest, 278 U. S. 562 ....60, 73

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930.

DEFOREST RADIO COMPANY, *Petitioner*, *v.* GENERAL ELECTRIC COMPANY, *Respondent*.	No. 630. Langmuir Patent 1,558,436.

ON WRIT OF CERTIORARI TO THE CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT.

BRIEF ON BEHALF OF RESPONDENT.

Opinions of the Courts Below.

The opinion of the Court of Appeals of the District of Columbia awarding priority to Langmuir in the Patent Office interference between Langmuir and Arnold of the American Telephone & Telegraph Company is reported at 6 Fed. (2d) page 704 (Op. p. 91). The opinion of the trial court holding invalid the Langmuir patent is at 23 Fed. (2d) 698 (Op. p. 96). The memorandum decision of the Circuit Court of Appeals for the Third Circuit affirming the decision below, Judge BUFFINGTON dissenting, is not reported, but is at Vol. III, page 2007 and at (Op. p. 125). The opinion of the same Court on rehearing, sustaining the patent, by Judges BUFFINGTON and DAVIS, Judge WOOLLEY dissenting, is reported at 44 Fed. (2d), page 931 (Op. p. 126).

Statement of the Case.

Subject-matter involved.

The invention is an improvement in electrical vacuum discharge devices of the type known as "hot cathode" tubes, in which current flows through an evacuated space from a heated cathode called the filament to a cold anode called the plate. The modern radio tube is a familiar example of such a device.

As stated in the specification, the tubes of the patent are distinguished by the regularity and reproducibility of the current, as contrasted with prior art hot cathode devices in which the current was irregular and non-reproducible. This difference is due to a difference in the type of the electrical discharge; the tubes of the patent operate by what is termed "pure electron discharge," as distinguished from the prior art devices in which the conduction of current depended upon "gas ionization."

The petitioner (defendant below) admits infringement of every claim of the patent (Vol. 1, p. 39). In its attempt to defeat the patent it resurrects the prior art tubes which long ago it discarded, but now asserts are the identical devices of the invention.

The first practical radio tube was the Fleming valve, a two electrode tube.

DeForest improved upon Fleming's valve by adding a third electrode which he called the "grid." He called this device an "audion." It was an improvement upon, but an infringement of, the Fleming valve (*Marconi* v. *DeForest*, 243 Fed. 560).

Counsel for petitioner say that the three electrode tube revolutionized the electrical arts. It was not DeForest's audion which did these things. It added very little, if any, impetus to the art; so little in fact that until after Langmuir's invention, crystal detectors were used in preference to DeForest audions in such an important station as the Government Station at Arlington (I. R. p. 1602). It was Langmuir's tube which as Judge MORRIS said,

> "because of its stability, reproducibility and power, has made possible radio broadcasting, modern radio reception and long-distance telephony" (Op. p. 106).

One great trouble with the DeForest audion was that it was erratic and tricky; no two audions acted alike and no one audion would act the same way very long. As DeForest himself said in 1915 (I. R. p. 1502):

> "In the first place, anyone who has had considerable experience with numerous audion bulbs must admit that the behavior of different bulbs varies in many particulars, and to an astonishing degree. The wing (plate) potential-wing (plate) current curves for different bulbs, or even for the same bulb at different times, under different conditions (filament temperature, etc.) vary widely.
>
> "What may appear to be a fixed law for one bulb may not hold for another."

This is the kind of device which petitioner made and sold before and for some years after Langmuir's invention. In 1919, however, it discontinued this type of tube and announced the adoption of a new type, which it described in a trade bulletin as follows (Vol. 4, p. 158):

> "The chief difference between this tube and the type T tube of similar mechanical construction is in its evacuation. The old style type T was an ionic or gaseous tube very unstable in operation and requiring a variable 'B' battery. It had the decided disadvantage that after continued use the tube would get 'hard' and require more 'B' battery until it reached such a state as to be inoperative. The new 'VT' tube, like the DeForest standard tubes to-day, is purely an electronic tube exhausted to a very high vacuum, so that it is nongaseous and will stand very high plate potentials. When used as a detector, however, a battery of from 20 to 40 volts is sufficient to give a proper plate current, although voltages of 80 to 100 may be used without detrimental effect upon the tube. The 'B' battery moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work."

In the same bulletin petitioner stated (Vol. 4, p. 159):

> "The old type gaseous tube with the candelabra base can be used similarly, except that a variable 'B' battery of from 20 to 50 volts is required. The gaseous type tubes are, however, no longer being manufactured."

The new tube which petitioner described as "purely an electronic tube" is the Langmuir tube. The "old type gaseous tube" which was "very unstable in operation and requiring a variable 'B' battery" and which "had the decided disadvantage that after continued use the tube would get 'hard' and require more B battery until it reached such a state as to be inoperative," is the audion which is now presented as a complete anticipation of the invention.

The critical adjustment of the B battery voltage to which the bulletin refers is characteristic of gaseous tubes, and is a reliable test to determine whether a tube is operating by gas ionization. It will be helpful to remember this when the Court comes to consider petitioner's argument that the DeForest audions were not gaseous tubes.

What the patent purports to cover.

Counsel for petitioner have entirely misapprehended, or at least misstated, our position. The invention is not a mere matter of vacuum; as Judge BUFFINGTON said in the opinion of the Court (Op. p. 141):

> "But a vacuum, or indeed change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so coordinate and interwork that current flow is not affected by gas."

This is and always has been our position. The thing which distinguishes the tubes of the patent from similar devices of the prior art is not the vacuum, but the type of the discharge. The invention is a tube in which the current is uniform, predictable and reproducible at any voltage, because it does not depend upon gaseous conduction, as contrasted with the DeForest audion, which as we have seen, was "very unstable in operation" because the conduction of current depended upon gaseous ionization. The vacuum in a Langmuir tube is important only as one of the elements which in proper combination produce the desired result, and this is precisely what the patent teaches us.

Nor do we contend "that any DeForest audion (except a 'detector' tube) which properly performs its intended function, is covered by the Langmuir patent." On the contrary, this is the petitioner's position. Our position is that a DeForest audion, whether a detector or amplifier, when properly performing its intended function, depended upon gas ionization; this was the thing that made it tricky, but it was also the thing that made it work. The difference between a Langmuir tube and a tube operating by gas ionization is not that one will work properly and the other will not, but that when both are properly performing their intended functions they operate in entirely different ways because they depend upon different principles of operation.

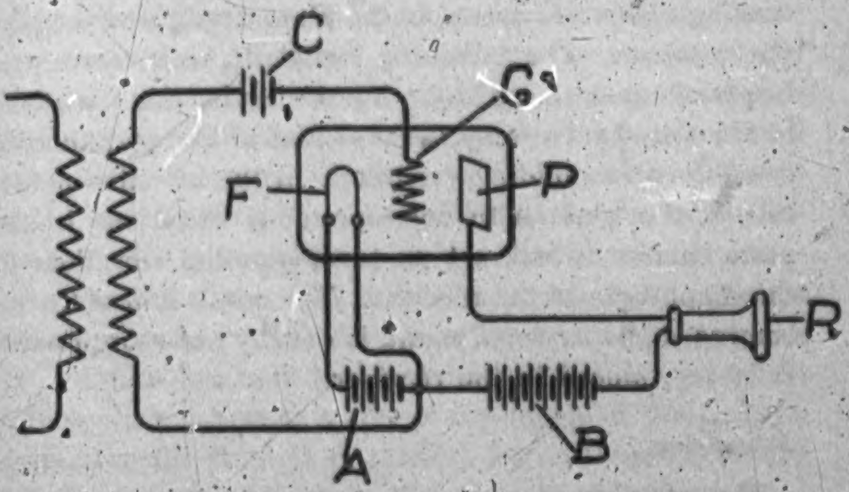
Scientific principles involved.

To understand the difference in principle of operation between a Langmuir tube and a DeForest audion the Court must understand the difference between a pure electron discharge and a discharge through ionized gas, and how this difference is manifested in the action of the tubes. While the petitioner's explanation of the scientific principles involved is reasonably accurate as far as it goes, it is entirely inadequate, and the statement "that the amount of the gas residue *permissible* in any particular tube depends upon the use to which the tube is to be put and the voltage under which it must operate" is ambiguous and misleading.

The amount of gas "permissible" in a tube operating by gas ionization is one thing; the amount of gas "permissible" in a tube if it is to operate by pure electron discharge is something quite different, and this is true even though the two tubes are put to the same use and operate under the same voltage.

As this is a matter of controlling importance we shall take the liberty, at the risk of repeating some things which have been correctly stated by the petitioner, to explain first the general principles of operation common to both types of tubes, and then to point out the difference in principle of operation between a Langmuir tube and a DeForest audion *when put to the same use and operating at the same voltage.*

The principle of operation of a radio tube.



In a radio tube of the audion or three-electrode type we have an evacuated bulb, inclosing a cathode or negative electrode (F) called the filament, an anode or positive electrode (P) called the plate, and a third electrode or grid (G) between the filament and plate. The filament is heated to incandescence by passing a current of electricity through it. In battery-operated sets, this current is supplied by the A battery; its sole function is to heat the filament. Another battery, commonly called the B battery, is connected between the filament and plate, the negative pole to the filament and the positive pole to the plate. When used as an amplifier, a telephone receiver (R) or loud speaker is inserted in the circuit between the battery and the plate. This is called the plate or output circuit. A third battery, commonly called the C battery, may be connected between the filament and the grid. This is called the grid or input circuit.

When the filament is lighted, electrons or negative charges of electricity are boiled out of the filament, and these being attracted by the positive potential or pull of the plate, are carried across the tube to the plate, causing a flow of current in the plate circuit and through the receiver. The incoming signal or voice current is imposed upon the grid or input circuit; the variations of the sound wave vary the potential of the grid, thereby causing corresponding variations in the effective potential of the plate with corresponding variations in the plate current, which set up corresponding vibrations in the diaphragm of the receiver. The result is that the incoming signal or voice sound is exactly but more powerfully reproduced in the receiver.

Saturation.

The number of electrons emitted by the filament is determined by the temperature of the filament. This is known as Richardson's Law. But the current delivered by the tube depends not upon the number of electrons emitted, but upon the number of electrons drawn across the tube to the plate, and this varies with the voltage. When the voltage is sufficiently high to draw all of the electrons emitted from the filament to the plate, the tube is said to be saturated. When a tube is saturated no further increase in voltage will affect the amount of current, and therefore in this range, which is called the saturation range, the current will not respond to changes in voltage. As the operation of a radio tube depends upon this very response to changes in voltage, it follows that a radio tube is always operated in the range below saturation, and this is the range with which we are particularly concerned. When a tube is operating within this range, it is said to be operating on the "space current."

Ionization.

If there is any appreciable residual gas in the tube, or if during the operation of the tube gas is evolved from the parts of the tube, the passage of the electrons from the filament to the plate at voltages in excess of the so-called ionization voltage, causes the gas molecules to disintegrate. This is called ionization. Ionization occurs at definite voltages, varying somewhat with different gases, but the evidence shows that it *begins* to be important as a factor influencing the flow of current somewhere between 20 and 30 volts. The physical phenomenon is rather complicated, but it is sufficient for the purposes of this case to know that when ionization is present in a tube, the gas acts as a sort of conductor of the current, *increasing* the current to a value beyond what it would be at the same voltage in the absence of ionization.

The result is that in a gaseous tube saturation is reached at lower voltages than in a non-gaseous tube with the same filament emission, but in the range above ionization and below saturation, which as we have seen is the range in which a radio tube is always operated, a gaseous tube, because of the increased current due to ionization, is more responsive to slight changes in voltage. Therefore, a gaseous tube is more sensitive, both as a detector and as an amplifier, than a non-gaseous tube, but its range of operation is more limited (Vol. 2, p. 1261).

A more serious objection, however, is the erratic behavior of such a tube. If gas is evolved from parts of the tube the pressure is constantly changing; moreover the pressure is not the same in any two tubes. As the amount of ionization varies with the pressure of the gas, and as the conductivity of the gas varies with the amount of ionization, the current varies in different tubes, and in the same tube at different times. Moreover as it was desirable to operate a gaseous tube just below the point of saturation in order to obtain the maximum effect of ionization in the conduction of the current, it was necessary to adjust the B-battery voltage for each tube and for the same tube at different times to compensate for the varying conductivity of the gas and to keep the tube within its operating range. This accounts for the critical adjustment of the B-battery voltage, which as we have seen (p. 4) was characteristic of gaseous tubes.

Judge WOOLLEY had an entirely wrong idea of ionization. He speaks of the ions fighting the electrons and of gas as an enemy of conduction. The ions do not fight the electrons; they keep the electrons from fighting among themselves; they "police" the electrons, according to page 9 of petitioner's brief; gas is not an enemy of conduction, it is a friend of conduction, but an erratic and unreliable friend.

Blue glow.

Blue glow is associated with ionization, but the terms are not interchangeable. At any such voltages as those at which DeForest worked, blue glow is a visible sign of extreme ionization, occurring at about the point of saturation (Vol. 3, p. 1713). In this condition manifestly the tube will not operate as a radio tube.

Blue glow does not mark the *beginning* of ionization: ionization begins at the ionization voltage; blue glow occurs at some higher voltage, varying with the pressure of the gas (Vol. 3, p. 1718; Vol. 2, p. 1247). Within this range the current is influenced by ionization, increasingly so as the voltage is raised to that at which blue glow occurs, and as we shall see, the best results were obtained with a gaseous tube when the voltage was critically adjusted to that just below the point at which blue glow occurred.

The point we wish to make clear is that absence of blue glow is no indication that the current is not affected by ionization. The mere fact that a tube operates at voltages above ionization voltage without evidence of blue glow is no indication whatever that the current is not substantially affected by ionization. We emphasize this statement because both Judge WOOLLEY and Judge MORRIS were evidently confused on this point.

The audion was always operated below the blue glow point, but it always operated by ionization, whether as a detector or as an amplifier. It was, as we shall see, ionization that made DeForest's audions such sensitive amplifiers; when they broke into blue glow they failed to operate (Jewett, Vol. 1, p. 411), but very substantial ionization existed in the DeForest audion without blue glow, as appears from the testimony of defendant's expert Chaffee at Vol. 1, page 274, and from the testimony of Hogan at Vol. III, page 1723, who says that the ionization sharply affects the current in an audion "long before the energy in the ionization discharge will cause a visible blue glow."

Pure electron discharge.

If the tube is so prepared and proportioned, that is to say, if the parts are so thoroughly freed of occluded gas that no gas is evolved during operation, and if the vacuum and the relation of the electrodes is such that no appreciable ionization takes place when the tube is operated at voltages substantially in excess of ionization voltages, we then have what is known as a "pure electron discharge" tube. As the patent tells us (Vol. IV, p. 3, lines 110-114):

> "As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterized by regularity and reproducibility with given conditions."

The given conditions are the filament temperature and the B battery voltage, both of which may be predetermined. With a given filament temperature the current is determined solely by the B battery voltage. The result is that the tube is reproducible, by which we mean that the tube will operate the same way, day after day, and may be replaced with another tube which will operate the same way, without any adjustment of the A battery rheostat or the B battery voltage.

It is clear from the foregoing that the difference between a tube operating by pure electron discharge and a tube operating by gas ionization is a difference in the essential nature of the electrical discharge.

It is equally clear that this difference is evidenced by the fact that tubes operating by pure electron discharge will operate at a fixed B battery voltage, whereas tubes operating by gas ionization require critical adjustment of the voltage.

This is precisely the difference which the DeForest bulletin (Vol. 4, pp. 158, 159) points out between the old style gaseous audion and the new purely electronic tube when put to the same use and operated at the same voltage. "The old type gaseous tube * * * can be used similarly except that a variable 'B' battery of from 20 to 50 volts is required" (*supra*, p. 4).

Stability and reproducibility in a tube are matters of enormous practical importance. The modern radio receiving sets with six or more tubes in complicated circuits; the modern telephone relay; the modern X-ray tube, have been made possible only because of the absolute uniformity and reproducibility of the tubes. Such development would have been impossible with tubes which required constant and critical adjustment of the B-battery voltage. It would be impossible for instance to have a modern radio receiving set with six or more tubes each requiring constant and critical adjustment of the B-battery voltage, and requiring a different adjustment every time a tube was replaced.

The methods of getting high vacuum.

The idea that any useful flow of current could be obtained in the absence of gas was opposed to the general belief and experience of the art. Moreover, the preparation of such a tube involved problems new in the art. It was not simply a matter of pumping a very high vacuum which would be destroyed by the evolution of gas when the tube was operated; the new and difficult problem was to get all the gas out of the parts of the tube so that there would be no further evolution of gas during the operation of the tube.

The petitioner says that all this was old in the art. The fact nevertheless remains that no one before Langmuir produced such a tube. The inference is irresistible that the art did not know how.

History of the Langmuir application.

The petitioner seeks to create the impression that the patent as it issued covered an invention entirely different from that originally claimed when it was filed, and quotes Judge WOOLLEY's opinion to that effect.

The suggestion is not justified by the facts. The same argument was made by Arnold in the interference proceeding and was overruled by the Law Examiner (Op. p. 15) and by the Board of Examiners in Chief (Op. p. 62).

Langmuir's patent application was filed October 16, 1913. It was entitled: "Electrical Discharge *Apparatus* and the Process of Preparing the Same" (Vol. VI, p. 662). As the Law Examiner of the Patent Office held in Arnold's motion to dissolve the Arnold-Langmuir interference (Op. p. 1), and as is evident on comparison of the original specification at Vol. VI, pages 662-673, with the final specification of the patent (Vol. IV, p. 2), the application as filed fully disclosed the new tube which Langmuir had invented and the process of preparing and producing it. The original claims were process claims; but product claims were introduced by an amendment filed two months later, December 28, 1913, *prior to any action by the Patent Office.* One of these claims reads (Claim 8, Vol. VI, p. 676):

> "A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

Claim 11 of the patent as issued reads:

> "A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current

> produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

Moreover every one of the claims of the patent as issued reads directly on the invention as it is described in the original specification.

On October 18, 1913, two days after the filing of the patent application, Langmuir presented before the American Physical Society, a paper which was published in the December, 1913, issue of the Physical Review (Plaintiff's Exhibit 21, Physical). This paper contains a full disclosure and explanation of the invention (I. R. pp. 1595-1596).

Langmuir understood well enough what his invention was. His patent solicitor seems to have had trouble in drawing claims which would accurately define the invention in Patent Office language. That is an entirely different matter. It accounts for the fact that the application after being at issue in 1915, was allowed to forfeit. But it was promptly renewed, and in following this practice, respondent's solicitor was merely availing himself of the right which the Patent Statutes gave him (*U. S.* v. *Bell Telephone Co.*, 167 U. S. p. 224, at pp. 246-247), and following the usual Patent Office practice.

Petitioner insinuates that respondent is in some way responsible for the delay in the final issue of the patent. The facts do not warrant any such insinuation. Arnold filed an application for the same invention on November 2, 1915. On November 18, 1915, Arnold's attorney wrote to the Patent Office calling attention to Langmiur's application and suggesting an interference (I. R. p. 19). The interference was declared August 8, 1916. Proceedings in the interference were suspended during the war at the request of the Secretary of the Navy (Vol. 4, p.

209). With the exception of this interruption, the proceedings were conducted certainly with as much dispatch as is usual in such cases. Certainly respondent is not chargeable with the delay in the issuance of the patent after Arnold's application was filed, any more than it is chargeable with the delay of six years in reaching a final determination of the validity of the patent in this suit.

Arnold interference.

On November 2, 1915, Arnold of the American Telephone & Telegraph Company filed his application for a patent on the same invention. After an interference was declared, Arnold moved to dissolve the interference on the ground that the invention was not patentable. Every conceivable prior art reference was cited, and nearly two thousand pages of testimony were taken on the motion to dissolve. After careful consideration the Law Examiner concluded that the invention was novel and entitled to patent protection (I. R. pp. 2462-2471).

Thereupon the interference was proceeded with, the case being carried to the Court of Appeals of the District of Columbia, and resulting in a finding by that Court that Langmuir was the first inventor.

The defense of priority in the present case was conducted by the Telephone Company, which appeared by its own counsel and with its own witnesses (Vol. 1, p. 399).

Summary of Argument.

We shall confine the argument to an answer to the petitioner's six points, rearranging the order to correspond to what we conceive to be a more logical method of presentation. For the convenience of the Court we shall indicate under each heading the point of the petitioner's brief to which the argument is addressed.

1. The definition of the invention adopted by the majority of the Court is the definition which is found in the specification and the claims of the patent. It is not, as petitioner asserts, a new definition advanced for the first time on the motion for reargument; on the contrary it is the definition which respondent urged at the trial and in the argument before the trial court, and in the brief originally filed with the Circuit Court of Appeals.

In the practical prior art devices the conduction of current depended upon gas ionization; the art moreover believed that unless there was enough gas to act as a conductor no current could flow and the tube would not work, and experience seemed to confirm this belief. In simple language Langmuir's invention consisted in taking out the gaseous conductor upon which the prior art relied and putting nothing in its place. (*Petitioner's second point.*)

2. The invention is not merely a DeForest audion capable of operating at higher voltages. The essential difference is that at any voltage the tubes of the patent are stable and reproducible, as contrasted with the audion which was always erratic and non-reproducible. The invention is not a vacuum or degree of vacuum; the vacuum is important only as one of the elements of a combination which produces a new, useful and unexpected result. Such a tube was new in the art and required new and different vacuum technique to produce it. The old tubes operated on the old principle of ionic or gaseous conduction; the new tubes operate on the new principle of pure electron discharge. (*Petitioner's first point.*)

3. The audions relied upon to prove the defense of prior use were gaseous tubes operating by gas ionization. The fact that a tube may amplify at 40 volts or more is no indication that it is a pure electron discharge tube, and the uncontradicted evidence shows that the tubes in question were gaseous tubes. DeForest had no idea of a pure electron discharge; his own statements show that what he wanted was a gassy tube; a tube exhausted to a particular optimum gas pressure in order to utilize the maximum useful effect of ionization. (*Petitioner's fourth point.*)

4. The question of priority was decided by the Patent Office tribunals in favor of Langmuir in a contest between the respondent and the American Telephone and Telegraph Company, which has openly defended the present case on this issue. The case for the patent has been strengthened, not weakened, by the evidence [illegible] the present suit. Langmuir made the invention when he made and operated a pure electron discharge tube in August, 1912, more than two months before Arnold's alleged date of conception. Arnold's whole idea was to take a DeForest audion and by pumping a better vacuum to extend the range of operation to somewhat higher voltages without modifying the essential nature of that operation. This is not the invention. His conception and disclosure were inadequate in that they did not include any adequate idea of means. The inadequacy of his conception is evidenced by his inconsistent statements and by his inability to make good tubes until after Langmuir's invention was disclosed to the public. (*Petitioner's third point.*)

5. The testimony on the defense of prior use was taken by deposition and not before the trial judge. The issue of priority depends not upon questions of fact but upon

inferences to be derived from facts which are substantially undisputed. The rule that the finding of the trial judge on disputed issues of fact will be treated as unassailable, therefore, has no application in this case. *(Petitioner's fifth point.)*

6. The defense of double patenting has not been sustained by any judge who has heard this case, and is utterly without merit. *(Petitioner's sixth point.)*

ARGUMENT.

POINT I.

The definition of the invention adopted by the majority of the Court is the definition which is found in the specification and the claims of the patent. It is not, as petitioner asserts, a new definition advanced for the first time on the motion for reargument; on the contrary, it is the definition which respondent urged at the trial and in the argument before the trial court, and in the briefs originally filed with the Circuit Court of Appeals.

In the practical prior art devices the conduction of current depended upon gas ionization; the art moreover believed that unless there was enough gas to act as a conductor no current could flow and the tube would not work, and experience seemed to confirm this belief. In simple language, Langmuir's invention consisted in taking out the gaseous conductor upon which the prior art relied and putting nothing in its place. (Petitioner's second point.)

Definition of the invention.

As we have seen, the definition which the Court below adopted was (Op. p. 141):

> "But a vacuum, or indeed change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so coordinate and interwork that current flow is not affected by gas."

This is precisely what the patent says; for example, Claim 2, which Judge WOOLLEY accepts as typical, reads:

> "2. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization."

Confining ourselves to the specification as originally filed in order to meet petitioner's suggestion that the invention underwent some change during the progress of the patent through the Patent Office, we find the invention described as follows (Vol. VI, p. 664, lines 10-15):

> "In devices made in accordance with my invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas."

The specification goes on to say (lines 24-27):

> "As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterized by regularity and reproducibility with given conditions."

The definition which the Court adopted is, morover, the same definition which counsel for respondent advanced before the trial court (Vol. II, p. 951):

> "Mr. Davis: The invention as I look at it, if your Honor please, is a tube in which the relation of the parts, the geometry of the tube, the nature of the gas, the amount of the gas, are so coordinated that a pure electron discharge will flow above ionization voltages."

The petitioner's real complaint is that we were successful for the first time upon the reargument in explaining the invention in such a way that the Court understood it.

In the petition for reargument (Vol. III, p. 2014) we said:

> "In simple language, Langmuir's invention consisted in taking out the conductor which was in the Fleming valve and the DeForest audion and putting nothing in its place; he dispensed with what was regarded as an essential element in the operation of the tube and by doing so made a tube which worked infinitely better."

Petitioner says that this is an entirely new and different definition of the invention from anything which had previously been suggested. It is new only as a matter of phraseology; in substance it is exactly what we said at the trial and in a brief filed on the original argument before the Court of Appeals. In that brief (p. 10) we said:

> "In the purely electronic tube—Langmuir's tube—the current is carried across the space between the electrodes by a procession of 'electrons,' which are very small negative charges or units of elec-

> tricity, 'substantially unaffected by positive ionization' of the gas, as Langmuir says in his patent. The action would take place exactly the same even in the wholly imaginary condition called 'a perfect vacuum.' It is a simple, clean, dependable phenomenon, uncomplicated by any gas action whatever.
>
> "The old audion, as we have seen, was an ionic or gaseous tube; in that tube 'ionization' of the gas was a vital factor in the conduction of the current."

Again (p. 18) we said in the same brief:

> "The fundamental difference between the two devices is that in Langmuir's tube there is no ionization which substantially affects the current, while in the audion ionization is a vital factor in the phenomenon of current conduction."

To say, as we did in the petition for reargument, that Langmuir's invention consisted in taking out the conductor which was in the DeForest audion and putting nothing in its place is simply a striking way of stating the same thing. In fact the petitioner, in describing the phenomenon of ionization, says that "the positive ions act like traffic police for the electrons" which suggests the same idea of a conductor.

Petitioner concedes on page 42 of its brief that if our definition is correct, **"patentability follows almost as a matter of course."** It contends, however, that the definition is not correct, in that the Fleming and DeForest devices did not have a conductor of gas.

This is the controlling question in the case. Before referring to the citations upon which the petitioner relies, let us see what Fleming and DeForest and other workers in the art said on the subject.

The contemporary theory regarding conduction in a hot-cathode tube.

For many years the art believed that electric current at any reasonable voltage would flow only through a metallic or liquid conductor. Then came Edison in 1884 with his great discovery of the "Edison effect," which was that somehow electric current would flow in a vacuum tube across a gap from a heated filament to a cold plate or anode. This was a startling discovery, because, at first thought, it appeared to be utterly inconsistent with the accepted belief that current would flow only through a conductor. But like all great discoveries it appeared simple enough when it was explained. The explanation was that there was enough gas in the tube to form a conductor, or, as it was sometimes described, that there was a "column of conducting gas" which served as a conductor to carry the current across the gap from the filament to the plate. In the 1914 edition of the Century Dictionary and Cyclopedia, the Edison effect is described as

> "a phenomenon of the vacuum of incandescent lamps, consisting of an electric glow near the ends of the filament, caused by a current flowing through the gases between the terminals, or from a third terminal and the negative leg of the filament."

Fleming merely utilized the Edison effect in a vacuum tube with its column of conducting gas for the detection of radio signals.

DeForest simply improved the Fleming valve by adding the grid.

Both the Fleming valve and the DeForest audion were gaseous tubes. While Fleming and DeForest and the art generally did not understand just what the action of the gas was, they visualized it and spoke of it as a physical conductor, and regarded it as essential.

Fleming in his scientific paper delivered before the Royal Society in 1905, after describing the behavior of his valve, said (Vol. V, pp. 148-149):

> "the facts so exhibited are well-known characteristics of *gaseous conduction in rarefied gases.*"

citing J. J. Thomson's book "Conduction of Electricity Through Gases."

In 1908, in an article published in Cassier's Magazine, Fleming said:

> "The form of oscillation valves devised by the author depends on the unilateral *conductivity of a mass of rarefied gas* contained between an incandescent and a cold-conducting surface" (I. R. p. 1337).

In the 1910 edition of his book Fleming said:

> "In both Mr. Marconi's and the author's above-described method of employing the valve, we are utilizing the unilateral *conductivity of the ionized gas* which it possesses in virtue of the electrons discharged from the incandescent filament. On the other hand, we may employ this detector in another manner, depending on the fact that such ionized gas does not obey Ohm's law as a conductor" (I. R. p. 1343).

In his 1916 book Fleming continued to speak of the "ionized gas" in his valve as a "conductor" (I. R. p. 1345).

In a patent granted to DeForest in 1907 he describes the audion as

> "an evacuated vessel enclosing a sensitive *conducting gaseous medium* maintained in a condition of molecular activity" (I. R. p. 1496).

In discussing a paper which he read before the American Institute of Electrical Engineers in 1906, DeForest was asked whether the action of the audion depended upon the ionization of residual gases within the vacuum, or whether the vacuum was so perfect that the ions or electrons came from the electrodes themselves, to which his answer was (I. R. p. 1493):

> "I think it is due to the ionization of the residual gases; the gases still exist in the lamp, because the vacuum is only that which obtains in all incandescent lamps."

At the same meeting, when asked whether the residue of gas left in the exhausted envelope had anything to do with a certain "lag effect," DeForest said:

> "Well, of course, the gas has something to do with the phenomenon. *If the exhausting process is carried too far, the audion loses its sensitiveness. The gas particles, rather than the particles of the metal dust, are the carriers*" (I. R. p. 1496).

In his patent No. 1,201,273, issued on an application filed in 1915, DeForest explains the conductivity of the audion as due to the "ionizing of the gas in the evacuated vessel" and speaks of "the conductivity of the surrounding or interconnecting gas medium" (Vol. IV, p. 330, lines 40-43 and 96-98).

Gernsback, in a critical study of the operation of the audion, said that

> "the operating principle is the shattering of a column of conducting gas by a received electrical impulse" (I. R. p. 1505).

And the art was right; the gas was not merely the thing that made the audion "tricky" and irreproducible; the gas was the thing that made the audion work. If you got rid of the gas, you made the audion inoperative; it might be an obvious way to get rid of the trickiness, but in the view of the art it would have been very much like cutting out a man's tongue to cure him of stuttering.

We have quoted DeForest's statement that if the exhausting process was carried too far the audion lost its sensitiveness; experience confirmed this statement. Sometimes an audion would "clean up" in operation; that is to say, the vacuum would become higher and the tube would become what was known as "hard." A hard audion was not a good audion, and it was common practice to resort to the expedient of heating the tube in order to liberate gas from the walls, and so to increase the gas pressure (reduce the vacuum) enough to "soften" it to that value at which the audion would function. When an audion got so hard that it would not respond to such treatment, it was discarded as useless; as the defendant said in its 1919 circular:

> "after continued use the tube would get 'hard' and require more 'B' battery until it reached such a state as to be inoperative" (*supra*, p. 4).

If anyone went to the art for an explanation of why this was so, he would have been told that it was because there was not enough gas in the tube to form a conductor, and that without such conductor no current would flow.

For instance, in the United States patent of Von Lieben, Reisz and Strauss, applied for as late as June, 1912, for a form of hot-cathode tube seriously considered by the Telephone Company for telephone relay uses in early 1913 (Vol. I, pp. 514-516; Petitioner's Brief, p. 70), it is said (I. R. p. 1440):

> "It is a well known fact that exhausted discharge tubes can be worked only for a comparatively short time, as the discharge ceases after a short period if it is continuously maintained for some time. * * *"

The patentees go on to state that the discharge ceases because the resistance of the tube increases as the gas cleans up.

And this was the common view of the art; for example, Dr. W. R. Whitney, director of the Research Laboratory of the General Electric Company, said in a paper read before the American Institute of Electrical Engineers in June, 1912, shortly before Langmuir's invention was made:

> "*In connection with this work of Fleming's, we have studied the effect of the condition of vacuum on the current, and also found that the presence of gas is necessary for this negative discharge*" (I. R. p. 1514).

Langmuir described at I. R. page 1557 some of the work which led to this conclusion.

Arnold in his patent application stated (I. R. p. 498):

> "It has been commonly supposed that the electrons thus emitted *must be utilized to ionize the residual gas in the vacuum tube in order that the device might operate efficiently.*"

And in his testimony he confirmed this statement (I. R. p. 499).

When Langmuir discussed his invention with the distinguished physicist Wien and told him that he had succeeded in obtaining a pure electron discharge in the very highest vacuum, Wien exclaimed "Dass kann nicht sein"

(That can't be so) (Vol. III, p. 1941). The great physicist Rutherford was of the same opinion in 1914 (I. R. p. 1513). Prof. Robert Pohl of Germany wrote Langmuir in 1914, "congratulating me on the work that I had published in the *Physikalische Zeitschrift* and pointing out how the paper had changed his views on this question of electron emission in high vacuum and was likely to change the views of a great many other German scientists" (I. R. p. 1929).

Even after Langmuir's invention had been published, DeForest insisted that Langmuir was working on the wrong track, or as he put it in the discussion of Langmuir's paper read before the Radio Institute in 1915:

> "I believe, however, that Dr. Langmuir has, by working into these extremely high vacua and the high potentials necessitated thereby, *pursued the less promising of two paths of research*" (Pl. Ex. 104, physical, p. 292).

The evidence of gas conduction in the Fleming valve and DeForest audion.

The art did not know just how the gas acted as a conductor, and it was wrong in believing that without such a conductor no current could flow. It was Langmuir who taught the world these things, and his explanation is now universally accepted. But the art was right in believing that there was a gaseous conductor in the audion, and that the useful flow of current depended upon gaseous conduction.

If the Court should entertain any doubt on this point we hope it will read Langmuir's deposition in the Interference Record, particularly commencing at page 1599, where he discusses the difference between tubes of the patent and tubes of the prior art, and also his testimony beginning at Vol. II, page 1236, where he discusses the same subject with particular reference to the DeForest audion and the Fleming valve. The whole matter is too complex to be covered in a single sentence, but for the convenience of the Court we quote portions of Langmuir's testimony.

At I. R. page 1599, he says:

> "Thermionic devices utilizing a pure electron discharge are characterized by constancy and reproducibility in their action, and by a long, useful life and by the fact that large amounts of power can be controlled by them. In each of these respects they differ radically from the devices of the prior art such as the Fleming valve, the audion, the Von Lieben tube, the Wehnelt rectifier and the Lilienfeld X-ray tube *which all used and depended upon ionization.*"

At Vol. II, page 1242, he says:

> "In other words, in the devices of the old art, in the DeForest audion, the pressure was continually changing. It sometimes increased and it sometimes decreased. * * *
>
> "These things were going on in the most erratic and ungovernable way in the old devices and that is true of all devices that are poorly exhausted.
>
> "If there is a pressure of gas such that the ionization produced by it modifies the space charge, partly eliminates the space charge, and therefore allows more current to flow than would otherwise flow, then any change in that gas pressure will cause a change in the ionization and space charge will be eliminated to a different degree and there will be a resulting change of current."

At I. R. page 1325, Langmuir, referring to the Fleming valve, testified:

> "his currents were totally different from what they would have been in the absence of ionization."

Defendant's expert Chaffee testified to the same effect (Vol. I, p. 262, XQ431, *infra*, p. 43).

Defendant's witness Arnold, in his patent application, stated (I. R. p. 498):

> "The DeForest audion, according to the printed description thereof by its inventor (see Proc. A. I. E. E., Vol. 25, p. 735, 1906), and according to the patents therefor (U. S. Patents Nos. 841,387 and 879,532) depends upon the principle of gas ionization. The same is also true of the Fleming detector (See statement contained in U. S. Patent No. 954,619)."

We have already referred to the DeForest Bulletin of 1919 which refers to the "old style" "ionic or gaseous" tubes. Another bulletin published by the DeForest Company in 1915 shows beyond question that the audions which the defendant was making and selling at that time were gaseous tubes. The bulletin states (Vol. IV, p. 137):

> "If too much battery 'B' voltage is applied in any Audion Detector, a blue glow will appear in the bulb or may be seen around the edges of the plate or wing, and a roaring sound will generally be heard in the telephone receivers."

In the same bulletin we are instructed regarding the proper adjustment of the B voltage (Vol. IV, p. 140):

> "Now start the switch B at the lowest point 12 and turn to the right until a blue discharge occurs in the Audion bulb, or a hissing noise occurs in receivers. Bring the switch back one point at once, as the blue discharge, if prolonged, is detrimental to the bulb."

There was no difference in this respect between the audion detector and the audion amplifier; for the same bulletin says (Vol. IV, p. 142) that the directions for operating an amplifier are the same as for a detector (see also p. 36, *infra*).

Here we see the same critical adjustment of the B voltage to the point just below that at which blue glow occurred which the defendant in its 1919 Bulletin says was necessary with old style gaseous tubes.

Langmuir explained the reason for this critical adjustment (I. R. p. 2007):

> "This careful adjustment to an optimum value of the voltage is just what was common practice among those who used the audion for receiving radio signals. The best amplifying action is obtained just before the strongest ionization effects are obtained. This usually occurs a little below the voltage at which appreciable blue glow occurs, but the sharp rise in the current proves that space charge is being greatly modified by the presence of positive ionization."

There can be no doubt therefore that both the Fleming valve and the DeForest audion, when operating at voltages above the ionization voltage, depended upon ionization; the gas acted as a conductor of the current.

Langmuir's testimony cited by petitioner.

The petitioner quotes Langmuir as repudiating our position that the Fleming valve and the DeForest audion depended upon gaseous conduction. The argument, which confused Judge WOOLLEY, is based upon an incomplete quotation from Langmuir's testimony, the effect of which is entirely reversed when read in connection with the context.

In the original specification Langmuir had said, describing the action in the old-style gassy tubes, "the positive ions take part in the conduction of current, giving at first erratic readings on measuring instruments connected in circuit."

The statement was subsequently cancelled from the specification and the following substituted:

> "Under these circumstances the phenomena of *conduction* across the tubes are the result of the action and interaction of the electrons and the ions. These phenomena are in general erratic and non-reproducible."

In cross examination, Langmuir was asked whether the original statement would have been true if it meant that "the positive ions take part in the conduction of current *by acting as conductors of current*." His answer was in effect that the statement would not be scientifically accurate. From this petitioner seeks to draw the conclusion that Langmuir repudiated the theory of gaseous conduction in prior-art tubes, but if petitioner had quoted the whole of Langmuir's statement it would be apparent that such was not the case, because Langmuir had just said (I. R. p. 1774, XQ67):

> "The sentence 'The positive ions take part in the conduction of current' is a perfectly natural way of expressing the fact that the presence of positive ions greatly increases the current under certain conditions. *In fact, since the current is increased as the result of the presence of positive ions,* it is absolutely true that the positive ions *'take part' in the conduction of current*. It does not necessarily follow from this statement that the current is carried by the positive ions. The statement is simply a rather loose way of stating that the current is dependent on the positive ionization."

It is evident from this that the change was merely one of phraseology and not of substance, and that Langmuir never repudiated the theory of gas conduction in prior art tubes.

This is further confirmed by the following statement which appears in the original specification as well as in the patent:

> "The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device known as the 'Audion.' This device has been used as a receiver for radio-telegraphy and *depends in its operation upon the rapid change of the discharge current when gas ionization begins*" (Vol. VI, p. 63).

Petitioner's references to prior art on conduction of electricity by gas.

Petitioner says there is no testimony in the record that either Fleming or DeForest ever *purposely* left a *definite* residue of gas in their tubes for the purpose of conducting the current or of making them operate.

Fleming paid no attention to his vacuum; he was satisfied with the ordinary incandescent lamp vacuum of his time. DeForest definitely said that the action of the audion was due to the ionization of the residual gas, and that *if the exhausting process is carried too far, the audion loses its sensitiveness* (*supra*, p. 25).

What DeForest knew was that if the vacuum was so poor that a tube blue glowed at 15 or 20 volts, it was no good for his purposes because it gave him no reasonable range of operation above ionization and below saturation voltages. He also knew that if the vacuum was too good the tube was inoperable. What he wanted, therefore, and what he used, was a tube exhausted to the optimum pressure which would give him a maximum effect of ionization with a reasonable range of operation.

Fleming was just as vague about the pressure in his valves. While he speaks of the "highest attainable vacuum," we know, and the petitioner's witnesses admit, that his valve was a gassy tube and that his current at voltages above ionization operated by gaseous conduction (*infra*, p. 43).

The petitioner quotes Waterman's testimony in the case of *Marconi* v. *DeForest*, 236 Fed. 942. It does not, however, quote the most significant part of his testimony, which is at Vol. III, page 1488:

> "A. Well, in order that the electrons may have undisturbed passage across, it is necessary that there should not be too many gas molecules in the way. I am going in a minute to read what Fleming had to say about that, about the significance of the vacuum. If the vacuum is so high that the electron streams across from the filament to the plate are not seriously interfered with then the vacuum is sufficiently good for the purpose. But if there is very much gas present—
>
> "Q. What do you mean by 'very much'?
>
> "A. *I mean if a vacuum is not equal to a reasonably good incandescent lamp vacuum*, for example, then the bulb gets freaky."

Petitioner's counsel think they find some inconsistency between Hogan's testimony given in the *Hewitt* case in the year 1919 and his testimony in this case. Hogan himself saw no such inconsistency. Maybe Hogan was wrong in the *Hewitt* case, but no witness says he is wrong in this case. The significance in the reference, however, lies not in what Hogan or any other witness may have said, but in what the Court decided, namely, that the Telephone Company's tubes, which were admittedly the tubes of the Langmuir patent here in suit, *depended upon a principle and mode of operation clearly different* from that of the Hewitt tube, which was a gassy tube, in that the Telephone Company's tubes operated independently of ionization whereas the Hewitt tube depended upon ionization for its action (272 Fed. 194 and 392).

It is a novel proposition that a case should be decided on the testimony of witnesses given in some other case, directed to a different state of facts, but if petitioner wishes to urge such a proposition, it ought, in fairness to the Court, to call attention to the testimony of its own expert, Millikan, who, testifying in the same case for the Telephone Company, said, and in so saying was sustained by the Court, that the devices used by the Telephone Company worked "*on an entirely different principle*" (Vol. I, p. 118), which he explained was due to the fact that they *were "evacuated to such a degree that the residuary gases play no part in the operation*" (p. 119), so that the current was governed by the space charge, unaffected by positive ionization (p. 115).

Here is a clear recognition by Millikan that the difference between Langmuir's tubes and the tubes of the prior art was a difference in principle and mode of operation.

Langmuir's references to Lilienfeld, which the petitioner has also quoted in connection with its first point, will be discussed in connection with our answer to that point (*infra*, p. 45).

The quotation from Lord Kelvin contains no suggestion that the Edison effect does not depend upon gas.

Von Beyer speaks of working in the highest possible vacuum, when in fact we know that when he lighted his filament the pressure was about 10 microns and that it was

> "necessary to renounce the study of the effect of different gases—because of the continuous evolution of gas from the wire and also because of the occlusion of gas which always occurs" (I. R. p. 2005).

Petitioner quotes Judge MAYER's opinion in the *Marconi-DeForest* case. In the same case Judge HOUGH, speaking for the Court of Appeals, said (243 Fed. 565):

> "The gaseous medium of the audion is nothing but the commercial vacuum of the ordinary electric light bulb—air being a gas, and the bulb containing some residual air, in other words defendant (DeForest) uses the same 'vacuous' vessel that Fleming does."

The petitioner says that the reference to gaseous tubes in the DeForest 1919 Bulletin can refer only to the detector tubes. But the Bulletin makes no distinction between detectors and amplifiers, and the uncontradicted evidence shows that the pressure was the same in both (Vol. III, p. 1620). Moreover, an earlier DeForest Bulletin issued in 1915 shows that there was no difference in this respect between detectors and amplifiers (*supra*, p. 30), and DeForest's fundamental paper on the audion amplifier, published in 1913, after Langmuir had made his invention, makes it clear that the audion amplifier was just as gassy as the audion detector (I. R. pp. 1497-1500).

In conclusion petitioner makes the amazing suggestion that the new purely electronic tube described in the 1919 bulletin is nothing more than the old gaseous audion which the bulletin tells us was very unstable in operation and had the decided disadvantage that, after continued use, the tube would become hard, requiring more B-battery voltage, until it reached such a state as to be inoperative.

The petitioner says that it is fantastic for us to contend that if the vacuum in a DeForest tube was made better by him, or became better in use, the tube was no longer operative, but if it was made better by Langmuir the usefulness was greatly increased.

This is not our contention. When the vacuum in a DeForest audion became better with use, the audion became useless. Langmuir's invention is not a useless, but an immensely useful, thing.

A hard audion was useless because it was still a gaseous tube, designed for use as such. The only way to make it operate was to increase the gas pressure to the value at which the gas would act as a conductor; it was common practice to do this by heating the tube so as to liberate more gas and increase the density. This is exactly what the DeForest bulletin recommends (Vol. IV, p. 137). When this expedient failed the audion was discarded.

The Langmuir tube is a useful tube because its operation is not dependent upon gas. Langmuir dispensed with the gaseous conductor upon which the useful operation of the DeForest audion depended, and by doing so made a tube which worked infinitely better.

POINT II.

The invention is not merely a DeForest audion capable of operating at higher voltages. The essential difference is that at any voltage the tubes of the patent are stable and reproducible as contrasted with the audion which was always erratic and non-reproducible. The invention is not a vacuum or degree of vacuum; the vacuum is important only as one of the elements of a combination which produces a new, useful and unexpected result. Such a tube was new in the art, and required new and different vacuum technique to produce it. The old tubes operated on the old principle of ionic or gaseous conduction; the new tubes operate on the new principle of pure electron discharge. (Petitioner's first point.)

The petitioner asserts that the invention is nothing more than a Fleming valve or DeForest audion capable of operating at higher voltages and with more power. It says:

> "The advantage of improving the vacuum lies not in getting a *new* kind of performance, but in getting *more of the same kind.*"

If this were the invention we think the patent would never have gotten out of the Patent Office. But it is not the invention, and in another part of the brief petitioner's counsel stoutly contend it is not the invention. At page 85, in an effort to prove that Langmuir did not reduce the invention to practice in August, 1912, they say that Langmuir's August tube, which was operated at 200 and 250 volts, did not embody the invention because the discharge was "still greatly affected by ionization." Yet in the next breath (p. 98) they ask the Court to find that simply because some DeForest audions may have operated at 54 or 67½ volts they must have operated by pure electron discharge substantially unaffected by ionization.

The prior art devices.

The petitioner refers to three prior art devices which it claims embody the same structure and principle of operation as the tubes of the patent. They are: the DeForest audion, the Fleming valve and the tube described in Lilienfeld's German paper published in 1910.

The DeForest audion.

By an ingenious play on words the petitioner makes a plausible argument that any tube which amplifies at voltages above the ionization voltage is a tube of the patent, from which it asks the Court to conclude that because the old style gaseous DeForest audions amplified at voltages above ionization, they must have operated by pure electron discharge. The introduction to this amazing argument is subtle. At page 27 of the brief, after having enumerated the characteristics of a pure electron discharge as stated in the original specification, the petitioner says:

> "All these criteria are summed up in the simple statement that there must be absence of 'harmful ionization' as this term is employed by respondent's witness, Hogan."

Petitioner then ignores what Hogan said he meant by "harmful ionization" and substitutes a definition better suited to the argument, which is that harmful ionization is ionization such as would make the tube inoperable, and from this definition petitioner argues that any tube which amplifies is a tube of the patent.

The argument, of course, would apply equally well to a detector. The audion detectors, as well as amplifiers, were always operated above ionization voltages (Van der Bijl, I. R. p. 99), so that the petitioner's argument logically leads to the conclusion that a detector, which was admittedly a gas device (Petitioner's Brief, p. 95), was none-the-less a pure electron tube of the patent.

The trouble with the argument is that neither the patent nor Hogan gives this definition of "harmful ionization." Hogan explained very clearly what he meant by harmful ionization (Vol. I, p. 96, XQ29):

> "Harmful ionization would be that which would interfere with the operation of the device in such a way as to produce a low power limit or affect its uniformity of operation, or otherwise produce difficulties."

Therefore, if harmful ionization is to be used as the test it must be used in the sense in which Hogan used it.

The test is not whether a tube will amplify, but whether it will amplify uniformly and reproducibly, and this is the test which petitioner's own experts give as the most satisfactory test to distinguish between a tube operating by pure electron discharge and a tube operating by gas conduction. Petitioner's expert, Millikan, said (I. R. p. 840):

> "Hence, it is unquestionably true, as I stated in my original testimony that, barring the 3-electrode test, the *showing of an ideal and reproducible characteristic is the most simple and practical test we have for a pure electron discharge.*"

Petitioner's expert, Van der Bijl, said (I. R. p. 778):

> "I look upon a discharge as a pure electron discharge *if the characteristic is sufficiently steady and reproducible* to enable us to use the device to per-

> form satisfactorily any one or more of the functions for which it is designed."

It is exactly the test of harmful ionization which petitioner points out in another part of its brief (p. 9) where it says:

> "For reasons which need not be here stated, however, the gas content in a tube, and so the amount of ionization, varies with temperature, the life of the tube and other things, so *that erratic and undesirable operation may result.*"

So also from the standpoint of practical use, ionization is harmful if it makes the tube erratic and irreproducible. The audions which DeForest furnished to the Telephone Company and which petitioner now says operated without "harmful ionization" were nevertheless "of practically no value in the telephone plant" (Vol. II, p. 721), because they were critical and erratic. As petitioner's witness Jewett, one of the Telephone Company's engineers, said (I. R. p. 2218):

> "I saw, however, that if the remarkable action which it evinced with small alternating current input on the grid and *with the plate battery voltage carefully adjusted to its optimum value* could be obtained with an input alternating current of the magnitude which must be provided for in telephone operating conditions, and if this operation could be obtained reliably, *that is, if the erratic behavior of the DeForest audion could be eliminated*, then it might be an instrument of considerable importance for telephone service."

The careful adjustment of the plate battery voltage to its optimum value and the erratic behavior of the audion to which Jewett refers establish beyond question that these audions depended for their amplification upon the effects of ionization, just as Langmuir has explained (*supra*, pp. 29 and 31).

The critical adjustment of the B-battery voltage in the audion was not to get a pure electron discharge, but to get a discharge in which ionization played the maximum useful part.

Langmuir regards as "harmful" the ionization which DeForest regarded as essential.

So from the point of view of the user of a Langmuir tube, the ionization which DeForest thought was helpful and necessary is "harmful"; the modern user of tubes demands a tube which does not require constant and critical adjustment. So just as the expressions "high vacuum" and "highest possible vacuum" mean one thing to a steam engineer and mean another thing to Fleming and mean an entirely different thing to Langmuir and the modern art, so the expression "harmful ionization" means one thing when used from DeForest's point of view and another thing when used from the point of view of the Langmuir patent.

The difference between a Langmuir tube and a DeForest audion is not merely a matter of the voltage at which the two tubes will operate. The audion was intended to operate at some voltage critically adjusted for each particular tube and for the varying condition of the same tube, somewhere between 20 and 50 volts. The DeForest Company recommended a variable battery of from 30 to 36 cells (normally about 45 to 54 volts). With the B-battery voltage carefully adjusted to the optimum value, and with absurdly small currents, the audion would amplify. At the same voltage a Langmuir tube would amplify, but the Langmuir tube would operate the same hour after hour, and day after day; the audion would not operate the same very long and no two audions would operate the same at any one time. The reason is that the current in a Langmuir tube, being independent of any action of the gas, is steady and reproducible. The current in a DeForest audion, being dependent upon the varying conductivity of the gas, is erratic and irreproducible, requiring constant adjustment of the B-battery voltage to compensate for the varying conductivity of the gas. The essential difference is that the two tubes, operating under identically the same conditions, depend upon entirely different principles of operation; the audion on the principle of gas conduction, the Langmuir tube on the principle of pure electron discharge.

The Fleming valve.

Fleming, the inventor of the Fleming valve, described his invention in 1905 in a scientific paper before the Royal Society (Vol. V, p. 143). In this paper he described the characteristic operation of his valve, illustrating it by curves showing the current readings at different voltages. The defendant's expert, Chaffee, testified that he had examined these curves; when asked what they indicated he said (Vol. I, p. 262):

> "A. They indicate certainly the presence of gas.
> "XQ432 They are bad curves from the standpoint that we are discussing now?
> "A. Yes, they certainly indicate presence of positive ionization."

Fleming's subsequent publications up to and after the date of publication of Langmuir's work show that he regarded his valve as operating by gaseous conduction (I. R. pp. 1335-1347).

Petitioner does not rely upon this scientific article; it prefers to rest its case, so far as Fleming is concerned, on an article which Fleming published at about the same time in a very "popular" English journal (I. R. p. 1351), copied in the "Scientific American," in which he uses the terms "very perfect vacuum," and "highest attainable vacuum," and says that a vacuum is high "when it is reduced to one hundred-millionth of an atmosphere." Fleming was simply indulging in striking hyperbole permissible in a non-scientific article. In those days nobody knew how to measure a vacuum of a hundred-millionth of an atmosphere (Vol. I, pp. 208-209). What Fleming was really talking about is demonstrated by another statement in the same article, which the petitioner does not quote (Vol. V, p. 174):

> "when the vacuum is very high (that is, if the residual gas pressure is something less than one ten-millionth of an atmosphere) the phenomena becomes simplified. We then observe the well-known effects of the Crookes or Roentgen tube. The electrons in the negative electrodes are projected from it owing to the great electric force with very high velocities; and as their path is not sensibly disturbed by the sparsely distributed molecules of the remanent gas, we have all the phosphorescent and other remarkable effects due to the bombardment of these electrodes, and their impact against the glass walls of the vessel or objects placed in the tube. This state makes itself evident by apple-green phosphorescence of the glass vessel."

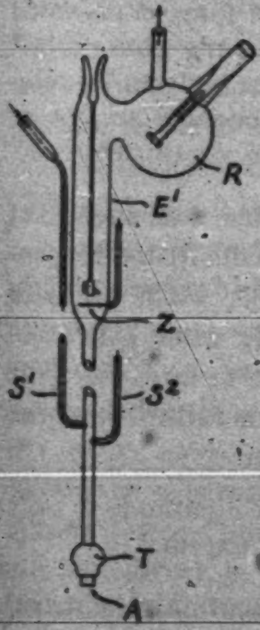
So the vacuum to which Fleming referred was the vacuum of the old Roentgen X-ray tube, which had a cold cathode and in which the conduction was caused and conditioned by the gas ionization, and which, like the audion, ceased to operate when the vacuum became too high (Vol. II, pp. 1175-1178). The actual gas pressures in these old X-ray tubes were substantially the same as those in the DeForest audion and in the carbon-filament incandescent lamp of those days. This was also the pressure in the Fleming valve (Vol. III, pp. 1574, 1660, 1661), as Fleming himself repeatedly said (I. R. p. 1309) and as the Court of Appeals of the Second Circuit held in *Marconi* v. *DeForest*, 243 Fed. 560.

This Fleming matter is discussed at Vol. III, pages 1676-1679 and at I. R. pages 1307-1362.

The Lilienfeld experimental tube.

Petitioner quotes with reference to Lilienfeld a few disconnected sentences from Langmuir's deposition. Langmuir fully discussed Lilienfeld's work and showed what it was that Lilienfeld did, at I. R. pages 1364-1407; see also Hogan, Vol. III, pages 1697-1709.

The Lilienfeld paper described certain laboratory experiments performed with a complicated and utterly useless tube which is here illustrated.



During the experiments the tube was kept immersed in liquid air and was never sealed off from the pump. The current was carried by an action entirely different from that of a radio tube, and no possible utility for such a device has been suggested by any one. The only use to which it was ever put was to demonstrate to Lilienfeld's satisfaction a theory of physics which all the experts ridicule (Chaffee, Vol. I, p. 338; Hogan, Vol. III, p. 1702; Millikan, I. R. p. 155).

Lilienfeld's paper taught the world nothing useful. It is true, as Langmuir frankly said, that Lilienfeld took precautions to get the highest vacuum that he knew how. But the conduction in the Lilienfeld tube was not Langmuir's conduction; his tube "operated on a totally different principle" (I. R. p. 1784); in Lilienfeld's tube no electrons passed directly from cathode to anode; they progressed through the tube by a series of jerky steps by a mechanism known as "secondary electron emission" (I. R. pp. 1066-1071). This caused the energy of the discharge to be delivered to the walls of the tube (Vol. V, p. 368) rather than to the anode, which protected the anode from bombardment (I. R. pp. 1380-1381). Langmuir has no hesitation in stating that Lilienfeld's vacuum was good enough to prevent positive ionization from affecting *such* a discharge, but nobody has suggested that such a discharge has any practical use (I. R. p. 1398). As the Law Examiner said (Op. p. 13):

> "The Lilienfeld device with its long, constricted tube is obviously impractical for any commercial purpose. The walls would tend to melt under electron bombardment and would become so hot as to furnish vapors under their own vapor pressure."

Lilienfeld's arrangement of electrodes was such that it was impossible to bombard them sufficiently to produce a Langmuir tube (I. R. pp. 1433, 1403; see also Vol. III, p. 1531), as appeared strikingly when Lilienfeld tried to put his theories to practical use in an X-ray tube with a hot filament; the attempt was a failure because, as Lilienfeld himself said (I. R. p. 1400):

> "The drop of potential of such a cathode is only a few volts even in an extreme vacuum."

This means that he was unable to maintain sufficient vacuum to enable him to operate an X-ray tube with a hot cathode (I. R. p. 1400). He contented himself with a form of X-ray tube which admittedly works because of gas ionization and is inoperable without gas (Vol. I, p. 280).

The alleged conformity of the tube of Lilienfeld's 1910 paper to certain tests useful for ascertaining the presence of a pure electron discharge in a practical tube is without significance; for example, the fact that Lilienfeld's "secondary emission" discharge was independent of filament temperature under certain conditions simply means that the current under those conditions was determined by the secondary emission phenomena (Vol. III, p. 1725) and constitutes no proof that it would have been determined by space charge in the absence of the secondary emission. Lilienfeld himself repeatedly said that he had no space charge in his tube (Vol. I, pp. 331-334; Vol. V, pp. 476 and 395).

There is no indication that space charge actually limited his currents (Vol. III, p. 1706). The constancy of the current was actually due to an enormous electrical resistance in series with the tube (Vol. III, p. 1705).

These matters are fully discussed at Vol. III, pages 1697-1709, 1724, and I. R. pages 1779, 1364-1407.

It seems absurd to suggest that the claims of a patent on an invention which has done what Langmuir's invention has done must contain limitations to distinguish them from any such useless toys as that which Lilienfeld describes, but it is impossible to find in Lilienfeld's tube on any theory a discharge "substantially unaffected by * * * secondary electron emission from the walls of the tube" (Claim 1); or "tube walls" "fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode" (Claim 2); or "the energy of the discharge delivered mainly at an electrode or electrodes" (Claim 25), &c.

The vacuum of the patent.

The petitioner says that the invention cannot be the degree of vacuum. We agree with this statement; it is exactly what the patent says.

As Langmuir said (Vol. 2, p. 1240):

> "The pressure does not make any difference in a tube, if the tube has good characteristics, is reproducible and stays reproducible during its life. No one would object to the tube because it had ten microns of gas in it, that would be the last thing to think of. But if it has ten microns of gas in it and that gas changes and the change of that gas causes the characteristics to change in an irregular way, in a non-reproducible way, then the gas pressure becomes important."

The invention is not a vacuum, or even a degree of vacuum; the vacuum is important only as one of the elements which in proper combination produce a desired result.

High vacuum in prior art.

The petitioner quotes several references in an effort to show that the methods necessary to obtain the vacuum of a Langmuir tube were old and well known. They are: Dwyer, Soddy, Doane and Bessel-Hagen.

The *Dwyer* patent covers an old style carbon filament incandescent lamp with the vacuum of the DeForest audion. It, of course, discloses nothing about getting the gas out of an anode or plate, which was the big problem. Defendant's expert Chaffee admits at Vol. I, pages 231-232, that this patent does not tell us how to make the Langmuir tube.

The *Soddy* patent covers a vacuum pump. This patent was cited as a reference against the second, third and fourth Langmuir patents which are not involved in this appeal, and it was expressly stated by counsel for petitioner that it was not cited against the first patent which is the only patent involved in this appeal (Vol. I, p. 346). Another Soddy reference which was offered by the petitioner but which is not cited in the brief (Defendant's Exhibit No. 18) discloses an experiment by which Soddy proved to his own satisfaction that when a hot cathode tube was thoroughly exhausted no current at all would pass through it (Vol. III, p. 1580).

The *Doane* article discloses nothing more than the old art carbon filament incandescent lamp exhaustion technique.

The *Bessel-Hagen* article described some experiments made with a tube in which the gas pressure increased the moment the current passed through the tube to a value considerably higher than that in the DeForest audion (Vol. III, pp. 1669 and 1670; Vol. I, p. 342). In the same article it is said (Vol. I, p. 342):

> "The electric current requires the ponderable gas particles as carriers, in order to cross from one electrode to the other."

None of these references discloses a pure electron discharge tube and none of them discloses the precautions necessary to produce a vacuum maintainable during operation in a hot cathode tube necessary if the device is to operate by pure electron discharge. We call particular attention to Langmuir's summary at I. R. pages 1489-91, of the difference between the old art which their citations typify, and the modern art which Langmuir created.

The petitioner quotes from the opinion of the Law Examiner but does not quote his conclusion. After considering all of the prior art references cited against the patent, including those referred to in the petitioner's brief and many others, the Law Examiner dismissed them all with the statement (Op. p. 12):

> "It is not seen that any of the remaining references made fully available to the public by proper disclosure the device now claimed in the issue as reformed, or that the proposed combinations of references, *with results not suggested by any one of them, were obvious. The fact seems incontrovertible that a substantial and valuable contribution to the art has been made and that, within the limits explicitly stated or necessarily implied in the claims retained, it is entitled to patent protection.*"

The novelty of pure electron discharge.

Petitioner criticizes us for referring to the pure electron discharge of Langmuir's tube as a "new type of discharge." Petitioner says it is not new, but petitioner's witness Richardson, in his book published in 1916 refers to the characteristic phenomenon of pure electron discharge as

> "an interesting effect which was discovered and explained by Langmuir" (Vol. IV, p. 339).

If, as petitioner contends, this thing which Langmuir did was nothing more than an obvious development of the art, why did it never occur to Fleming or DeForest, or others experienced in the art? Judge Morris said that the radio art was young, and there was no pressing need for such an improvement. But the art was not so young. Wireless telegraphy had been in practical use since 1898 (138 Fed., p. 671). If the art was in its infancy, it was because it was being held back for the want of just such a device as Langmuir gave it. The art would be in its infancy today if it still depended upon the Fleming valve and the DeForest audion.

But whatever the fact may be about the radio art, certainly the telephone art was not satisfied with the inadequate devices upon which it then had to depend. Telephone engineers had visions of a transcontinental line. They realized, as defendant's witness Jewett put it, that to solve the problem "it was necessary to enlarge the art beyond anything that we knew" (Vol. I, p. 403) and that "the solution must be found in what was essentially an inertialess type of repeater, an amplifying device which involved the discharge of electricity through some sort of conducting medium that did not involve the moving of actual physical matter" (Vol. I, p. 404). They worked on this problem for a year and a half; the best solution which they found was a mercury arc repeater, which was never used.

DeForest was himself a telephone engineer. He appreciated that in the audion he had the ideal device if he could get rid of the trickiness and increase the power level to that which was required on an ordinary commercial line.

Here was a challenge to DeForest's knowledge and inventive ability. He was desperately in need of funds, and the success of his negotiations with the Telephone Company was of vital consequence (*Westinghouse* v. *DeForest*, 21 Fed. 2nd, at p. 925). If he had known how to overcome the limitations of the audion which obviously made it unsuitable as an element in a telephone repeater, his success would have been assured. *But he did not know how.* He risked the success of this vital demonstration upon a device which, as he recognized and admitted (Vol. I, pp. 497-8), and as Arnold testified, because of these limitations was "of practically no value in the telephone plant" (Vol. II, p. 721).

As the Supreme Court found in the *Telephone* case (126 U. S. 567), the "ordinary laws that govern human conduct" are more reliable guides to the truth than the testimony of a cloud of witnesses.

POINT III.

The audions relied upon to prove the defense of prior use were gaseous tubes operating by gas ionization. The fact that a tube may amplify at 40 volts or more is no indication that it is a pure electron discharge tube, and the uncontradicted evidence shows that the tubes in question were gaseous tubes. DeForest had no idea of a pure electron discharge; his own statements show that what he wanted was a gassy tube; a tube exhausted to a particular optimum gas pressure in order to utilize the maximum useful effect of ionization. (Petitioner's fourth point.)

The defense of prior use.

This defense is beautifully illustrative of the fundamental fallacy of the petitioner's whole argument on the question of patentability. As we shall see, it leads to the absurd conclusion that the old DeForest audion, which the petitioner in its 1919 bulletin tells us had "the decided disadvantage that after continued use the tube would get hard and require more B battery until it reached such a state as to be inoperative," was after all nothing more nor less than a Langmuir tube.

Facts as to detector and amplifier operation.

The petitioner's argument proceeds from certain premises which are either unsupported by any evidence or in contradiction of the undisputed evidence.

The petitioner states that the ordinary DeForest audion detector was recognized as a gas device and as such had an ionization voltage of about 25 volts and that it was, therefore, customary to use the detector with an impressed voltage of approximately 22½ volts; in other words, that the detector was ordinarily used at voltages below ionization. The petitioner's own testimony is just the reverse. Van der Bijl testified (I. R. p. 99) that the audion was never operated below ionization and (I. R. p. 194) that the detector was commonly operated from 30 to 50 or 60 volts.

Petitioner also makes the statement that when voltage *very slightly* above ionization voltage (25 volts) was impressed upon the audion detector it would blue-glow. Here again the statement is not borne out by the evidence. The voltage at which a tube will blue-glow, as we have seen, depends upon the pressure. The DeForest Company recommended for an audion detector, as well as amplifier, a variable battery of some 30 to 36 cells (usually about 45 to 54 volts) and the instructions were to adjust the battery at the voltage just below that at which blue-glow occurred.

It is true, as petitioner says, that when blue-glow appears an amplifier becomes inoperative, but the same is true of a detector, and it is true, in either case, whether blue-glow appears at a voltage slightly above the ionization voltage or whether it appears at some substantially higher voltage. But the fact that a tube operates, whether as an amplifier or detector, without blue-glow, is no indication that it is operating by pure electron discharge (*supra*, p. 11).

From these false premises the petitioner argues that because certain audions may have amplified at 54 or 67½ volts (as to which there is no proof) they must have operated by pure electron discharge.

The argument is the same as that which the petitioner advanced under its first point and is completely disposed of in our answer to that point (*supra*, pp. 38-42). The fallacy of the argument is further demonstrated by the facts that

(a) no witness has testified that the tubes upon which the petitioner relies to make out this defence were pure electron discharge tubes;

(b) the evidence in so far as it shows anything about the operation of these tubes shows clearly that they operated by gas ionization (*infra*, p. 56);

(c) both Langmuir (Vol. II, p. 1285) and Hogan (Vol. III, p. 1614) testified positively and without contradiction that the process of evacuation used for these tubes could not possibly have produced a vacuum sufficiently high to avoid substantial ionization or anything better than the vacuum of a DeForest detector;

(d) during the taking of depositions the petitioner had a tube exhausted by the same process for the purpose of offering it in evidence but it was never offered and respondent was never afforded an opportunity to test it (Vol. II, pp. 1042, 1060-1063).

DeForest's letter to the McCandless Company.

Petitioner refers to this letter as though it proved that DeForest appreciated the desirability of a vacuum such as to permit of a pure electron discharge.

If DeForest had any such appreciation it is surprising indeed that he was not called as a witness.

The fact, of course, is that the letter shows no such thing. All it shows is that DeForest was not satisfied with a tube which blue-glowed at 15 to 20 volts—quite naturally because such a tube would saturate at voltages lower than those at which it was intended to operate, either as a detector or amplifier. He wanted a better vacuum than that, certainly; but all he wanted or thought he could use was the vacuum of the audion detector, which normally operated from 30 to 50 or 60 volts, the same optimum gas pressure that he always wanted.

Langmuir's testimony.

Petitioner quotes Langmuir's testimony as proof that the maximum amplifying power of an amplifier tube containing gas is secured at approximately 27 volts and asks the Court to draw the conclusion that any tube which amplifies at any voltage above 27 volts must therefore be a Langmuir tube.

We ask the Court to read this testimony (Vol. III, p. 1427). What Langmuir did say was that a gassy tube amplified very well; that a *particular* tube amplified best at about 27 volts, and not nearly so well at 40 volts. Just because one tube amplified best at 27 volts and another at 54 or 67½ volts does not mean that one was substantially affected by ionization and the other was not. It means simply that the critical voltage was different, due to the difference in the gas pressure. This was typical of all prior art audions and one of the great objections which the petitioner pointed out in its 1919 circular. In each case the audion was operating above ionization voltages, and the amplification was due to ionization.

Tungsten cathodes.

Finally the petitioner resorts to the desperate argument that because Lamont and Hyde may have used tungsten filaments, they may have obtained by accident a sufficiently high vacuum to cause the tubes to operate without appreciable gas ionization. The supposed authority for this is Langmuir's statement that in a *tungsten incandescent lamp,* after continued use, the pressure was probably less than one-millionth of a millimeter of mercury. Langmuir completely disposes of this argument at I. R. page 1491, where he explains that in an audion, unless special precautions are used to free the anode from occluded gas "this gas continues to come off practically indefinitely, *so that the clean-up effect of the tungsten filament is not sufficient to maintain a low pressure*"—by which Langmuir meant the pressure of a pure electron discharge; not the pressure in a "hard" audion, which was something like five microns (*infra,* p. 57), which was the pressure of an ordinary carbon filament incandescent lamp.

What the evidence shows regarding the California tubes.

But we do not have to speculate about these tubes, because the evidence shows very definitely what they were. Petitioner's witness Hewlett, when asked about the audions which petitioner now says he operated at 67½ volts, said (Vol. 2, p. 1008):

> "The voltage depended upon the degree of exhaustion of the particular tube I had in use and I would say it ranged around about sixty volts, but I had a glass beaker with a thermometer and the tube in the oil of this beaker and by lighting a small alcohol lamp under this beaker I could somewhat control the amount of B-battery used for best results.

> "Q17. What was the effect of heating the vacuum tube in the manner you describe?
>
> "A. Heating the tube lowered the amount of B-battery used on the tube."

In a bulletin published by the DeForest Company in 1915 it states (Vol. 4, p. 137):

> "A hard bulb can be 'softened' by heating very carefully and evenly over a flame for a few minutes."

Referring to Hewlett's testimony, plaintiff's expert, Hogan, said (Vol. III, p. 1616):

> "That is exactly like the tube heating that was commonly used by radio operators in the early years of the audion. The heat applied to the glass walls results in disengaging gas within the tube and therefore increasing the gas pressure in the tube and reducing the voltage at which a blue glow can be had, and also the operating voltage of the tube. A blueglow at sixty to seventy-five volts shows in the ordinary audion construction with a gas pressure of something like four to six microns."

It is evident, therefore, that these tubes which petitioner now says were the identical device of the patent are the identical old-art gaseous audions which petitioner in its 1919 bulletin (*supra*, p. 4) tell us "had the decided disadvantage that after continued use the tube would get hard and require more B-battery until it reached such a state as to be inoperative."

In other words, according to petitioner, the Langmuir tube which, to use the language of Judge Morris, "because of its stability, reproducibility and power, has made possible radio broadcasting, modern radio reception, and long distance telephony" is nothing more than the old hard audion which the art regarded as useless.

While we do not subscribe to petitioner's conclusion, we do submit that if Langmuir had done nothing more than to develop such a marvelous use for a device which was discarded as useless, he would be entitled to the credit of having made an important invention.

POINT IV.

The question of priority was decided by the Patent Office tribunals in favor of Langmuir in a contest between the respondent and the American Telephone and Telegraph Company, which has openly defended the present case on this issue. The case for the patent has been strengthened, not weakened, by the evidence in the present suit. Langmuir made the invention when he made and operated a pure electron discharge tube in August, 1912, more than two months before Arnold's alleged date of conception. Arnold's whole idea was to take a DeForest audion and by pumping a better vacuum to extend the range of operation to somewhat higher voltages without modifying the essential nature of that operation. This is not the invention. His conception and disclosure were inadequate in that they did not include any adequate idea of means. The inadequacy of his conception is evidenced by his inconsistent statements and by his inability to make good tubes until after Langmuir's invention was disclosed to the public. (Petitioner's third point.)

The Arnold defense.

Whether Dr. Arnold or Dr. Langmuir was the first inventor was the subject of a long interference proceeding in the Patent Office, in which some two thousand pages of printed testimony were taken.

The Langmuir application had been filed on October 16, 1913. Two days later Langmuir presented and orally summarized a paper on his work before the American Physical Society in New York. Arnold was present and participated in the discussion (I. R. p. 1596). The paper was published in the December, 1913, issue of the Physical Review.

It is now claimed that in November, 1912, Arnold made the invention in question. If he did, he did nothing to assert that fact until November 2, 1915, although he had known for two years what Langmuir had accomplished and was taking the credit for.

When the Arnold application was filed his attorney asked for an interference with the Langmuir application. The interference was declared. Then Arnold moved to dissolve the interference for lack of patentability. He lost. When he and his assignee, the American Telephone & Telegraph Company, had thus failed to block the Langmuir application, they proceeded with the contest of priority. The Examiner of Interferences and the Board of Examiners in Chief awarded priority to Langmuir. The Assistant Commissioner reversed the Board. Then the case went to the Court of Appeals of the District of Columbia, which reversed the Assistant Commissioner and decided that Langmuir was the first inventor; the patent accordingly was issued to Langmuir.

In the present case the defense that Arnold was the first inventor was openly conducted by counsel for Arnold's assignee, the American Telephone & Telegraph Company, and they appear on the brief now filed as "of counsel as to Point III."

A proceeding under R. S. 4915 between the Telephone Company and General Electric Company is pending in the Southern District of New York, awaiting the outcome of this case.

Since Arnold and the American Telephone & Telegraph Company, parties to the interference proceeding, are thus openly conducting this defense in the present suit, and as the decision here will be practically conclusive in the 4915 case, it would seem that this is a case in which by analogy there should be applied the rule of *Morgan* v. *Daniels*, 153 U. S. 120, recently applied in *Victor* v. *Brunswick*, 273 U. S. 670, and in the *Feed-Back Cases*, 278 U. S. 562.

The critical dates.

Arnold claims to have conceived the invention on November 1, 1912, and to have reduced it to practice November 29, 1912, and at various subsequent dates. It is our position that Langmuir made the invention in August, 1912, and that, therefore, the Arnold defense has no standing. It is further our position that Arnold did not conceive the invention on November 1, 1912, or reduce it to practice on November 29, 1912, or at any time of the slightest importance in this controversy.

The Court of Appeals of the District of Columbia, following the Board of Examiners in Chief in the Patent Office, held that Langmuir conceived the invention in August, 1912, and reduced it to practice November 19, 1912, and that Arnold neither conceived nor reduced to practice at any time during the year 1912.

Langmuir's Work.

Prior to July, 1912.

Langmuir is a graduate of Columbia University, 1903, and Ph. D. of the University of Goettingen, 1906, and since then has been the recipient of many scientific honors and degrees throughout the world. He came to the General Electric laboratories in 1909. The first problem on which he worked led him to a study of gases in filaments. This was the beginning of a research which lasted many years. One of the fruits of that research was the present invention; another was the gas-filled lamp, the patent for which was sustained in *General Electric* v. *Nitro-Tungsten*, 261 Fed. 606, and other suits, and was referred to by this Court in *United States* v. *General Electric*, 272 U. S. 480.

This early work is summarized at Vol. II, pages 1075-1116. From that testimony it appears that in this work Langmuir accumulated a unique knowledge of vacuum conditions existing in devices carrying substantial electric currents and a unique technique in producing and maintaining vacua.

By 1911 he and an assistant had spent several months investigating thermionic currents in low gas pressures. He testified in the interference, I. R. page 1557, as to what was the general opinion in 1911:

> "In a general way, however, the results seemed to indicate that, if a perfect vacuum could have been obtained, the currents would have stopped entirely.
>
> "I think that practically all the men in the laboratory, who had thought much on the subject, agreed with Dr. Whitney that the evidence seemed pretty strong that, with the very high vacua ob-

> tained in well made tungsten lamps, especially if they were run above their normal voltages, the thermionic currents were negligible and would have disappeared entirely if the traces of residual gas could have been eliminated."

But Langmuir was not satisfied; as he said at I. R. page 1557:

> "My own attitude could best be described as an open mind,"

The July and August, 1912 work.

Early in 1912 he began to take a more active interest in the subject. He discussed the matter with Coolidge, he was familiar with the work of others in the thermionic field. He set his assistant Sweetser to study the "clean-up" phenomenon, which was then not understood. Sweetser was working by Langmuir's side, and what he did was under Langmuir's constant supervision and intimate direction.

Langmuir appreciated that for his purposes it was necessary to have a tube in which no gas would be evolved from the electrodes or any other source during the operation. Accordingly, using all of the technique which he had accumulated, he produced a tube which from the point of design and preparation was different from anything ever made before. The elaborate processes through which this was accomplished are decribed by Langmuir (Vol. II, pp. 1116, 1120, 1122) and by Sweetser, I. R. pages 1704, 1705-1707.

After the tube was thus thoroughly freed of the occluded gas and thoroughly exhausted, Langmuir's procedure was to let a little nitrogen into it and, by passing a high voltage current from the cathode to the anode, to clean up this nitrogen by a physical and chemical action which is explained by Langmuir (I. R. pp. 1561-2). Thus, he could observe how the tube acted while the gas pressure became lower and lower, as the nitrogen was automatically cleaned up by the action of the current.

Very careful records were made of what was done. These records, mostly in Sweetser's handwriting, are in evidence as Plaintiff's Exhibits 99 and 100 and are fully explained by Sweetser at I. R. pages 1704-1720 and by Langmuir at I. R. pages 1561-68.

The first run on the tube was made on August 20, 1912. The current between the cathode and anode was at 250 volts. The records show that as the pressure of gas diminished and approached five-tenths of a micron the current dropped from 18 to 15 milliamperes. At five-tenths of a micron the current suddenly dropped to 5 milliamperes and stayed there. This drop in current is described at Vol. II, page 1125:

> "That (the fall of current) is due to the clean-up phenomenon that was going on as a result of the electrical discharge taking place between those two terminals at a difference of potential of 250 volts. And then a very remarkable phenomenon took place in that the current dropped suddenly from 16 to 15 and then to 5, up to 15, down to 5, and then stayed at 5 milliamperes."

The next day, August 21st, a second run was made with a lower effective voltage, 200 volts, under which circumstances it was to be expected that the final current would be smaller. It was 3 milliamperes (Vol. II, p. 1127).

Langmuir testifies at Vol. II, page 1128:

> "*In my opinion, there cannot be the slightest doubt but that* the currents at these lower pressures

> in this device at that time, were currents from 3 to 5 milliamperes with 200 to 250 volts, in which *the current was limited by space charge, and was not substantially affected by ionization of the gas.*"

In the interference proceeding Langmuir, testifying to his work of August 20-21, said (I. R. p. 1563):

> "The foregoing results show clearly that when the pressure of 0.5 microns was reached an entirely different type of discharge began to take place. The results show that the 18 milliampere current was determined by the electron emission from the filament, the space charge effect having been eliminated by the presence of gas. This saturation current remained practically constant as the pressure was lowered, until at about 0.5 microns the number of positive ions present in the space became insufficient to neutralize the space charge. A slight further disappearance of gas caused the current to be limited by space charge, and the current thus fell from 18 to 5 milliamperes. As the pressure decreased still further to 0.34 microns, the space charge current underwent only an insignificant change (to 4.5 milliamperes), *showing that at these lower pressures the space charge was substantially unaffected by positive ionization.*"

On August 28th he repeated the first run of August 20th. As to this referring to Sweetser's records, he testified (Vol. II, p. 1129):

> "Low pressures were again employed, and a little lower down on this page, beginning at 3.08 o'clock a run was started, again at a temperature of 2225 degrees, and the nitrogen cleaned up almost exactly as it did in this Run 1, which I have just been describing. Again the current which was obtained with 250 volts on the anode, and with the use of a milliammeter to measure the current,

> changed from 5 to 17, and then suddenly to 5 milliamperes at almost exactly the same pressure that was recorded before. That is, the pressure at the first reading that gave 5 milliamperes, the pressure was 0.4 micron."

Langmuir next let in a little nitrogen, and again cleaned it up. Here again when the pressure diminished to five-tenths of a micron the current dropped from 17 to 5 milliamperes, exactly the same results as in run No. 1 of the previous week. As to this drop Langmuir testified (Vol. II, p. 1130):

> "*This is just another illustration of this same fact, that we had passed from the condition where there was* a space charge which was eliminated by *the presence of positive ions,* so that the current was limited by saturation, and suddenly, when the pressure reached below a certain point, the supply of ions was no longer sufficient to neutralize the space charge, *and the current became limited by space charge.*
>
> "Now, these pressures of 0.4 micron are a good deal higher than the pressures that were used or ordinarily exist in pure electron devices today; but they are pressures that can be duplicated at any time with a device of this kind at present and give pure electron discharge under these conditions.
>
> "The reason that the positive ions at this pressure of 0.4 micron play no part in the neutralizing of the space charge, is that the positive ions go to the walls of the tube."

This work is recorded in Sweetser's record sheets, Plaintiff's Exhibit No. 99 (physical). It began July 20th and was prosecuted continuously until September 13th.

The tube used in this work we submit was the tube of the patent, its construction and its evacuation were such that it operated by pure electron discharge substantially unaffected by ionization.

In each of the runs, that of August 20th, that of August 21st, and that of August 28th, the tube behaved in the same way; thus it showed the practical characteristic of the tubes of the patent, namely, that the current is reproducible and not tricky.

Langmuir quite frankly admits that he did not then draw the conclusion that he had a pure electron discharge substantially unaffected by positive ionization. He had the tube, which he had carefully prepared, and he knew how he had prepared it, he knew how it acted and he kept the most elaborate records of that, but he did not then understand the theory of its action. Indeed he was puzzled. By the accepted theory of the time, in such a high vacuum there should have been no current at all. But there was current, and that current had not responded to changes in filament temperature in accordance with Richardson's formula. These discrepancies excited Langmuir's attention, so much so that he arranged to see Richardson in New York and talked the matter over with him for a whole afternoon on the campus of Columbia University, but Richardson had no explanation to offer.

Langmuir was then interrupted by some other work which he had previously begun. In November he resumed this work, determined to work out the theory of the action.

In November, 1912, Langmuir worked out the theory of the action of his tube.

Langmuir prepared three more tubes. The operation of these highly evacuated tubes on November 19, 1912, is fully described in the interference record, I. R. page 1571, *et seq.*, and in the testimony at Vol. II, page 1139, *et seq.*

Every step is carefully recorded in Langmuir's note book and every possible sort of data set down. On page 139 of his note book he summarized what he had done. The period during which the tube was cleaning itself he called "the first stage." Of the second stage, that is, after the gas had been eliminated, he wrote in the note book (I. R. p. 1575):

> "(6) The second stage is characterized by reproducibility, especially of the maximum current."

Referring to this entry he testified (Vol. II, p. 1151):

> "The maximum current referring to the current observed with the maximum filament temperatures, which is the current which is limited by space charge independently of ionization."

Thus, he calls attention to the important practical characteristic of the tubes of the patent, the reproducibility of the current, the absence of that trickiness that characterized the old tubes operating by gaseous conduction.

Under date of November 22nd he enters in his note book his "new theory of Edison current" (I. R. p. 1576). It is a clear statement of the effect of space charge, the factor which controls the action of the current when unaffected by positive ionization.

Langmuir immediately disclosed these results to his associates (I. R. p. 2123). He regarded them "of vital importance" (I. R. p. 1577) and instructed Sweetser to make another tube like that of August. The preparation and exhaust of this tube are elaborately described by Sweetser at I. R. pages 1712-1715.

On November 21, 1912, Langmuir began a series of experiments on this tube (Vol. II, p. 1163). On November 26, 1912, he operated it on alternating current, which current it rectified, at voltages in excess of 480 and with substantial currents. It embodied the invention in every respect (Vol. II, pp. 1165-1166; I. R. pp. 1583, 1585, 1723, 1728).

The discharges were characterized by reproducibility and constancy (I. R. pp. 1725, 1583, 1584, 1587).

On November 30, 1912, Richardson visited the laboratory. Langmuir showed him his tubes in operation and showed him that when the tube was operating in the range below saturation the current did not follow Richardson's law, but was independent of the filament temperature. Richardson was surprised, because, as he said (I. R. p. 510):

> "At first sight this looked as though there was something the matter with my theory."

But when Langmuir went on to show that as the voltage was increased to the point of saturation the current increased to the proper value, Richardson was very much relieved, because, as he said (I. R. p. 510),

> "I was naturally very pleased with these experiments as they showed that the currents were not saturated; whence it followed that the true value of the emission was not given by the currents at high temperatures and the current limitation was not due to my theory's breaking down at high temperatures."

The "current, limitation," of course, was due to space charge. And in his book published later Richardson speaks of this limitation of current by space charge as

> "an interesting effect which was discovered and explained by Langmuir" (Vol. IV, p. 339).

Richardson testifies that when he went away he carried with him one or two of Langmuir's tubes (I. R. p. 512).

On December 10, 1912, Langmuir discussed his invention with Coolidge and fully disclosed it to him, and suggested that the principle of a tube operating without ionization be applied to an X-ray tube, and Coolidge, profiting by this suggestion, developed his well known X-ray tube (*infra*, p. 84).

The next month, January, 1913, Langmuir not merely suggested but confidently told Alexanderson that his, Langmuir's, tube operating without ionization was just what Alexanderson needed for use in a radio receiving set, and made some tubes for him for that purpose. Thus the Langmuir tube in the Alexanderson circuit became the basis for most of the receiving sets on the market up to the present time.

Langmuir's invention was made in August, 1912.

The tube of August, 1912, was not accidently produced, it was carefully prepared by the most expert and ingenious methods and for the deliberate purpose of freeing it from gas. The currents which it produced were not accidently obtained; they were no freak phenomena; they were reproducible, and they were reproduced again on August 21st and again on August 28th and again and again in November. That these currents were reproducible is the common, practical test of the tube of the patent. The data of the performance of these tubes were daily recorded and the records are in evidence; the data prove that they were operated by pure electron discharge unaffected by ionization. Finally we have the unquestionable testimony of Langmuir himself, drawn from this data, that the August tube was the tube of the patent.

Langmuir's tube was thus perfected and operated in August, 1912, two months before Arnold had an idea on the subject. Since Langmuir perfected it in August, 1912, he invented it in August, 1912. Mr. Justice STORY in *Washburn v. Gould*, Fed. Cases 17, 214, declared:

> "Whoever first perfects a machine, is entitled to the patent and is the real inventor."

The modern exception to this doctrine for the benefit of the prior conceiver in the exercise of due diligence has no application here, for Arnold does not claim to have entered the field until November, 1912.

The petitioner's criticism of Langmuir's work.

The petitioner's main attack on Langmuir's work of August, 1912, is based on Langmuir's frank admission that he did not at that time know that he had "a pure electron discharge substantially unaffected by positive ionization." It is not necessary that he should have known; it is elementary patent law that an inventor need not understand the theory of his invention.

Langmuir had, and knew that he had, a *tube* which was carrying substantial currents at substantial voltages (Vol. II, p. 1128). It had a hot cathode and a cold anode: it was a Fleming valve, of a new kind, *a kind that operated very steadily and reproducibly at high voltages.* It responded to all of the claims of the patent, except a few claims which are limited to the third electrode.

Whether or not Langmuir knew the theory of the action of the tube, he knew how he had made the tube, and he made other like tubes that worked the same way.

Petitioner's counsel say there can be no reduction to practice without precedent conception, and that there can be no conception without "perception," that since Langmuir did not know the theory of how the tube operated he could not conceive the invention.

This psychology of the act of invention is of account when a man is trying to claim as his date of invention a date back of the time he perfected his machine; the American patent law lets him have the benefit of the antecedent date of conception provided there is disclosure and diligence in reducing to practice. But when, as here, the inventor is not trying to carry his date back of the time he perfected his machine there is no need to go into the question. Surely a man has invented his machine when he has deliberately built one which works; there may be dispute as to whether he invented it at some earlier date; there is no disputing the fact he has invented it when he builds it and it works.

The cases which the petitioner cites have no application. *Tilghman* v. *Proctor*, 102 U. S. 707, was a case in which an accidental effect, unappreciated and never followed up, was relied on to anticipate a subsequent patent for an important invention. *Pittsburgh* v. *Cowles*, 55 Fed. 301, was a case of the same kind. The rule, as stated in these decisions, was expressed by Judge TAFT in the latter case as follows:

> "Accidents of this character cannot be relied on as anticipations of a patented process * * * when the operator does not recognize the means by which the accidental result is accomplished and does not thereafter consciously and purposely adopt such means as a process for reaching the result."

But Langmuir's August tube was not an accidental effect, unappreciated and not followed up. Langmuir recognized the means by which he had accomplished the result and thereafter consciously and purposely adopted the same means for producing other tubes with which he accomplished the same result. It was not in any sense an abandoned experiment. He followed up his work until he had worked out the theory of the operation of the tube and explained to the world for the first time how and why current flowed in such a tube.

The petitioner also attacks Langmuir's August work upon the ground that there is no evidence that Langmuir had any conception of the utility of such a tube.

Its utility was self-evident. A tube with a hot cathode and a cold anode was a known, useful rectifier for alternating currents disclosed as such by Fleming and by Wehnelt. Langmuir's tube was obviously a two-electrode rectifier having all the capabilities of the Fleming valve and the Wehnelt rectifier and also having the new property that it operated very steadily and reproducibly at high voltages. Langmuir proceeded to rectify alternating current with a similar tube in November of the same year.

Petitioner attempts to meet this conclusive demonstration by saying (p. 84 of its brief):

> "This is not true because it was recognized the rectifiers, like detectors, work better with considerable residual gas."

Petitioner says this in spite of the fact that one of the admittedly infringing tubes which it sells and which is here in evidence (Pl. Ex. No. 5) is a pure-electron-discharge two-electrode rectifier. For rectifying current at very low voltages gassy rectifiers are preferable (Vol. II, p. 1352), but Langmuir's pure-electron-discharge tube without a grid, used as a rectifier, and so described in his patent (p. 5, line 35), is a commercial device, used up to 100,000 volts at least (I. R. p. 1607) and was employed on a large scale in airplanes during the great war at exactly the voltage which Langmuir used in August, 1912 (I. R. pp. 1189 and 1607).

In the *Feed Back* cases, DeForest was accorded a date of invention based upon an accidental result of certain experiments conducted by his assistant in August, 1912, although there was not a word of evidence in that case that DeForest then appreciated any utility for the thing on which he subsequently was granted a patent. In that case the Court of Appeals in the Third Circuit said (21 Fed. [2nd] 925, affirmed 278 U. S. 562):

> "Whether DeForest advanced toward the invention intelligently or stumbled upon it is a matter of no concern, for it was an invention none the less. The United States Government and three great industrial corporations claim it and all the world is using it. DeForest may have made the feed-back hook-up without any preceding notion of how it would work; an order of things, we surmise, not unusual in electrical inventions. *It did work. Whether DeForest or Van Etten at once knew its theory of operation and its capabilities is not important if they recognized the phenomena and were able, at will, to re-set the circuit and reproduce the result.*"

Langmuir's invention of August, 1912, could be, and was, reproduced at will thereafter.

Petitioner next says that the evidence taken at the trial in Court, and which was not before the Patent Office, shows that the discharge in Langmuir August tubes was not a pure electron discharge substantially unaffected by positive ionization. The reference is to the testimony of the defendant's expert Becker, who, while characterizing the discharge as a "new type of discharge" and admitting that the current was limited by space charge (Vol. III, pp. 1792-1793), contended that certain experiments which he had made with an approximately duplicate tube showed that the space charge was not pure and that further reduction of the gas pressure would still further have reduced the current (Vol. III, p. 1799).

Langmuir's testimony in rebuttal (Vol. III, pp. 1916 to 1923) completely disposes of Becker's suggestion and demonstrates beyond question that the discharge in the August tubes was a pure electron discharge.

The next attack which defendant makes on Langmuir's work in November is based upon the fact that Langmuir was a highly qualified physicist and on the assertion that he was not producing practical results, but discovering scientific facts.

Langmuir is a great physicist, but he is also a great inventor of practical, useful things. We have said that August tubes were obviously capable of rectifying alternating current. The November tubes *did* rectify alternating current.

Petitioner next quotes from a note book entry which Langmuir made on March 23, 1913, and says it shows that it was not until that date that Langmuir had any conception of the invention.

The quotation in the petitioner's brief is incomplete. What follows in the note book entry makes it perfectly clear (Plaintiff's Exhibit 131, Physical p. 34):

> "It may be that an audion so made (if of the same dimensions and design as the DeForest) will not be as sensitive as the DeForest but by proper design (*i. e.*, making grid close-meshed, and perhaps using double grid, and by making the distances very small by using spacing devices, etc.) I expect to very greatly increase the sensitiveness

(this we have already done with No. 2 which appears to be three or four times more sensitive than the DeForest audion)."

No. 2 was a three-electrode or audion type tube which White had made under Langmuir's direction for Alexanderson. The evidence is positive that it operated by pure electron discharge (Vol. II, pp. 1191-1198).

In view of the fact that Langmuir had a tube in August, 1912, which did operate by pure electron discharge, that he made three tubes in November, 1912, which operated the same way, that Sweetser made another tube in November which also operated the same way, that Langmuir had given to Richardson in November, 1912, a pure electron discharge tube, had fully disclosed his invention to Coolidge in December, 1912, and to White in February, 1913 (I. R. pp. 1640-43; Vol. III, pp. 1468-70), and had made and operated three-electrode tubes for Alexanderson early in March, 1913, this note book entry cannot possibly mean that he had no conception of the invention until that date.

The entry is perfectly clear when read in connection with Langmuir's previous work. Both the two-electrode tubes and the three-electrode tubes which he had constructed up to that time had filamentary anodes, instead of the plate anodes of the commercial Fleming valve or DeForest audion. This was an expedient to which Langmuir resorted because of the difficulty of cleaning up a solid anode, something which he had tried to do and failed.

Therefore, all that this entry can possibly mean is that on March 21, 1913, at a time when he had constructed and operated both two-electrode and three-electrode pure electron discharge tubes *with filamentary anodes*, Langmuir recorded his determination to construct a pure electron discharge, three-electrode tube with the *plate anode* of the conventional DeForest audion.

Arnold's Work.

The Court of Appeals of the District held that Arnold did not conceive the invention until long after Langmuir's reduction to practice (Op. pp. 94-5).

Arnold's alleged conception.

Arnold's so-called conception of the invention was nothing more than a DeForest audion operating at a somewhat higher voltage than 40 volts. His whole idea was that, if he took out "more of the residual gas" (Vol. I, p. 414) he could raise the voltage at which blue glow appeared. As he himself said (I. R. p. 2166):

> "We observed at this time that the blue haze appeared when an attempt was made to operate the tube at higher voltages than about 40 volts; and *in connection with my disclosure to him, that there would not be any blue haze if proper precautions were taken to remove the gas,* I also pointed out that *this* would enable us to operate the tube at higher voltages and that this operation at such a high voltage would retain *the advantageous characteristics of operation already obtained at low voltages,* while giving greatly increased output and allowing proper operation over a wider range of input voltages."

Arnold did not know that when the audion operated, as it normally operated, at voltages below the voltage at which blue haze appeared, it was dependent upon gas ionization, and he did not know that the erratic behavior and the necessity for critical adjustment to which Jewett referred were due to gas effects which were *not* manifested by blue haze (*supra*, p. 41). On the contrary, he thought and said that when the audion was operating with the plate voltage carefully adjusted to the optimum value "the action was purely electronic" (I. R. p. 24).

As Langmuir said (I. R. p. 2057):

> "Arnold frequently speaks of audions in a way which indicates to me that his viewpoint in regard to the development of these tubes has been very different from mine. For example, on page 39 [I. R. p. 2193], he says:
>
> " 'the principles of operation of the high vacuum repeater bulb that I contemplated were the same as for the original DeForest and McCandless audions, such as DeForest Audion 7-A, *when they were kept below the voltage at which gas effects appear*.'
>
> "(Page 41) [I. R. p. 2195]:
>
> " 'Being interested in the operation of the DeForest tubes at voltages below those at which gas effects became apparent, I took the data,' etc.
>
> "From these and similar statements it is clear that Arnold retained the viewpoint that he had in November, 1912, where he observed a blue haze in the neighborhood of 40 volts and noticed that different tubes showed this blue haze at different voltages. He felt therefore that all he needed to do was to lower the gas pressure a little so that he could raise this voltage from 40 to 100 volts, and then his problem would be solved. He did not have in mind any new and fundamental modification involving a new type of discharge."

Arnold had no conception of a new type of discharge. His conception, if he had been able to realize it, would have resulted in nothing more than a DeForest audion with the same erratic characteristics and with the same critical adjustment of voltage to the optimum value except that the optimum value might be somewhat higher.

This is not the invention; Arnold's alleged conception was therefore not a conception of the invention.

And Arnold's subsequent work showed that he had no conception of a tube which would operate steadily and reproducibly at any voltage. His test of a good tube was the voltage at which it showed blue glow (I. R. p. 2823). He was quite satisfied if he could raise the voltage at which blue glow appeared, notwithstanding the current was irreproducible at any voltage substantially above ionization voltage.

Accordingly Arnold regarded a tube as a good tube if it did not show blue glow at voltages in which he was interested, and he testified in this suit that one such tube showed a pure electron discharge up to 240 volts (Vol. I, p. 611), although, as he had to admit on cross examination, the curves which he produced showed that the current was completely irreproducible above 23 volts (Vol. II, p. 657; See also I. R. p. 2068).

Arnold's idea of means.

The Board of Examiners in Chief held that Arnold's alleged conception of November 1, 1912, was incomplete in that it included no adequate idea of means (Op. p. 68).

Petitioner seeks to meet this by quoting from the opinion of the Assistant Commissioner to the effect that if anyone conceived the idea that a rubber button was a good thing, he could go to a rubber manufacturer and have him make a rubber button and that this would be invention. But in this case there was no manufacturer to whom Arnold could go; the normal man skilled in the art did not know how to make such a "button."

Moreover, Arnold did not propose to rely upon the skill of someone else to reduce his invention to practice. He himself was the man skilled in the art, and as part of his disclosure he stated very definitely his idea of means, which was merely to exhaust the DeForest audion by the technique which he used in exhausting his mercury arc rectifier, supplemented by the use of liquid air and charcoal. It is not possible by these means to turn a DeForest audion into a Langmuir tube (Vol. III, p. 1913; Vol. III, pp. 1726-9; I. R. pp. 1101-2; I. R. p. 2055). Moreover these are not the means which Arnold now says he later used in his reduction to practice.

Neither in his disclosure of November 1, 1912, nor in the records of his later work prior to a note book entry of one of Arnold's assistants dated in October, 1913 (Vol. III, p. 801; Vol. IV, p. 327, No. 63), did Arnold make any reference to this new idea of means which he now says he used in his reduction to practice.

Petitioner's explanation for this striking circumstance is that Arnold simply followed a procedure which was such well known and standard practice that nobody would think of recording it. This explanation is emphatically contradicted by the fact that some three years later Arnold applied for a patent upon this very procedure, claiming it as an invention, and testifies that when he filed his application he regarded it as an invention, and something different from his mercury arc technique (Vol. II, pp. 785-786).

Therefore the petitioner's position amounts to this, that a conception and disclosure are complete although they contain no idea of means and although the necessary idea of means involves something so novel as to be the proper subject of a patent.

And that Arnold did not have any adequate idea of means, and that the knowledge of men skilled in the art was not sufficient to supplement the inadequacy of his disclosure, is conclusively demonstrated by his first attempts to make some good tubes. In December, 1912, he instructed Trimble to "repump some of the DeForest or McCandless make of audions to see if we could get any better vacuum in them" (I. R. p. 2246).

This was after Arnold's alleged reduction to practice. Trimble was a man highly skilled in the art; he was the man who had been carrying out the mercury arc exhaust for Arnold. He tried to repump some of the DeForest audions to see if he could get any better vacuum in them *and he failed dismally.*

Arnold excuses Trimble's failure by saying that "a very important part of the procedure is to learn how to so conduct the exhaust that the filament will not be destroyed during the exhaust" (Vol. II, p. 749). This was something which Trimble still had to learn in December, 1912. Just when and where Arnold learned it we are not told; certainly he did not learn it from his mercury arc work, which involved no such problem, because the mercury arc has no filament. It is, however, vitally significant that Arnold never succeeded in making any good tubes until after Langmuir's Physical Review paper was published.

Arnold's later work.

This is enough so far as conception is concerned. Arnold's alleged reduction to practice by Audion 7-A is too late. His preliminary statement sets it at November 29, 1912 (I. R. p. 2156). As the Board of Examiners in Chief held (Op. p. 69), it was at best a mere accident which he did not appreciate and which he could not repeat.

The results of that accident are discussed by Langmuir at I. R. pages 2027-2042. The day after the test on which petitioner relies another test showed that the tube was again a very gassy tube. So it was not reproducible (I. R. p. 2031).

Arnold has been inconsistent about many things; strikingly so in connection with his Audion 7-A, where he has reversed his position not once, but twice, as the exigencies of his case seemed to require.

When Arnold swore to his preliminary statement in the interference, he relied on the November 29, 1912, tests of his audion as his reduction to practice of the invention.

When, on his motion to dissolve the interference, he was contending that there was no invention, he produced these same tests as characteristic of a typical prior-art DeForest audion (I. R. pp. 470-477).

And when, on priority in the interference, he again decided to claim that he was the inventor, he again produced these same tests as proof of his reduction to practice, and testified that the tube "did not belong in the same class with the original DeForest audions" (I. R. p. 2182).

And again in the present case he presents these tests as proof of his reduction to practice of the invention.

In February, 1913, Arnold staged a demonstration for the purpose of proving the practicability of transcontinental telephony with his new relays. Although he claims to have reduced to practice in November, 1912, he used in this demonstration not tubes of the invention, but old-style DeForest audions, and in order to adapt the transmission to the limited energy capacity of the audions, the power level was kept much lower than on a commercial line, and he used some of his mercury arc repeaters at the end of the line in order to get the necessary amplification in the receiver.

But while a low power level was possible in a laboratory experiment, it would have been impracticable in an ordinary commercial line, as Arnold testified (Vol. II, p. 742).

It is incredible that if Arnold had conceived the invention and reduced it to practice months before, he would have been satisfied by a demonstration so inconclusive as this.

Petitioner says on page 77 of its brief that this demonstration was "a distinctly by-the-way incident, and not at all an important or official test." Arnold's testimony in the interference, I. R. page 2199, is:

> "It was a somewhat spectacular demonstration as is evidenced by the circumstance that President Vail of the American Telephone and Telegraph Company and other notable officials of that company and of the Western Electric Company witnessed the demonstration. It was the first test of an equivalent of the transcontinental line that had ever been undertaken."

Arnold staged another important, but less spectacular, demonstration in October, 1913. In September his assistant Kendall installed a repeater at Philadelphia, using some of Arnold's tubes. After more than a month spent in testing and adjusting, the repeater was switched in on a line between New York and Washington and it worked—exactly as the DeForest audions had worked in the February demonstration.

Kendall's written instructions for the use of these tubes specified plate voltages of about 30 to 50 volts, just what was used with the old DeForest audions, *and the record of this test shows that the voltage on the tubes was being constantly adjusted.* Moreover Kendall's instructions specified the use of a protective device, a device on which Arnold later filed a patent application. In his application, which was filed April 16, 1914, describing his device he says (I. R. p. 2345):

> "It has been found in the usual audion structure that when energies of considerable magnitude, *such, for instance, as are encountered in ordinary telephone systems,* are impressed upon the input circuit of the audion, *a blue haze appears in the bulb of the audion.*"

Arnold's dream in November, 1912, was an audion which would handle the energy required for an ordinary commercial line, which was about 1 watt. In October, 1913, he had succeeded in producing some tubes which handled something less than .005 of a watt. At about the same time Langmuir was working with two kilowatts at 40,000 volts in a single tube (Vol. III, pp. 1460-61).

If Arnold had made any invention by October, 1913, it was not in improving the DeForest audion, but in redesigning the telephone circuits so as to adapt them to the limits of the old DeForest audion.

In October, 1913, as we have seen, Langmuir orally summarized (Vol. III, p. 1405, XQs639-641) his paper published in the December, 1913, issue of the *Physical Review.* Arnold was present (I. R. pp. 478 and 1596). About December 1st the *Physical Review* paper appeared. A few months later Arnold's people had some good tubes, capable of handling about half a watt (Vol. II, p. 725, XQ641). A few months after that the San Francisco line was operated with pure electron discharge tubes (Vol. I, p. 526, Q221, and p. 529, XQ241).

POINT V.

The rule of Adamson v. *Gilliland has no application in this case. (Petitioner's fifth point.)*

From what we have said above it is clear that this case turns on inferences or conclusions to be derived from substantially undisputed facts, and not upon findings of fact based upon conflicting testimony. Such being the case, the conclusions of the trial court are not binding on this Court (*The Britannia*, 153 U. S. 130; *Harkin* v. *Brundage*, 276 U. S. 36; *Corona Tire Co.* v. *Dovan Chemical Corp.*, 276 U. S. 358, 375).

Moreover, on the issue of priority the concurring decisions of the Examiner of Interferences, the Board of Examiners in Chief, the Court of Appeals of the District of Columbia and the United States Circuit Court of Appeals for the Third Circuit certainly outweigh the authority of the trial court.

On the issue of prior use the testimony was not taken before the Court, so that the rule of *Adamson* v. *Gilliland* (242 U. S. p. 350) would not apply in any event.

POINT VI.

The defense of double patenting has not been sustained by any judge who has heard this case, and is utterly without merit. (Petitioner's sixth point.)

On December 10, 1912, Langmuir disclosed to Coolidge the invention of the pure electron discharge tube which he had made and suggested to Coolidge that he attempt to apply that invention to the X-ray tube with which Coolidge at that time was very familiar.

Petitioner asserts in its brief that the only thing which Langmuir told Coolidge at that time was that tungsten would emit electrons in high vacuum. But Coolidge testifies that on that day Langmuir told him (Vol. III, p. 1512):

> "That when these filaments had been carefully freed from gas in a high vacuum, he had found it possible to maintain a discharge, a pure electron discharge, from a hot filament, that the electron emission had instead of decreasing with the removal of gas from the tungsten filament, which was to be used as a cathode, had increased up to a certain point, and from there on it remained steady, and that this was a thoroughly reproducible condition."
>
> "how he had freed what he was handling of gas and water vapor in order to get the high vacuum" (p. 1549)
>
> "to produce a new X-ray tube operating on a new principle, on pure electron flow" (p. 1549).

We proved this as a complete disclosure on December 10, 1912, of Langmuir's invention to a competent scientist who was capable of understanding it.

Langmuir did not invent the Coolidge X-ray tube; nobody ever contended that he did. But he disclosed to Coolidge an invention which he, Langmuir, had made and reduced to practice,—the invention of the pure electron discharge tube, and he also suggested to Coolidge the use of the principle of that tube in an X-ray tube.

It was not an easy suggestion to realize; Langmuir admits that he would have then been unable to realize it himself (Vol. II, p. 1295). Coolidge did realize it, after long and difficult research (Vol. III, p. 1520), and he revolutionized the X-ray technique to an extent which can best be appreciated by reference to I. R. pp. 1679-

1682, from which it appears that the advantages of reproductibility, reliability, etc., so important in the use of Langmuir's tubes in the radio art, are even more important proportionately in the X-ray art.

The prospect of an instrumentality so useful in relieving human suffering led to a rapid development and early commercial use of the Coolidge tube. A patent application was filed for it on May 9, 1913. The claims submitted with the application show that whoever prepared it assumed that Coolidge was the inventor of whatever was common to his tube and Langmuir's tube. The basis of this may have been some notes made by Coolidge in May, 1912 (Vol. III, pp. 1506-1508).

It is clear on the record that Coolidge was not the first inventor, that his crucial experiment made in September, 1912, caused him to feel that he had failed flatly—and he stopped (Vol. III, p. 1561), only to take the matter up when Langmuir's invention was disclosed to him a few months later.

Accordingly, when the true facts were ascertained, the Coolidge claims were limited to the X-ray tube which he had invented, and in the Coolidge specification were inserted the words which now appear in the Coolidge patent (Vol. VI, p. 1026, l. 64):

> "Certain broad aspects of the apparatus and methods herein disclosed are not of my invention but are the invention of Irving Langmuir and are defined by the claims of his allowed application, Serial No. 84,242, renewed March 14, 1916, and his application, Serial No. 876,432, filed December 10, 1914."

This obviously prevents any claim from the Coolidge patent being interpreted as broad enough to cover the

Langmuir tube. There is, therefore, no double patenting under the well-known doctrine set forth in Judge TAFT's decision in *Thomson-Houston* v. *Ohio Brass Company*, 80 Fed. 712 (C. C. A., 6th).

The "prolongation of the monopoly" is inherent in any case where the fundamental patent and the patent on an improvement issue at different dates, as they normally do, and are assigned to the same assignee. During the life of the broad patent no one can lawfully use the broad invention without license. During the life of the narrow patent no one can lawfully use the narrow invention without license. If it happens that the same assignee owns both patents, as it often does, then the period in which that assignee has the right to keep everyone else from using the narrow invention is the longer period during which either one of the patents is alive (*Ohio Brass* case, 80 Fed. at p. 727). As the Court of Appeals for the Sixth Circuit said in *Dayton Fan & Motor Co.* v. *Westinghouse Electric & Manufacturing Company*, 118 Fed. 562, 571:

> "And no valid reason exists why the patentee of an invention may not enjoy the privilege of a stranger in thereafter obtaining a patent for an independent invention made by him, although it relate to the matter of his former patent, and was described, but not claimed, therein, provided he has not dedicated such independent invention to the public";

And as Judge LEARNED HAND held in the Southern District of New York, in *Van Heusen Products, Inc.* v. *Earl & Wilson*, 300 Fed. 922:

> "There is no case in the books to which I have been referred which holds that the defense of double patenting applies between two independent

> inventors, merely because one has taken an assignment of the other invention. Nor is there any reason on principle to hold anything of the sort. The assignment makes no difference; each patent standing precisely as if there had been none such. The earlier inventor should and will prevail, if the inventions are the same; if they are different, both ought to stand. The only reason whatever for the defense of double patenting is that, since the inventor is the same in each, the defense could not succeed that the inventor of the second was not the first inventor."

If Coolidge made no invention, which we deny, then the Coolidge patent is invalid, and created no monopoly, but that would not affect the Langmuir patent (*Ohio Brass* case, at p. 727). If Coolidge made an invention, there is no reason why his assignee should not have a monopoly of it, as well as a monopoly of Langmuir's different and broader invention.

CONCLUSION.

The framers of our Constitution in their great wisdom foresaw the importance of stimulating and encouraging inventive skill and energy; accordingly they wrote into the Constitution a provision giving to Congress the power to promote the progress of science and useful arts by securing for limited times to authors and inventors the exclusive rights to their respective writings and discoveries.

The wisdom of this farsighted provision is abundantly attested by the amazing progress of science and the useful arts, particularly in the last quarter of a century. This progress has been due in large measure to the organized research work which is constantly being carried on in large corporations like the Telephone Company, the General Electric Company, du Pont and many others.

In his speech on the occasion of the Edison celebration, President Hoover said:

> "If we would have our country improve its standards of living and at the same time accommodate itself to the increasing population, we must maintain on an even more liberal scale than before our great laboratories of both pure and applied science."

Relying on the promise held out by the Constitution and assured by the patent statutes, the respondent many years ago organized and has since maintained a wonderful research laboratory, dedicated to the creation of useful inventions for the immediate benefit of itself, but for the ultimate benefit of the country and all mankind.

The invention here involved is perhaps the greatest of the many great inventions which have emanated from that laboratory.

The arguments advanced to defeat the patent are specious; the principal argument is predicated upon the assertion of scientific fact which finds no support in the record and is contradicted by petitioner's own witnesses. But as this Court said in *Diamond Rubber Co. v. Consolidated Rubber Tire Co.*, 220 U. S. 428, at 435:

> "But the law has other tests of the invention than subtle conjectures of what might have been seen and yet was not. It regards a change as evidence of novelty, the acceptance and utility of change as a further evidence, even as demonstration."

This language is singularly apt. The utility of Langmuir's invention is attested by the statement of Judge Morris that the Langmuir tube

> "because of its stability, reproducibility and power has made possible radio broadcasting, modern radio reception and long distance telephony."

Its novelty is demonstrated by the fact that the practical workers of the art had failed to develop such a device at a time when the progress of the art was standing still. Its novelty is further convincingly demonstrated by its universal acceptance in preference to the old art devices, yet these old art devices, which long ago were abandoned in practice, are now resurrected and produced as a complete anticipation of the invention.

If a patent on a meritorious invention can be destroyed by mere plausible talk, by mere reiterated assertion of things which are not so, then the promise which the Constitution held out for meritorious invention is a false promise, and the promotion of science and the useful arts and the progress of industry must inevitably suffer.

Respectfully submitted,

RALPH B. EVANS,
HUBERT HOWSON,
PAXSON DEETER,
ALBERT G. DAVIS,
Of Counsel.

April, 1931.

FILE COPY

Office Supreme Court, U
FILED
MAY 7 1931
CHARLES ELMORE CR
CLER

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930.

No. 630.

DeFOREST RADIO COMPANY, Petitioner,

v.

GENERAL ELECTRIC COMPANY, Respondent.

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT.

RESPONDENT'S BRIEF IN REPLY TO BRIEF OF AMICI CURIAE.

✓ RALPH B. EVANS,
✓ HUBERT HOWSON,
PAXSON DEETER,
✓ ALBERT G. DAVIS,
Of Counsel.

HOWSON & HOWSON,
Solicitors for General Electric Company.

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930.

No. 630. LANGMUIR PATENT 1,558,436.

DeForest Radio Company, Petitioner,

v.

General Electric Company, Respondent.

ON WRIT OF CERTIORARI TO THE CIRCUIT COURT OF APPEALS FOR THE THIRD CIRCUIT.

RESPONDENT'S BRIEF IN REPLY TO BRIEF OF AMICI CURIAE.

The brief of the *amici curiae* is inconsistent with itself as well as with that of petitioner. In one mood it repeats the petitioner's fallacious play on the words "harmful" ionization and "satisfactory" operation. In another mood it admits the difference between the DeForest tube and the Langmuir tube; that the Langmuir tube operates with a pure electron discharge (p. 21), and admits that the ionization in a DeForest tube affects the current (p. 8). It labors through five pages to show how easy it ought to have been for one skilled in the art to modify a DeForest audion so that it would be a Langmuir tube, which means of course to take the tube which petitioner's witnesses prove was "entirely unsuited for telephone repeater service" (Vol. I, l. 413) because it would not handle an ordinary telephone conversation (Vol. I, p. 519) and make it into the tube which is today handling long-distance telephone conversation all over the world.

It contends that if Langmuir's tube is not the identical tube of the prior art, it is a natural and obvious development which any one skilled in the art would perceive and realize. The argument is predicated on a kind of reasoning which would destroy any patent which ever has been issued. It is also predicated on a complete indifference to the facts—to such facts as that DeForest obviously was unable to do what is now said to have been so easy and so obvious. As this Court said in *Diamond Rubber Co.* v. *Consol. Rubber Tire Co.*, 220 U. S. 428 at p. 434,

> "Its simplicity should not blind us as to its character. Many things, and the patent law abounds in illustrations, seem obvious after they have been done, and, 'in the light of the accomplished result, it is often a matter of wonder how they so long 'eluded the search of the discoverer and set at defiance the speculations of inventive genius.' (Pearl *v.* Ocean Mills *et al.*, C. D., 1877, 133; 11 O.G., 2; Barn. & A., 469; Fed. Cas., 10,876.) Knowledge after the event is always easy, and problems once solved present no difficulties, indeed, may be represented as never having

> had any, and expert witnesses may be brought forward to show that the new thing which seemed to have eluded the search of the world was always ready at hand and easy to be seen by a merely skilful attention. But the law has other tests of the invention than subtle conjectures of what might have been seen and yet was not. It regards a change as evidence of novelty, the acceptance and utility of change as a further evidence, even as demonstration."

To the Chemical Foundation in 1931 what Langmuir did in 1912 seems natural, simple and obvious. To the art of 1912 it would have seemed heresy—which is just what it seemed to DeForest as late as 1915 (main brief, p. 28). As we have pointed out in our main brief, the workers in the art firmly believed that gas was necessary to the operation of a hot-cathode tube. The fact that a "hard" audion was useless confirmed that view. So also did the best scientific opinion of 1912. (Vol. II, pp. 21, 1133-37; I. R., pp. 1507-1522; 1925-1930, 1372, 509; Vol. II, I. R., 1135; Vol. III, pp. 1509-1513; I. R., p. 2121, 272 Fed., page 397; main brief, pp. 27-28.)

Under these circumstances to suggest in 1912 that taking out the gas would avoid some of the evils which beset the user of a DeForest tube, would have been like suggesting that cutting a man's tongue out would cure him of stuttering.

The whole argument is also obviously destroyed by Lilienfeld's admitted failure to make an operative hot-cathode X-ray tube *after* his 1910 work (I. R., p. 1400) and by the fact that he was obliged to fall back on gas conduction to make the X-ray tube of his patent 1,222,010. We do not believe, as the *amici curiae* suggest, that he ultimately produced a pure-electron-discharge tube, after Langmuir and Coolidge had succeeded, but before he knew of their success. But if he did it does not lead to the conclusion suggested, for if the theory of the *amici curiae* were correct he could have done it anytime after 1910.

Lilienfeld's hot-cathode tube failed because it was gassy (I. R., p. 1400). Either he believed, as others did, that the gas was essential, or he was unable to overcome the difficulties inherent in a hot-cathode high-vacuum tube, difficulties which the art did not know how to overcome (Vol. III, pp. 1726-1729, 1913; Vol. II, p. 1269; I. R., p. 2057). Millikan's views to the contrary are based upon the fact that the experience of that eminent scientist was with tubes in which the difficulties did not appear, for he had no experience with hot-cathode tubes (I. R., p. 144, lines 10-26 and pp. 1242-61). We have seen in our main brief, pp. 80-83, that these difficulties were too much for Arnold. Nobody knew how to achieve a high vacuum *maintainable during the operation of a hot-cathode tube.* It was not a pump that they needed, for the pumps that they had were good enough (Vol. II, p. 1711; I. R., pp. 2044-2045, 1491 and 882); it was the "know how." As Langmuir said at I. R., p. 1277:—

> "the degree of vacuum at which a device is sealed off is of very minor importance as compared to the condition of the walls of the tube

and the condition of the electrodes. That is, the amount of gas which is contained in a vacuum tube, even if the pressure at the time of sealing off is 1000th of a millimeter, is very small in comparison with the amount of gas that may be liberated from the walls of the tube and from the electrodes during operation of the tube, unless very special precautions have been taken to eliminate these sources of gas."

At page 1283, I. R., he said:—

"It is an entirely different matter, as we have seen from the experiment with the 'nickel anode tube,' *when heated electrodes are present.* In that case it is necessary to heat the electrodes to a very high temperature and for relatively long periods of time during exhaustion. In fact, it is necessary to carry the treatment of the electrodes in our ordinary present-day thermionic devices to a point which no one had any conception of prior to 1912."

At page 1249, I. R., he said:—

"The point that I want to make is simply that the characteristics of our modern thermionic devices are so fundamentally different and they had been so little studied by workers outside of the industrial laboratory that practically no one realized that the older and prevalent ideas as to discharges in vacuum were not applicable to them."

We refer also to Vol. III, pp. 1726, 1662-1664; Vol. II, pp. 1270-1276; I. R., pp. 1489-1491 and 1280. Those most skilled in the art were satisfied that any hot-cathode tube must necessarily develop quantities of gas in operation (I. R., pp. 1426, 1280, 1288-1289).

The Langmuir invention is not a matter of degree; it is the elimination of an element upon which the operation of the prior art devices depended. The difference between a DeForest audion and a Langmuir tube is not a difference in the part which gas plays in their operation; the difference is that the audion depended upon gas for its operation whereas in the Langmuir tube gas plays no part whatever. Langmuir took out the variable (gas) of the prior art devices and put a constant in its place.

Of course there is no "sudden beginning or sudden stoppage of ionization" (*a. c.* brief, p. 21); of course by gradually introducing gas into a Langmuir tube we could change its operation from that of the pure electron discharge to that of the DeForest audion by imperceptible gradations, just as by mixing paints we might pass from the jet black of India ink to the whiteness of a clean sheet of paper by imperceptible gradations. But black is black and white is white, and the Langmuir tube, with its marvelous capabilities, is a different tube from the DeForest tube—operating on a different principle and producing different results.

There is no case in the books where a change of this sort has been held to be a change of degree. The law on this subject is laid down by this Court in many decided cases, such as the *Eibel Process* case, 261 U. S. 45, and the *Minerals Separation* case, 242 U. S. 261.

Langmuir's invention is not a principle. Langmuir discovered a new principle, but he invented and produced a new tube. It is the new tube which his patent covers,—a tube which, because of its construction, operates in accordance with that principle, just as the paper-making machine in *Eibel* v. *Minnesota*, 261 U. S. 45, operated on a new principle because of its construction. Langmuir's claims are just as detailed and definite as those of the patent in the *Eibel* case.

The Chemical Foundation appeared for the first time in this case after the decision of U. S. Circuit Court of Appeals, as one of the *amici curiae*. The statements of fact made on its behalf in the opening pages of the brief are therefore, of course, outside the record. Under the circumstances we felt that it was proper and only fair to inform the Court at the hearing as to the position taken by the Chemical Foundation, when its interest was the encouragement of American scientific research and invention, rather than the destruction of a meritorious patent resulting from such research and invention.

Under the circumstances we hope and believe that it is proper to refer to the same matter here.

In the year 1925 this same Chemical Foundation published and widely circulated a pamphlet entitled "What Price Progress," in which it said, in a chapter entitled "Science in Industry":—

> "Mention the names of *Langmuir*, Coolidge, Whitney and Steinmetz in any civilized country and the well-informed man will be able to enumer-

ate some of their accomplishments. But there are hundreds of others in the employ of the General Electric Company, some of whom have contributed greatly to the store of scientific knowledge and achievement. * * *

"In addition, through its contributions to the development of the radio, it has entertained and instructed millions in this and other countries, and besides, in the development of the X-ray machine and other medical appliances, the group has alleviated suffering and made human lives happier. * * *

"The General Electric's is one industrial laboratory in which the pursuit of science is a part of the routine. Fundamental research is not merely tolerated, it is encouraged and even required. *Langmuir's development of the vacuum tube was directly due to fundamental research; that is, systematic investigation of phenomena for the purpose of discovering new facts and laws. As a result of his investigations in this field we have the vacuum tube, which gives us radio of the quality we now enjoy, transcontinental telephonic communication, the super X-ray tube of Coolidge,* and ultimately we may have the vacuum tube as a necessary link in the elongation of power transmission. * * *

"The wonders of the vacuum tube have only begun to be applied to the service of man. This great development is based on the electron theory of electricity, a purely scientific discovery. The electron is a negative particle of electricity which feels freer and more sportive in a vacuum than anywhere else. It leaps from crag to crag, that is, from filament to plate, straining itself through the grid of DeForest. *Until Langmuir took up the study of the habits of the electron it had never known what it was to gambol in a high vacuum, having theretofore always disported itself in low vacuums.* * * *

"Applying Langmuir's discoveries to the X-ray, Coolidge developed a high vacuum tube known as the Coolidge X-ray tube. * * *"

Now the Chemical Foundation says that Langmuir's tube is the identical thing of the prior art as typified by the Fleming valve and the DeForest audion; now it alleges that the Coolidge X-ray tube which in the pamphlet it specifically and correctly identifies as an application of "Langmuir's discoveries" is anticipated by Lilienfeld, and infringes the Lilienfeld patent. Although its counsel say on page 3 of their brief: "The degree of vacuum shown in the Lilienfeld patents is the same as that claimed in the Langmuir patent in suit No. 1,558,436," the fact is, as admitted by petitioner's witnesses in this case and as found by Judge Thacher, that the Lilienfeld tube is a gaseous tube, depending on gas for its operation.

The Chemical Foundation sued respondent on the Lilienfeld patent 1,222,010. The bill was dismissed by Judge Thacher in the Southern District of New York, in an opinion (not yet reported) delivered March 31, 1930, affirmed on the opinion below by the Court of Appeals of the Second Circuit on May 4, 1931. Judge Thacher said in that opinion:—

"Operation of the Lilienfeld device is shown to be dependent upon ionization, and to be subject to definite limitations when subjected to very high voltages. * * *

"Instead of employing an auxiliary hot cathode in aid of the electron discharge from a cold cathode, the Coolidge Tube eliminates ionization entirely and by the use of a hot Tungsten Cathode succeeds in producing a deluge of electrons which, under the pressure of very high voltages and without any aid from any auxiliary device, are swept across from cathode to anode in a pure electron stream."

Judge Thacher's conclusion is confirmed by the present record. Respondent's experts testify (for example at Vol. II, page 1276) and Petitioner's expert Chaffee admits, that the tube of this Lilienfeld patent operates by gas ionization; "if there were no gas ionization the current would go out" (Vol. I, page 280).

The other matters discussed in the brief of *amici curiae,* such as the alleged prior use by DeForest in California and the alleged prior invention by Arnold, for the most part mere repetition of petitioner's brief, are dealt with in our main brief.

Respectfully submitted,

Ralph B. Evans,
Hubert Howson,
Paxson Deeter,
Albert G. Davis,
Of Counsel for Respondent

FILE COPY

JAN 19 19
CHARLES ELMORE C

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DeFOREST RADIO COMPANY,
Petitioner,

vs.

GENERAL ELECTRIC COMPANY,
Respondent.

BRIEF OF AMICI CURIAE

JOHN F. NEARY,
RAMSAY HOGUET,
MARTIN T. FISHER,
Of Counsel.

New York, January 17, 1931.

TABLE OF CONTENTS

PAGE

Introductory Statement ---------------------------------- 1

Summary of Argument ---------------------------------- 1

Argument:

I. The question here sought to be reviewed is of great public interest. The parties upon whose behalf this brief is filed have grave responsibilities to the public. The responsibility of each party will be affected seriously if the decree of the court below is permitted to stand. The influence will be general and country-wide ---------------------------------- 2

II. The Circuit Court of Appeals decided an important question of general law in conflict with the weight of the evidence ---------------------------------- 9

1. The findings of fact of the District Court were set aside by the Court of Appeals without regard to the practical rule that so far as the findings of fact of the judge who saw the witnesses "depends upon conflicting testimony, or upon the credibility of witnesses, or so far as there is any testimony consistent with the finding, it must be treated as unassailable," and this without assigning any reason therefor ---------------------------------- 9

2. The effect of the decision below is to hold valid a patent that differs only in degree from the prior art. This is plainly in conflict with the weight of authority ---------------------------------- 10

Conclusion ---------------------------------- 11

CASES CITED

Adamson *vs.* Gilliland, 242 U. S. 350 at 353 ---------- 2

Davis *vs.* Schwartz, 155 U. S. 631 at 636 ---------- 2

United States *vs.* Chemical Foundation, 272 U. S. 1 3

Westinghouse *vs.* DeForest, 278 U. S. 562 ---------- 5

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930.

No. 630

DeFOREST RADIO COMPANY,
Petitioner,
vs.
GENERAL ELECTRIC COMPANY,
Respondent.

BRIEF OF AMICI CURIAE.

Introductory Statement.

Counsel appearing herein as *amici curiae* file this brief on behalf of The Chemical Foundation, Inc., a corporation of the State of Delaware; Radiological Society of North America, a corporation of the State of Illinois; Radiological Research Institute, Inc., a corporation of the State of Delaware, and the Federal Telegraph Company, a corporation of the State of California.

Each of these corporations has a grave responsibility to the public, which responsibility will be seriously affected if the decree of the court below is permitted to stand.

Summary of Argument.

I. The question here brought to be reviewed is of great public interest. The parties upon whose behalf this brief is filed have grave responsibilities to the public. The responsibility of each party will be affected seriously if the decree of the court below is permitted to stand. The influence will be general and country-wide.

II. The Circuit Court of Appeals for the Third Circuit in the instant case decided an important question of general law in conflict with the decisions of this Court.

(1) The findings of fact of the District Court were set aside by the Court of Appeals without regard to the practical rule that so far as the findings of fact of the judge who saw the witnesses "depends upon conflicting testimony, or upon the credibility of witnesses, or so far as there is any testimony consistent with the finding, it must be treated as unassailable."

(*Davis* v. *Schwartz*, 155 U. S. 631 at 636;
Adamson v. *Gilliland*, 242 U. S. 350 at 353),

and this without assigning any reason therefor.

(2) The effect of the decision below is to hold as valid a patent that differs only in degree from the prior art.

Argument.

I. The question here sought to be reviewed is of great public interest. The parties upon whose behalf this brief is filed have grave responsibilities to the public. The responsibility of each party will be affected seriously if the decree of the court below is permitted to stand. The influence will be general and country-wide.

The Chemical Foundation, Inc., is a non-profit-making holder of patents formerly under alien enemy ownership, that issues licenses to all responsible American manufacturers, at a reasonable royalty; all earnings in excess of the necessary expenses of administration being devoted to research and other works of public benefit. It is the owner of patents issued to J. E. Lilienfeld, No. 1,122,011, dated December 22, 1914, and No. 1,218,423, dated March 6, 1917. These patents cover X-ray tubes and processes for producing X-rays of predetermined hardness. The degree of vacuum shown in the Lilienfeld patents is the same as that claimed in the Langmuir patent in suit No. 1,558,436. The application date of the earliest Lilienfeld patent No. 1,122,011 is prior to the claimed date of conception of the Langmuir patent in suit.

J. E. Lilienfeld, the patentee named in the above-mentioned patents, is the same Lilienfeld referred to in the opinion of the District Court, adopted as the opinion of the Court of Appeals for the Third Circuit on the first hearing of this case, and in the dissenting opinion of Judge WOOLLEY, upon the re-hearing, as a prominent worker in the art, who had produced a non-gaseous, high vacuum tube prior to Langmuir.

The Chemical Foundation, Inc., is, by its charter and the circumstances of its creation, with which this Court is familiar (*United States* vs. *Chemical Foundation*, 272 U. S. 1), operated in the interests of the public. To the extent that this corporation owns patent rights that are or may be claimed to be within the monopoly of the Langmuir patent, it is affected by the decision in the instant case.

As the owner of the Lilienfeld patents on X-ray tube and process, it is desirous of licensing the public in accordance with its non-profit-making program of operation.

The Radiological Society of North America is an association of users of X-ray apparatus and the like in connection with the practice of medicine. It has been active in attempts to improve the present X-ray tube trade conditions and to secure relief from the present burdensome monopolies on apparatus and supplies useful in the practice of medicine. It is composed of upwards of thirteen hundred leading members of the medical and teaching professions, users of X-ray and radiological appliances, each of whom will, under the decision and decree of the court below in the instant case, be subject to an extension of the burden of a monopoly already too heavy for the medical profession, and the public served thereby, to bear. It is a fact appearing in this record that the General Electric Company has already been enjoying patent protection on X-ray tubes since 1916, under the Coolidge X-ray tube patent, which protection will be extended for nearly ten years under the Langmuir patent, if the decree below is permitted to stand. It will be apparent that each member of the public treated by any appliances involving high vacuum tubes will be subject to the burden of this monopoly, although the General Electric Company has already reaped all the rewards to which it is entitled by virtue of any invention involved under the Coolidge patent. It is also to be noted that it appears in this record that the Coolidge invention was nothing more than the application of the high vacuum tube to the X-ray art.

The Radiological Research Institute is an association of workers interested in the development of X-ray tubes and kindred instrumentalities useful in the practice of medicine and is affiliated with the Radiological Society referred to, and is engaged in research directed toward obtaining relief from the monopoly of the General Electric Company in this field. The effect of the decree below is to permit the blanketing of all this work by a patent issued more than twelve years after the stated date of conception of the alleged invention.

In addition to the effect of the decree below upon the X-ray field, it has a serious and far-reaching effect upon the field of radio communication and the public served thereby, as will appear from the following:

This Court (*Westinghouse* v. *DeForest*, 278 U. S. 562) has held the DeForest patents, Nos. 1,507,016 and 1,507,017 to cover basic inventions of DeForest, and has thus made ownership of rights under these patents a necessary prerequisite to the manufacture of vacuum tube transmitting apparatus, which is essential in commercial radio transmission. It is impossible to compete commercially in the field of radio communication without operating rights under these patents.

The only person outside of the so-called Radio Corporation group (which includes the General Electric Company among others) and the Petitioner herein that owns rights under the DeForest patents is the Federal Telegraph Company. In fact, the rights owned by the Federal Telegraph Company under these DeForest patents are broader in scope than those held by any individual member of the Radio Corporation group and even broader than those held by the DeForest Company, the Petitioner herein. The Radio Corporation and the Federal Company are the only two persons holding rights under the DeForest patents in the field of radio telegraph communication for tolls.

It is, therefore, upon the Federal Telegraph Company that the hope of the public for a competitive system of radio communication rests and, in fact, it is due to the Federal Telegraph Company, and the rights that it holds under these DeForest patents, that the Radio Corporation is now subject to the competition of such a system. The rights of the Federal Telegraph Company are being exercised by it in the manufacture and sale of communication material and by the purchaser of such material, The Mackay Radio and Telegraph Company, a controlled company of the International Telephone & Telegraph Corporation, in the operation of its radio system. The public is thus gravely interested in the perpetuation of the existing competitive conditions and therefore in the continued operation of the Federal Company and its customers.

The decision sought to be reviewed would have the effect of depriving the Federal Company and the users of its apparatus of the right to compete with, and of putting a monopoly on radio communication into the hands of, the owners of rights under the Langmuir patent—that is, in the hands of the General Electric Company and of its associated Companies, particularly The Radio Corporation of America.

It is concededly impossible to carry on modern radio communication without high vacuum tubes, and since the invention attributed to Langmuir by the Third Circuit Court of Appeals upon the re-hearing is held to be this precise thing without limitation, the entire art will be at the mercy of Langmuir's assignee. The effect of such action upon the Federal Telegraph Company and users of its communication apparatus and upon the other parties to this brief is clear, as is also the effect upon the field each of them serves.

Aside from its effect upon each of the parties to this brief, the effect of the decree below upon the public interest would be far-reaching. Not only would all commercial radio telegraphic communication be delivered into the hands of the Radio Corporation and the entire X-ray tube art be delivered into the hands of the General Electric Company, but in addition to this, and as stated below, large numbers of persons not directly affected by these considerations would feel the result of this decision.

The patent is held by the decree below to cover the so-called vacuum tube used in every radio broadcasting receiving set and in every apparatus for radio communication. The result of this decree would be to put into the hands of the Radio Corporation and its associates a complete monopoly over the vital part of all of such radio apparatus and permit it to exact tribute from almost every family in the United States.

Except upon the payment of burdensome royalties, no manufacturer could build tubes especially suited to his product, and all communication systems, such as those used on airplanes, ships and elsewhere, including those of the Army and Navy, would be subject to their domination.

The record of the decisions of the Courts below indicate that the question of the validity of the patent in suit is, to say the least, a doubtful one. The lack of agreement of the judges who have had the matter under consideration is the surest evidence of this fact. Judge MORRIS, who tried the case in the first instance and who had the benefit of hearing the record made, and whose peculiar qualifications to decide a case of this character need not be enlarged upon, held the patent to be invalid. Upon the first hearing by the Court of Appeals, Judges WOOLLEY and DAVIS also held the patent to be invalid. After the re-hearing and about a year later, Judges BUFFINGTON and DAVIS held the patent to be valid, Judge WOOLLEY dissenting and adhering to his previous opinion. It will thus be seen that of the four judges who have heard this case, two have now decided for the patent and two against it, and one of the three who had previously decided against the patent now decides for it.

In effect, this extremely important matter depends entirely upon the change of mind of Judge DAVIS, who first held the patent to be invalid and now holds it to be valid. In this connection, the learned and exhaustive dissenting opinion of Judge WOOLLEY should be noted, particularly in view of the summary treatment the subject received at the hands of Judge BUFFINGTON speaking for the majority of the Court.

An additional reason for reviewing the decision of the Third Circuit Court of Appeals, were one necessary, is found in the fact that this decision fails to define the scope of the patent that it holds to be valid.

The decision of Judge BUFFINGTON held that the Langmuir invention is "a working tube in which all the elements, cathode, plate, vacuum, so co-ordinate and interwork that current flow is not affected by gas." He says: "Just what the degree of vacuum shall be is dependent on several elements and, as stated in the patent, cannot be exactly stated."

There is, therefore, no definition whatever of the *scope* of the patent. We believe the definition drafted by Judge BUFFINGTON is so broad that it could be read without difficulty whatever upon the prior art of record in this case.

In the year which intervened between the first decision of the Third Circuit Court of Appeals and the decision on the rehearing on November 11, 1930, a number of corporations have made large investments in the business of manufacturing radio tubes; apparatus has been designed and constructed to conform to certain tube constructions; contracts have been made for the manufacture and sale of apparatus, and many persons have taken positions from which they can withdraw only with serious loss. The present decision makes it impossible now for any of these manufacturers or users to know within what limits they may manufacture and operate. Of course, as a matter of theory, the industry may use the tubes of the prior art; but practically, where the dividing line is to be drawn between the tubes of the prior art and the tube attributed to Langmuir by the Court of Appeals, the Court does not state and the entire industry is, therefore, left in the dark. The decision of the Court of Appeals produces a chaotic condition in which large investment is imperiled and an industry is hopelessly arrested in its operation and development because no manufacturer or user is advised of the limits within which he may legally operate.

II. The Circuit Court of Appeals decided an important question of general law in conflict with the weight of the evidence.

1. *The findings of fact of the District Court were set aside by the Court of Appeals without regard to the practical rule that so far as the findings of fact of the judge who saw the witnesses "depends upon conflicting testimony, or upon the credibility of witnesses, or so far as there is any testimony consistent with the finding, it must be treated as unassailable," and this without assigning any reason therefor.*

We wish to subscribe to all that is said in the brief of the Petitioner in this connection.

And we wish to add that under the cases in this Court on this point, it is, in our judgment, unthinkable that this decree, *which is the result of the wavering judgment of Judge Davis,* shall be allowed to pass without review, where Judge Davis has first affirmed Judge Morris and then reversed him in the latter instance, *withholding any comment on the facts, so carefully considered and so fully discussed in the District Court's opinion.*

The only effect of the re-hearing was to change the mind of Judge Davis. And he remains silent as to the reasons for the change. Certainly he could not say that the findings of Judge Morris were without any testimony to sustain them. The Petitioner's Brief is full of such testimony.

We submit that where, as in this case, the public is so largely affected, proper respect for the law is only attained by prompt review of the decision in question.

2. *The effect of the decision below is to hold valid a patent that differs only in degree from the prior art. This is plainly in conflict with the weight of authority.*

We subscribe to the statements of the law contained in Petitioner's Brief on this point.

The uncontradicted testimony of the record shows conclusively that the art fully appreciated the relation of vacuum and voltage of the external circuit and knew that if it was desired to use a higher voltage in the external circuit without experiencing the deleterious effects of ionization, it was only necessary to exhaust the tube to a higher degree. In view of this, the majority of the Court below on the re-hearing was evidently misled by the language of the Langmuir patent into mistaking a mere difference in degree for a difference in principle.

We can find no other logical conclusion. This is a matter apparent on the reading of the *two* opinions in the Court of Appeals. Certainly, if the Court below is to find differences in the high vacuum of Lilienfeld and the high vacuum of Langmuir, it can, under the testimony of Langmuir quoted by Judge Woolley, be only a difference in degree.

Conclusion.

For the reasons given above, it is urged that the Petition be granted.

Respectfully submitted,

John F. Neary,
Ramsay Hoguet,
Martin T. Fisher,
Of Counsel.

New York, January 17, 1931.

We hereby consent to the filing of the foregoing brief.

Samuel E. Darby, Jr.,
Counsel for Petitioner.

Hubert Howson,
Counsel for Respondent.

FILED

MAY 1[illegible] 1931

CHARLES ELMORE CROPL

CLERK

FILE COPY

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930

No. 630

DEFOREST RADIO COMPANY,
Petitioner

v.

GENERAL ELECTRIC COMPANY
Respondent

MOTION AND BRIEF AS *AMICI CURIAE*

JOHN F. NEARY
RAMSAY HOGUET
MARTIN T. FISHER
Of Counsel for
The Chemical Foundation, Inc.
Radiological Society of North America
Radiological Research Institute, Inc.
Federal Telegraph Company

April, 1931

APPEAL PRINTING CO., [illegible] ST., NEW YORK CITY

INDEX

PAGE

Motion for Leave to File Brief as Amici Curiae ... 1

Brief of Amici Curiae ... 2

Introductory Statement ... 2
Summary of Argument ... 7
Argument ... 12

1. The invention, as defined by the Court below, is unpatentable, because (A) the definition lacks invention over the prior art acknowledged in the patent, and (B) it differs only in degree therefrom ... 12
   - (A) The definition lacks invention over the prior art acknowledged in the patent ... 12
   - (B) The definition differs only in degree from the prior art acknowledged in the patent ... 20

2. DeForest and Arnold, working independently of each other and of Langmuir, arrived at the result attained by Langmuir, as the thing obvious to one skilled in the art. Their acts lie athwart a finding of invention ... 22
   - DeForest ... 22
   - Arnold ... 25

3. Accepting the definition of the invention adopted by the Court below, we find that exact thing in the prior art ... 28
   - J. E. Lilienfeld ... 29
   - DeForest ... 33
   - Arnold ... 34

PAGE

4. The alleged invention is nothing more than a statement of the physical principle of pure electron discharge and therefore not patentable .. 37

5. Langmuir's only practical application of the principle of pure electron discharge was to the DeForest tube. This application was anticipated by both DeForest and Arnold. Hence claims directed to this use are void 42

Conclusion 45

TABLE OF CASES AND TREATISES.

Corona Company *v.* Dovan Corporation, 276 U. S. 358 30, 31, 32, 40

United States *v.* Chemical Foundation, 272 U. S. 1 .. 3

Westinghouse *v.* DeForest, 278 U. S. 562 5

Robinson on Patents, Vol. I, Sec. 79, page 121 36

IN THE

Supreme Court of the United States

OCTOBER TERM, 1930.

DEFOREST RADIO COMPANY,
Petitioner,

v.

GENERAL ELECTRIC COMPANY,
Respondent.

Motion for Leave to File Brief as *Amici Curiae.*

May it Please the Court:

The undersigned as counsel for The Chemical Foundation, Inc., Radiological Society of North America, Radiological Research Institute, Inc., and Federal Telegraph Company respectfully move this Court for leave to file the accompanying brief as *amici curiae.*

JOHN F. NEARY,
RAMSAY HOGUET,
MARTIN T. FISHER,
Counsel for
The Chemical Foundation, Inc.
Radiological Society of North America
Radiological Research Institute, Inc.
Federal Telegraph Company

Assented to:

Counsel for Petitioner

Counsel for Respondent

IN THE

Supreme Court of the United States

No. 630.

DEFOREST RADIO COMPANY,
Petitioner,
v.
GENERAL ELECTRIC COMPANY,
Respondent.

BRIEF OF *AMICI CURIAE.*

Introductory Statement.

Counsel appearing herein as *amici curiae* file this brief on behalf of The Chemical Foundation, Inc., a corporation of the State of Delaware; Radiological Society of North America, a corporation of the State of Illinois; Radiological Research Institute, Inc., a corporation of the State of Delaware, and the Federal Telegraph Company, a corporation of the State of California.

Each of these corporations has a grave responsibility to the public, which responsibility will be seriously affected if the decree of the Court below is permitted to stand.

The Chemical Foundation, Inc., is a non-profit-making holder of patents formerly under alien enemy ownership, which issues licenses to all responsible American manufacturers, at a reasonable royalty; all earnings in excess of the necessary expenses of administration being devoted to research and other works of public benefit. It is the owner of patents issued to J. E. Lilienfeld No. 1,122,011, dated December 22, 1914, and No. 1,218,423, dated March 6, 1917. These patents cover X-ray tubes and processes for producing X-rays of predetermined hardness. The degree of vacuum shown in the Lilienfeld patents is the same as that claimed in the Langmuir patent in suit No. 1,558,436. The effective date of the earliest Lilienfeld patent No. 1,122,011 (October 12, 1911) is prior to the claimed date of conception (August, 1912) of the Langmuir patent in suit.

J. E. Lilienfeld, the patentee named in the above-mentioned patents, is the same Lilienfeld referred to in the opinion of the District Court, adopted as the opinion of the Court of Appeals for the Third Circuit on the first hearing of this case, and in the dissenting opinion of Judge WOOLLEY, upon the re-hearing, as a prominent worker in the art, who had produced a non-gaseous, high vacuum tube prior to Langmuir. He is the author of the 1910 paper frequently referred to in the record, briefs and opinions (Deft's. Ex. 25, Rec., Vol. V, p. 315).

The Chemical Foundation, Inc., is, by its charter and the circumstances of its creation, with which this Court is familiar (*United States* v. *Chemical Foundation*, 272 U. S. 1), operated in the interests of the public. To the extent that this corporation owns patent rights that are or may be claimed to be within the monopoly of the Langmuir patent, it is affected by the decision in the instant case.

As the owner of the Lilienfeld patents on X-ray tubes and process, it is desirous of licensing the public in accordance with its non-profit-making program of operation.

The Radiological Society of North America is an association of users of X-ray apparatus and the like, in connection with the practice of medicine. It has been active in attempts to improve the present X-ray tube trade conditions and to secure relief from the present burdensome monopolies on apparatus and supplies useful in the practice of medicine. It is composed of upwards of thirteen hundred leading members of the medical and teaching professions, users of X-ray and radiological appliances, each of whom will, under the decision and decree of the Court below in the instant case, be subject to an extension of the burden of a monopoly already too heavy for the medical profession, and the public served thereby, to bear. It is a fact appearing in this record that the General Electric Company has already been enjoying patent protection on X-ray tubes since 1916, under the Coolidge X-ray tube patent (Deft's. Ex. 67, Rec., Vol. VI, pp. 1021-1029), which protection will be extended for nearly ten years under the Langmuir patent, if the decree below is permitted to stand (Rec., Vol. II, p. 1281; this brief, pp. 37, 38). It will be apparent that each member of the public treated by any appliances involving high vacuum tubes will be subject to the burden of this monopoly, although the General Electric Company has already reaped all the rewards to which it is entitled by virtue of any invention involved under the Coolidge patent. It is also to be noted that it appears in this record that the Coolidge invention was nothing more than the application of the high vacuum tube to the X-ray art (Coolidge, Rec., Vol. III, pp. 1514, 1546).

The Radiological Research Institute is an association of workers interested in the development of X-ray tubes and kindred instrumentalities useful in the practice of medicine and is affiliated with the Radiological Society referred to above, and is engaged in research directed toward obtaining relief from the monopoly of the General Electric Company in this field. The effect of the decree below is to permit the blanketing of all this work by a patent issued more than twelve years after the stated date of conception of the alleged invention.

In addition to the effect of the decree below upon the X-ray field, it has a serious and far-reaching effect upon the field of radio communication and the public served thereby, as will appear from the following:

This Court (*Westinghouse* v. *DeForest*, 278 U. S. 562) has held the DeForest patents, Nos. 1,507,016 and 1,507,017, to cover basic inventions of DeForest, and has thus made ownership of rights under these patents a necessary prerequisite to the manufacture of vacuum tube transmitting apparatus, which is essential in modern commercial radio transmission. It is impossible to compete commercially in the field of radio communication without operating rights under these patents.

The only person outside of the so-called Radio Corporation group (which includes the General Electric Company among others) and the petitioner herein that owns rights under the DeForest patents is the Federal Telegraph Company. In fact, the rights owned by the Federal Telegraph Company under these DeForest patents are broader in scope than those held by any individual member of the Radio Corporation group and even broader than those held by the DeForest Company, the petitioner herein. The Radio Corporation and the Federal Company are the only two persons holding rights under the DeForest patents in the field of radio telegraph communication for tolls.

It is, therefore, upon the Federal Telegraph Company that the hope of the public for a competitive system of radio communication rests and, in fact, it is due to the Federal Telegraph Company, and the rights that it holds under these DeForest patents, that the Radio Corporation is now subject to the competition of such a system. The rights of the Federal Telegraph Company are being exercised by it in the manufacture and sale of communication material and by the purchaser of such material, The Mackay Radio and Telegraph Company, a controlled company of the International Telephone & Telegraph Corporation, in the operation of its radio system. The public is thus gravely interested in the perpetuation of the existing competitive conditions and therefore in the continued operation of the Federal Company and its customers.

The decree of the Court below would have the effect of depriving the Federal Company and the users of its apparatus of the right to compete with, and of putting a monopoly on radio communication into the hands of the owners of rights under the Langmuir patent—that is, into the hands of the General Electric Company and of its associated Companies, particularly The Radio Corporation of America.

It is concededly impossible to carry on modern radio communication without high vacuum tubes, and since the invention attributed to Langmuir by the Third Circuit Court of Appeals upon the re-hearing is held to be this precise thing without limitation, the entire art will be at the mercy of Langmuir's assignee. The effect of such action upon the Federal Telegraph Company and users of its communication apparatus is clear, as is also the effect upon the other parties to this brief and upon the field each of them serves.

Aside from its effect upon each of the parties to this brief, the effect of the decree below upon the public interest would be far-reaching. Not only would all commercial radio telegraphic communication be delivered into the hands of the Radio Corporation and the entire X-ray tube art be delivered into the hands of the General Electric Company, but in addition to this, and as stated below, large numbers of persons not directly affected by these considerations would feel the result of this decision.

The patent is held by the decree below to cover the so-called vacuum tube used in every radio broadcasting receiving set and in every apparatus for radio communication. The result of this decree would be to put into the hands of the Radio Corporation and its associates a complete monopoly over the vital part of all of such radio apparatus and permit it to exact tribute from almost every family in the United States.

Except upon the payment of burdensome royalties, no manufacturer could build tubes especially suited to his product, and all communication systems, such as those used on airplanes, ships and elsewhere, including those of the Army and Navy, would be subject to their domination.

Counsel signing this brief, appearing on behalf of the parties named above, have, therefore, asked leave to submit this brief, presenting their argument in support of the prayer of the petitioner that the decree of the Court below be reversed, and the decree of the Trial Court be sustained.

SUMMARY OF ARGUMENT.

The definition of the invention suggested by respondent upon the rehearing in the Circuit Court of Appeals and adopted by Judge Buffington, speaking for the majority of that Court, is as follows (44 Fed. 2nd, 931, at p. 937):

> "But a vacuum, or, indeed, change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so co-ordinate and inter-work that current flow is not * * * objectionably affected by gas. Just what the degree of vacuum shall be is dependent on several elements * * * and cannot be exactly stated. In that regard the specification says: 'The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower * * *.'"

Counsel, in this brief, contend:

1. **The invention, so defined, is unpatentable because (A) the definition lacks invention over the prior art acknowledged in the patent, and (B) it differs only in degree therefrom.**

A. The patent in suit acknowledges the Fleming tube and the DeForest tube. Like the Langmuir tube, both are hot cathode, electron discharge tubes.

Fleming operates below ionization voltages and hence without any ionization effects and by a purely electron flow.

DeForest operates above ionization voltages. The ionization taking place in his tube affects the current flow, in some respects objectionably. By the theory of ionization, it was understood that ionization could be reduced by reducing the gas content (raising the vacuum) in the tube.

The method of raising the vacuum was known before Langmuir.

Therefore it was entirely within the skill of the calling to raise the vacuum (reduce the gas content) when it was desired to reduce the ionization, and to make the compensating changes in current and/or voltage to secure any desired result.

There was no invention involved in what Langmuir did.

B. Furthermore the tube of the patent differs from the Fleming and the DeForest tubes merely in the degree of vacuum.

This was admitted by respondent before the Court of Appeals.

And the result of such difference in degree was not new. To the man skilled in the art it was the to-be-expected result. According to Hogan, respondent's expert, there is no sudden beginning or sudden stoppage of ionization with changes in the gas pressure. The ionization changes gradually with the gas pressure. The discharge changes correspondingly from one materially affected by ionization to one not objectionably so affected, *i. e.*, a pure electron discharge according to Langmuir's terminology. Hence there is no new result in the reduction of ionization with reduction of gas by raising of vacuum. The alleged invention of the definition is a mere difference in degree, and there being no new result, there is no patentable subject-matter.

2. DeForest and Arnold, working independently of each other and of Langmuir, arrived at the result attained by Langmuir, as the thing obvious to one skilled in the art. Their acts lie athwart a finding of invention.

DeForest, in July and early August, 1912 (then in the employ of Federal Telegraph Company), when confronted by the necessity of avoiding excessive ionization, ordered the further evacuation of his tubes and succeeded in securing satisfactory operation, without objectionable ionization effects at voltages within the range specified by the patent (materially above ionization voltages).

Arnold, on November 1, 1912, did exactly the same thing, and with an entire appreciation of the scientific principle involved.

Since these two men were able to reach Langmuir's result by the application of the skill of their calling, their acts lie athwart a finding of invention, as Judge MORRIS puts it.

3. Accepting the definition of the invention adopted by the Court below, we find that exact thing in the prior art.

Three workers in the art did the exact thing prior to Langmuir:

(1) J. E. Lilienfeld in his 1910 paper (referred to by Judge MORRIS and Judge WOOLLEY) described a tube and a process, wherein and whereby he attained the invention of the definition with substantial identity. Such identity is admitted by Langmuir. The date is fixed by the publication and is unquestioned.

(2) DeForest in his 1912 tube, referred to under Point 2 of this brief, did the exact thing of the patent.

The identity is denied; but was accepted by the District Court and by Judge WOOLLEY in the Court of Appeals; and is not mentioned by Judge BUFFINGTON.

The date is fixed by the evidence.

(3) Arnold also did the exact thing as shown under Point 2. The identity is practically admitted, and was accepted by both Judge MORRIS and Judge WOOLLEY.

The date is contested, but, we submit, is proven.

Here, we have three instances of prior knowledge and/or use where the identity is clearly shown, and the dates admitted or established by controlling evidence.

Each instance is a complete statutory bar to the grant of a patent, even admitting patentability—which we do not.

4. The alleged invention is nothing more than a statement of the physical principle of pure electron discharge and therefore not patentable.

Claim 9 is broad enough to cover a modern X-ray tube, such as the Lilienfeld tube or the Coolidge tube. The Lilienfeld tube is admittedly the same as the Coolidge tube within the purview of this patent.

The Coolidge X-ray tube is admittedly covered by the patent in suit.

But in the Coolidge tube there is admittedly no space charge effect.

Nor does the 3/2 power law hold.

Nor is the straight line logarithmic plot obtained by plotting the discharge of the Coolidge tube.

All these phenomena are set out in the patent as tests for the presence of the invention.

But they are not present in the X-ray tube claimed to be covered by the invention.

Hence, the so-called "earmarks" do not define the invention as applied to such a tube. They are, therefore, not of the essence of the invention.

There is nothing left of the invention but a tube evacuated so as to operate with a pure electron discharge according to the circumstance of its use, without other limitation than that the voltages applied shall be above ionizing voltages. This limitation merely differentiates from Fleming. The alleged invention is a mere statement of the physical principle and is not patentable.

5. **Langmuir's only practical application of the principle of pure electron discharge was to the DeForest tube. This application was anticipated by both DeForest and Arnold. Hence claims directed to this use are void.**

Langmuir did not conceive this application of the principle until March 21, 1913. This is shown by his note book. Both DeForest and Arnold had made this application in 1912.

Even if this application were patentable, (which it is not), it was barred to Langmuir by the earlier knowledge and/or use of DeForest and Arnold.

ARGUMENT.

1. The invention, as defined by the Court below, is unpatentable, because (A) the definition lacks invention over the prior art acknowledged in the patent, and (B) it differs only in degree therefrom.

(A) The definition lacks invention over the prior art acknowledged in the patent.

The patent in suit (Plff's. Ex. 1, Rec., Vol. IV, pp. 1 to 10) states (p. 1, ll. 10-16) that in the tube of the patent the electric current is carried by electrons emanating from the cathode, independently of gaseous ionization, and differentiates thereby from the prior art tubes.

The theory of ionization is set forth (p. 1, ll. 34 to 75) from which it appears that when a definite amount of gas is present in a tube, a voltage of, say, 25 volts will cause the gas molecules to be split up into ions and electrons, whereupon through "the action and interaction of the ions and electrons" conduction of current across the tube is accomplished.

The patent recognizes the prior existence of both the Fleming tube (valve) and the DeForest tube (audion). Both were hot cathode electron discharge tubes. The patentee says (p. 1, ll. 92-102):

> "Another discharge device previously used to some extent was the Fleming valve. This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the voltages at which positive ionization by collision occurs. It was not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects."

The audion of DeForest is described in the patent (p. 1, ll. 77-92):

> "The phenomena above described as being characteristic of devices involving gas ionization are taken advantage of in an incandescent cathode device with three electrodes known as the 'Audion.' This device has been used as a receiver for radiotelegraphy and depends in its operation upon the rapid change of the discharge current when gas ionization begins. This point depends upon various accidental conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts."

From this it will be seen that the Fleming valve operated below the ionization voltages and thus without aid of ionization. He could have had no such aid since no ionization could have occurred. He was operating with a hot cathode from which the electrons emanated and were drawn over to the anode by the voltage applied at the anode. This was then purely an electronic flow, but below the ionization voltages rather than materially higher as claimed by Langmuir.

That it was within the knowledge of the art that Fleming had a purely electronic flow, is shown by Fleming's article in the Scientific American, published in 1906, in which it is said (Rec., Vol. V, pp. 168, 170, 171):

> "* * * a high vacuum may be a very good conductor, provided that the negative electrode is rendered incandescent. This shows that the obstruction which a high vacuum offers to the passage of electricity is not due to the mere reduction of the matter in the space (that is, to the rarefaction of the gas), but is, in some way or other, largely dependent upon the temperature of the electrodes; the resistance to the passage of electricity through a vacuum can be rendered very small by intensely heating the negative electrode.
>
> * * * * * * *
>
> If we take measurements of the current passing through the vacuum when the negative electrode is an incandescent carbon filament and the other a cold metal plate, and, at the same time, measure the difference of potential between the electrodes, we find that the conductivity, as measured by the ratio of current to voltage, is not constant, but varies with the electromotive force.
>
> * * * * * * *
>
> These electrons cannot escape from the mass when cold, because if they did they would leave it positively electrified. If, on the other hand, we electrify the mass negatively to a high potential and raise it to a high temperature, electrons can escape freely from it. In every mass of matter there is what we may call a certain 'electronic pressure';

> hence, it follows that the resistance which a high vacuum offers to the passage of electricity through it is, in fact, the resistance which is offered to the ejection or drawing out of electrons from the surface of the electrodes.

Since Fleming shows a pure electron discharge passing from the hot cathode to the anode when operated below ionization voltages, and DeForest shows objectionable effects of ionization, in substantially the same kind of a tube, when operated above ionization voltages, it is the contention of this brief that the man skilled in the art knew from the ionization theory that he could reduce the ionization in the DeForest tube while still operating above the ionization voltages, by reducing the gas content (raising the vacuum) of the tube. He knew how to raise the vacuum before Langmuir (Petitioner's Brief, pp. 21-25). So it was within the skill of the calling to avoid the objectionable effects of gas by raising the vacuum. This, we contend, is abundantly shown by the record.

Respondent's expert, Mr. Hogan, testified that the vacuum in the Fleming valve and in the DeForest audion is of the same order—about 1 to 10 microns for the Fleming tube and 5 to 10 microns for the DeForest tube (Rec., Vol. III, pp. 1660, 1677, 1682).

In the extract from the patent quoted above, Langmuir describes the operation of the DeForest audion as due to "the rapid change of the discharge current when gas ionization begins." This is an error. The operation is in fact due to the rapid change of the discharge current when the voltage applied to the tube is changed, exactly as in the Langmuir tube. However, the discharge current in the early DeForest tube, to which Langmuir is here referring, is admittedly increased by the effect of ionization, and this ionization admittedly causes irregularities in the operation of the tube and limits its usefulness. For the purposes of this section of the brief, therefore, we shall accept Langmuir's description of the operation of the DeForest tube as substantially correct.

When in the DeForest tube the voltage applied was, say, 25 volts, the gas in the tube, according to the theory, was ionized (Langmuir, Rec., Vol. II, p. 1246), and the ions resulting therefrom, by their interaction therewith, caused additional electrons to flow to the anode. This resulted in greater current (Langmuir, Rec., Vol. II, p. 1242), which was taken advantage of in a manner dependent upon the uses to which the tube was to be put. For our purposes here, we may disregard the particular use of the tube.

So long as the amount of ionization remained within definite limits, the tube functioned satisfactorily. But if too much ionization took place, it began to affect the usefulness of the tube (Langmuir, Rec., Vol. II, p. 1242).

From the theory of ionization expressed in the patent (p 1, ll. 40-56; Rec., Vol. IV, p. 2), it is clear that too much ionization could and would be cured by reducing the amount of gas in the tube (raising the vacuum), other things remaining constant (Langmuir, Rec., Vol. II, p. 1243).

With the knowledge that a pure electronic discharge would flow with a definite voltage and current (as in the Fleming valve), and the further knowledge that the amount of ionization at a higher voltage could be reduced by reducing the amount of gas present in the tube, was it not *within the skill of the calling,* when the necessity arose, to conclude that a pure electronic discharge without objectionable ionization effects could be secured at higher voltages (above the normal ionization voltages) by driving the reduction of the gas to the point where no harmful amount of ionization under the conditions of operation took place?

Let us see what the man skilled in the art would have done if he had been handed a DeForest tube, with the request to eliminate its erratic characteristics while at the same time increasing its power output.

Such a person would have observed at once, upon operating the DeForest tube, that its erratic operation was due to ionization of the gas in the tube (Langmuir, Rec., Vol. II, p. 1242; Arnold, Rec., Vol. I, p. 559). From his work with the Fleming tube, he would know that ionization is not necessary to permit a current to flow in a vacuum from a hot cathode to an anode. From his knowledge of the electron theory, he would know that the flow of current in both the Fleming and the DeForest tubes is made up of electrons, emitted from the hot cathode and passing to the anode under the attractive influence of the voltage applied to the anode. He would therefore have no hesitation in removing the ionization, on the score of stopping the electron flow. Further, he would know that the amount of ionization, other conditions being equal, depends upon the amount of gas present, and that the amount of ionization can be reduced by reducing the gas content. His first thought would therefore have been further to evacuate the tube and thus to reduce the ionization in the DeForest tube to the point where it was not harmful.

He would then consider the effect on the power output of the tube caused by reducing the amount of ionization. The power output is the product of the current flowing through the tube and the voltage applied across the cathode and the anode. He would know that the current flowing through the DeForest tube, ordinarily, was increased (over that flowing in the absence of ionization) by reason of the presence of the positive ions in the tube between the cathode and the anode. He would know, therefore, that as he reduced the ionization in the tube, he would also reduce the current, assuming other conditions to remain the same. As his problem called for improving the operation of the DeForest tube and also increasing its power output, he would know that he must apply higher voltages to the anode in order to draw more electrons over to the anode, and thus maintain the current at or above its former value—since he had reduced the current for a given voltage when he removed the effect of ionization.

The power output being the product of the voltage and the current, as stated above, it will be apparent that if the voltage be increased sufficiently to bring the current up to the value it had before the increase in the vacuum, the power output of the tube will have been increased. And any further increase in the voltage, with the consequent increase in current, will result in a corresponding increase in power output.

But it may be queried: Will not the increased voltage and current again increase the amount of ionization and put the tube back in the former condition of harmful ionization effect? In order to answer this, we must consider briefly the causes governing the amount of ionization. Ionization is due to collisions between electrons and gas molecules; so anything that tends to decrease the probability of such collisions will tend to decrease the amount of ionization, and vice versa. For the purposes of this case, we may disregard the minor influences of the velocities of the electrons and of the gas molecules, and consider merely the effect of the number of electrons and of gas molecules present in the space between the anode and the cathode. Obviously, an increase in the number of electrons will tend to increase the number of collisions, and a decrease in the number of gas molecules will tend to decrease the number of collisions. Hence the ionizing effect of any increase in the number of electrons (*i. e.*, an increase in the current flowing) due to an increase in the applied voltage, may be overcome by a suitable reduction in the number of gas molecules (*i. e.*, an increase in the degree of vacuum). Thus we see that a worker skilled in the art would appreciate that he would merely have to increase his vacuum sufficiently to keep the amount of ionization below the harmful limits for the desired conditions of operation.

By way of illustration, let us assume that the current flowing in the DeForest tube, which was the starting point of our skilled worker, was ample for the purposes desired (as indeed it would be for many uses of the modern high vacuum tubes even today). If then we increase the vacuum, resulting in a decrease in ionization and, thus, in current; and, *afterwards* increase the voltage to bring the current up only to its former value; there will have been no *net* increase in the number of electrons. There will, however, have been a decrease in the number of gas molecules, and, therefore, a decrease in the amount of ionization over that obtaining originally in the tube. Furthermore, there will have been an increase in the power output of the tube, since, though there has been no net change in the current, there has been an increase in the voltage, and hence in their product. We see, therefore, how simply a man skilled in the art could increase the power output of a DeForest tube and at the same time eliminate its erratic characteristics by reducing the amount of ionization.

There is no invention here over the prior art. The skilled worker has merely applied known principles.

(B) The definition differs only in degree from the prior art acknowledged in the patent.

Furthermore the tube of the patent differs from the Fleming and the Deforest tubes merely in the degree of vacuum obtaining in the tube. It was categorically admitted by respondent that the *only* difference between the DeForest tube and the Langmuir tube was that in the latter the gas had been reduced to a pressure of a few thousandths of a micron. This admission appears in its brief before the Court of Appeals at the first hearing, as follows (p. 30):

> "On the other hand, the invention may be realized by 'producing and maintaining', as the District Court put it, a pressure of a few thousandths of a micron in a DeForest audion."

There is no reference here to structure or geometry, because all of this is admittedly present in the prior DeForest tube.

A mere difference in degree is not patentable, unless some new and unexpected result is obtained. As we understand respondent's position, it contends that Langmuir obtained, by reason of this increase of vacuum, a pure electron flow substantially unaffected by ionization at voltages materially above the ionizing voltages, and that this was a new and unexpected result. We shall show in a separate section of this brief (p. 28 to p. 36) that Langmuir was not the first to obtain such a pure electron flow in a hot cathode vacuum tube; but for the purposes of this point, we shall assume that he was the first to do so.

It is clear from the record that there is no sharp line of demarcation between an electron flow substantially affected by ionization, as in the DeForest tube, and a pure electron flow as obtained and defined by Langmuir (this brief, pp. 24-25). As Mr. Hogan, respondent's expert, testified on direct examination (Rec., Vol. III, p. 1722):

> "If we leave the voltage the same and the electron current the same, and gradually increase the pressure, the gas pressure in the tube, the ionization in the tube will gradually increase. As we have all recognized, there is some measurable ionization, even below points at which ionization harmfully affects the space charge. There is no sudden beginning or sudden stoppage of ionization as a physical fact."

Conversely, as the gas pressure in a DeForest tube is gradually reduced (vacuum gradually increased), the amount of ionization will be gradually reduced until finally and inevitably we reach a point where the current flow is no longer objectionably affected by ionization. At this point we have a Langmuir tube operating with a pure electron discharge. The mere statement of this gradual change in cause and effect shows conclusively that there is no difference in kind. It is a mere difference in degree of vacuum, and the same thing is equally true as to the discharge. There is no difference in kind of discharge—it is always an electronic discharge—it differs only in the degree to which it is affected by the ionization changing with changing vacuum.

Since the alleged invention differs only in degree and no new or unexpected result was secured, there is no patentable subject-matter present and the patent is void.

2. DeForest and Arnold, working independently of each other and of Langmuir, arrived at the result attained by Langmuir, as the thing obvious to one skilled in the art. Their acts lie athwart a finding of invention.

DeForest.

DeForest in 1912 was employed by the Federal Telegraph Company, which at that time was operating a commercial radio telegraph service on the Pacific Coast (Rec., Vol. II, p. 1050). Its service demanded the best available apparatus, and DeForest, among others, was employed to perfect this service (Rec., Vol. II, p. 1045). Federal Telegraph Company in 1912 was employing DeForest tubes in amplifiers used in connection with high speed recording apparatus in its commercial work (Rec., Vol. II, pp. 1045, 1046, 1051).

In 1912, DeForest was confronted with a situation in which he found his tubes, in commercial operation, showing the effects of too much ionization. He knew at once that he needed to reduce the amount of gas present. So he ordered these tubes evacuated to a higher degree (Rec., Vol. II, pp. 1052, 1059). As a result of such further evacuation, he was able to apply a higher voltage and secured a result substantially free from objectionable ionization effects.

The record contains contemporary written evidence of DeForest's desire for a higher vacuum in his tubes and of the improved results obtained thereby. Under date of July 26, 1912, DeForest wrote to the McCandless Company (which was then manufacturing DeForest tubes for the Federal Telegraph Company) as follows:

> "Out of the last lot of 24 audion bulbs which you manufactured for us there are only 4 that came up

> to *proper sensitiveness test. Apparently the vacuum in the other bulbs is too low, because in these latter bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive"* (Deft's. Ex. 79-A, Rec., Vol. VI, p. 1061). (Italics ours.)

Shortly thereafter, on August 14, 1912, DeForest wrote again to the McCandless Company, saying:

> "We took two of the poorest of the discarded 20 to a San Francisco glass-blower, unknown to fame, *and had him exhaust same to as high a vacuum as his pumps would take.* These reexhausted bulbs now show a sensitiveness equal to those of the first four, *which proves conclusively that our contention is correct. For the work which we demand from these bulbs they are not sufficiently sensitive—and we would be glad therefore if you will reexhaust them.* You certainly should be able to put them in as good condition as the aforesaid San Francisco glass-blower" (Deft's. Ex. 79-B, Rec., Vol. VI, p. 1062). (Italics ours.)

The evidence is clear that these tubes, re-evacuated by the San Francisco glass-blower (Lamont by name), were used by the Federal Telegraph Company in its commercial operations at voltages running up to 54 volts (Tuel, Rec., Vol. II, p. 1052). There is also testimony that an amateur named Hewlett used similar tubes, evacuated by Lamont, at voltages in excess of 60 volts (Hewlett, Rec., Vol. II, p. 1008).

Naturally enough, no evidence was available as to the so-called "earmarks" or characteristics of the discharges in these Lamont tubes. These workers were not hunting for material to put in patent applications. They knew there was nothing patentable here. Lamont and others, however, testified in detail (Lamont, Rec., Vol. II, p. 1027, *et seq.*) as to the thoroughness of their evacuation, which followed in large part the procedure subsequently recommended by Langmuir (Lamont, Rec., Vol. II, pp. 1029, 1030). It was undoubtedly proven (Tuel, Rec., Vol. II, p. 1053; Watkins, Rec., Vol. II, p. 1055) that the tubes operated satisfactorily at the voltages mentioned. These voltages are not only "materially above ionization voltages" but are considerably above the lower limit of 40 volts set by Langmuir for his invention in claim 26 of his patent.

It is clear from the record that since these tubes operated *satisfactorily* at these high voltages, they must have operated without harmful ionization (Langmuir, Rec., Vol. II, p. 1263; Hogan, Rec., Vol. I, p. 97, Vol. III, pp. 1713, 1714). As satisfactory operation is the only essential test of the presence of the Langmuir invention (Langmuir, Rec., Vol. II, Q200, particularly pp. 1239-1240), these tubes had the discharge of the Langmuir tube. Dr. Langmuir defined a pure electron discharge, the presence of which respondent contends evidences a Langmuir tube, as follows (Rec., Vol. II, p. 1350):

> "Of course, the word pure is always a relative term which denotes a comparison between one thing and another. When I talk of pure electron discharge I have usually meant a discharge in which the effects of ionization do not materially influence the usefulness or characteristics of the device as it is to be used. That is what I think we always mean by purity."
>
> * * * * * * *
>
> "As I understand the word pure it means free from harmful ingredients or harmful effects and of course that necessarily implies that the very word harmful means harmful for some purpose.

> "Ionization always occurs in all tubes at voltages materially above the ionizing voltage. So to some extent no electron discharge can be absolutely pure. There will always be some ionization. So that by the word pure we necessarily mean free from ionization to an extent that is such that the ionization bring about no harmful or deleterious action."

DeForest in his 1912 tubes secured a vacuum such that the ionization present brought about no harmful or deleterious action, and may, therefore, properly be said to have arrived at the same point as did Langmuir in the alleged invention of the patent.

It certainly did not amount to invention for Langmuir subsequently to discover and set down the "earmarks" or characteristics of that tube. This is a mere matter of scientific observation.

Arnold.

On November 1, 1912, Arnold did exactly the thing that DeForest had done earlier in the same year. He was shown a DeForest audion that amplified weak telephone currents beautifully at low voltages, and functioned at those low voltages without harmful ionization (Arnold, Vol. I, pp. 555, 556, 567); but the currents were distorted and the tube failed to function in a suitable manner when higher voltages (higher power outputs) were attempted (Arnold, Rec., Vol. I, p. 560). He was asked how the tube could be made to operate properly as a telephone amplifier at the higher powers necessary in telephone work. Although he had never before seen an audion, he was acquainted with it from the literature (Arnold, Rec., Vol. I, p. 556), and he at once responded that the difficulties experienced were due to ionization of the residual gas, and that the difficulties could be eliminated and the ionization reduced until it was harmless by increasing the vacuum (Arnold, Rec., Vol. I, p. 559). He also made other suggestions, principally directed to improving the structure of the tube, but they are immaterial here (Arnold, Rec., Vol. I, p. 557).

Arnold was the representative "man skilled in the art", of whom we have spoken heretofore, and his reasoning and his conduct were exactly those that we described earlier (this brief, pp. 17 to 19) as to be expected of such a man. It did not occur to him that he had made an invention or that there was anything patentably new about this idea. As stated by Judge MORRIS in the District Court (Rec., Vol. III, p. 1964):

> "Moreover, the fact that falls but little short of a demonstration that the employment of the known pure electron discharge above ionization voltages in tubes of the DeForest type was but the availment of those skilled in the art of the store of knowledge that had been accumulated and lay ready at hand is that when Arnold, who had had long experience with electrical discharges in high vacuum, was shown a DeForest audion for the first time on November 1, 1912, and saw it in operation he immediately realized and said, in effect, that by increasing the vacuum the discharge would be sufficiently stable and at adequate power levels to enable the tube to be employed as a relay device in trans-continental telephony. While not unmindful that invention may sometimes be the result of an instantaneous happy thought, yet the state of the art is strongly confirmative of Arnold's own view at the time that the improvement suggested by him was obvious to one skilled in the art. The act of Arnold turns the scale so overwhelmingly that it lies athwart a finding of invention."

Like DeForest, Arnold appreciated at once that to use higher voltages and thus obtain increased power, he must employ a higher vacuum. Arnold probably knew more than DeForest about the underlying principles of operation of the tube, since the latter was more of an experimenter and perhaps not as highly a trained physicist, as was Arnold. But both men reached identically the same conclusion, and both considered the increase in the vacuum as merely a manufacturing expedient to fit the tube to the desired use. Both knew that the higher the voltage to be applied, the higher the vacuum should be. Very likely DeForest had no full realization of the extent to which the improvement in vacuum and the corresponding improvement of the tube could be carried, but he nevertheless succeeded in obtaining a tube of the patent that was satisfactory for his then purpose. Arnold, on the other hand, fully appreciated the electrical phenomena involved, and was able forthwith to carry the thought to its logical conclusion of substantial elimination of ionization.

On the strength of his recommendation, Arnold was at once authorized by his superiors to organize a department of the Telephone Company with the end in view of adapting the DeForest audion to the requirements of telephone service (Arnold, Rec., Vol. I, pp. 594, 595, 601). This ready and immediate acceptance of the suitability of a more highly evacuated DeForest audion for use in the telephone circuits is eloquent of the certainty of Arnold and his associates and equally of the obviousness of the higher evacuation. Before the end of the month, Arnold had improved the vacuum in one of the original tubes left with the Telephone Company by DeForest to the extent that it operated with a pure electron discharge fully within Langmuir's definition (Arnold, Rec., Vol. I, pp. 599, 603); and it operated satisfactorily up to 80 volts (Arnold, Rec., Vol. I, pp. 597, 598). This was the so-called Audion 7-A (Arnold, Rec., Vol. I, pp. 596, 603). The increased vacuum was obtained not by opening the tube and repumping it, but simply by using the phenomena of "clean-up," already familiar from incandescent lamp practice (Arnold, Rec., Vol. I, pp. 596, 597, 602). This tube completely demonstrated the correctness of Arnold's conclusions, and left him free to proceed with the problems of improving the mechanical design and life of the tube and fitting it into the existing telephone network. It also makes it unnecessary for us to consider his later work, since we are interested only in showing that he did a thing obvious to one skilled in the art, and hence unpatentable. Since what Arnold did, in the exercise of the skill of his calling, was exactly the sum total of Langmuir's accomplishment, it follows that the Langmuir patent is void for want of invention.

3. Accepting the definition of the invention adopted by the Court below, we find that exact thing in the prior art.

The Court of Appeals adopted the following definition of the invention: It is a working tube in which all the elements, cathode, plate, vacuum, so coordinate and interwork that current flow is not objectionably affected by the gas. We accept this definition and find this exact thing in the prior art.

For the purposes of this section, we shall also accept the position of the respondent that gas takes part in the conduction of current in the DeForest tube; but we do not agree that it is proper to speak of gas as a conductor. However, from our point of view, the controversy over the use of the term "gas conduction" has no place in the discussion of this point.

There is no disagreement that, in the tube of the patent, gas does not take part in the conduction of the current to any material extent. We shall pass, for the moment, the question whether the differences between the Langmuir tube and the early DeForest tube amount to invention; and we look to the prior art for that which has the substantial identity of the claimed invention, according to the Court's definition. We have no difficulty in finding three prior workers in this art who have each done the same thing in substantial, or exact, identity.

The first one was:

J. E. Lilienfeld.

When we read the admissions of Langmuir in the record (quoted by Judge WOOLLEY in his dissenting opinion and reproduced by petitioner in its brief, pp. 31, 32) we wonder what there is left to be said, honestly, about the claimed invention in this case.

For example:

There is the admission by Langmuir that

> "Lilienfeld probably succeeded in obtaining a discharge in high vacuum substantially free from the effects of positive ionization in the device he described in his 1910 paper."

No importance is placed by respondent on the word "probably".

The degree of vacuum attained by Lilienfeld is abundantly proven in his 1910 paper (Deft's. Ex. 25, Rec., Vol. V, p. 315). It is not understood that there was any intention to qualify in this respect either. In a further answer Langmuir admitted that Lilienfeld, in many of his experiments, realized a condition "where the lowering of the (gas) pressure (was brought) to such a point *that a further lowering brings about no further change.*" It was the same order of vacuum as Langmuir's. And as Langmuir again admitted, "the effects he (Lilienfeld) measured were not dependent upon gas ionization."

We cannot seriously consider as controlling the words "working tube," in the definition adopted by the Court below. The Court below based its finding of invention on *commercial use.* But the fact of commercial use is only helpful in case of serious doubt. If there is substantial identity in a prior knowledge, it is immaterial whether there was commercial use of the prior knowledge. This point was settled in this Court in the case of *Corona Co. v. Dovan Corp.*, 276 U. S. 358. Of course, the prior art device must have functioned in order that it be complete. But for the purposes of this case, the knowledge of the invention of the definition is complete when there is present a tube of substantially the construction of the broadest claims and in which there is an electron discharge free from objectionable effects of gas, working above ionization voltages.

What have we in the Lilienfeld disclosure? We have a tube used as an implement of research, but answering to the terms of the claims of the patent, and consequently anticipating them. While the device was experimental, the adaptation of the device to any commercial purpose contemplated by the patent, was obvious. In the sense that it produced a discharge of reproducible character, it was a "working tube." It had a hot cathode and an anode. Its vacuum was higher than required by the patent. Certainly it was higher than a few hundredths of a micron. And the coordination of the cathode and anode and of the vacuum under appropriate voltage (far above the ionizing voltages—Hogan, Rec., Vol. III, p. 1703) was such that the current flow was not objectionably, if at all, affected by gas.

It is difficult to understand how the respondent here can face the disclosure of J. E. Lilienfeld and persist in the claims of invention.

It will not do for the respondent to refer to the work of Lilienfeld as mere laboratory experiments. In the *Corona* case (276 U. S. 358), this Court has made clear the law with respect to prior knowledge as evidenced by laboratory work. If the substantial identity of the earlier work is established, it is a complete bar to a patent for the later invention, provided it has worked on any scale.

And moreover, if Langmuir's laboratory tubes and experiments may be the basis of his claim for a patent here, the equivalent work of Lilienfeld is an equally justifiable basis for establishing anticipation. Langmuir is subsequent to Lilienfeld in the essence of his invention. So the patent is invalid.

It would seem that patentability was found by the Law Examiner in the Patent Office not in discovering or producing anything new, but in perceiving the practicability of scientific facts known in the laboratory and in making practical useful devices embodying the scientific laws known in the laboratory. (See opinion of Commissioner of Patents in the Interference, blue pamphlet, pp. 10, 11.) It is true that there may be inventive subject-matter in such practical application of a principle. But if a tube is shown, as by Lilienfeld, in which the principle of pure electron discharge is clearly disclosed, can the subsequent inventor foreclose the prior discoverer of the right to make such use of his discovery as he sees fit? Of course, the particular use made of the principle may be monopolized by the subsequent inventor. But the subsequent inventor cannot thereby usurp all applications of the principle, even though the first discoverer had failed to put into force any practical application of his invention to the useful art. As a matter of fact, Lilienfeld did subsequently make such an application of his discovery to the X-ray art, and of this, we will treat in a later portion of this brief (pp. 38-40).

However, no such following up in any way affects the force or effect of the laboratory work as an anticipation. As was said by Chief Justice TAFT in the *Corona* case (276 U. S. 358, at p. 384):

> "It is a mistake to assume that reduction to use must necessarily be a commercial use. If Kratz discovered and completed, as we are convinced that he did, the first use of D.P.G. as an accelerator in making vulcanized rubber, he does not lose his right to use this discovery when he chooses to do so, for scientific purposes or purposes of publication or because he does not subsequently sell the rubber thus vulcanized, or use his discovery in trade, or does not apply for a patent for it. It is not an abandoned experiment because he confines his use of the rubber thus produced to his laboratory or to his lecture room. It is doubtless true that Kratz, by his course in respect to his discovery as to the use of D.P.G., has abandoned any claim as against the public for a patent, but that is a very different thing from saying that it was abandoned as against a subsequent discoverer or patentee."

The sole question here is whether what Lilienfeld did was in principle the same as that performed by Langmuir. If the identity is established, there is prior knowledge, and there cannot be, under the *Corona* case, any question of abandonment. And there cannot be any question of commercial use. If Lilienfeld, knowingly, has a completed thing, no one can, by subsequent act, exclude him from the use of that completed thing except by, and to the extent of, adding a further novel thing, in patentable coaction, to the thing completed by Lilienfeld. Therefore, we say that, if Lilienfeld has produced a tube with elements, the equivalent of Langmuir's elements, no amount of subsequent commercial application of substantially that thing can detract in any way from the exact quality of Lilienfeld's act. Whatever may have been the law before the *Corona* case, thereafter the statement by the Law Examiner is not the law as applied to this case.

In a subsequent section of this brief we will consider Langmuir's claims in connection with the X-ray tubes of Lilienfeld. But at this point, it is sufficient to point out that Claim 11 is broad enough to cover any tube in which the elements are the same as in the Lilienfeld experimental tube; and wherein the vacuum and the voltages are of the same order and relation. All that is stated, as the result, is that a pure electronic discharge shall be obtained free from appreciable effects of gas. That is the admitted result of the Lilienfeld tube. And unless there is added to the elements and vacuum and voltage of the Lilienfeld tube something novel and useful, and in inventive coaction with them, then no subsequent act of Langmuir can affect the quality or effect of Lilienfeld's act. It makes patenting of that thing to Langmuir impossible.

The next worker to do the same thing was

DeForest.

We have heretofore in this brief (pp. 22 to 25) described the DeForest work in 1912. For the purpose of this point we need only call attention to the fact that the precise tube of the patent was evacuated in such a way as to enable an electron discharge to be obtained substantially above ionizing voltages without objectionable effects from gas. If the facts are accepted, as they were by the District Court, then there can be no question that the invention of the definition adopted by the Circuit Court of Appeals was present in the DeForest 1912 tube, intentionally, purposely and commercially.

It is solely a question of fact, and we refer here to our discussion on pages 22 to 25 of this brief, and to the discussion of the same facts in the opinion of the District Court (Rec., Vol. III, pp. 1965, 1966). We are able to find but one conclusion on this issue of fact. The invention of the definition was present in the DeForest work in 1912 and prior to Langmuir.

And the third worker, knowingly and intentionally, doing the identical thing was

Arnold.

On pages 25 to 28 of this brief, we have attempted to show that in November, 1912, Arnold, too, completely developed the invention of the definition. He produced a tube of the exact construction of the tube of the patent and obtained an electron discharge substantially above ionization voltages without objectionable effects of gas.

If the facts of the existence of the tube and its operation are accepted, then there remains no problem—except that of date—for here, as in the DeForest use, the identity of the thing is complete. Moreover, it was intentionally and purposely created, and the principles of its operation were fully understood.

This work by Arnold was commenced on November 1, 1912, and was completed before Langmuir first saw a DeForest tube in February of 1913. It was prior to the work in November, 1912, first alleged by Langmuir as his conception and reduction to practice of the invention, in his sworn preliminary statement in the Interference proceeding in the Patent Office. However, the Arnold work was subsequent to the August, 1912, conception date, later advanced by Langmuir. It is, therefore, necessary to consider for a moment Langmuir's August, 1912, work, which was the only work by Langmuir on the invention contended by respondent to have preceded the latter part of November, 1912, specifically November 19th, 1912.

In the August work, Langmuir had a vacuum tube constructed like an incandescent lamp with two filaments, one of which he heated in the ordinary way, and the other of which he kept cold (Langmuir, Rec., Vol. II, p. 1116). Nitrogen was introduced into the tube, and a discharge caused to pass between the hot filament as a cathode and the cold filament as an anode by applying a potential of about 250 volts therebetween (Langmuir, Rec., Vol. II, pp. 1122, 1124). Langmuir was then interested only in studying the rate at which the nitrogen was "cleaned up" or caused to disappear by the discharge between the cathode and the anode (Langmuir, Rec., Vol. II, pp. 1116, 1122). When the nitrogen pressure reached a value of about 0.4 of a micron, the discharge current fell to a low value (Langmuir, Rec., Vol. II, pp. 1125, 1126). The tube was then refilled with the nitrogen gas for further experiments (Langmuir, Rec., Vol. II, p. 1130).

Respondent now contends that Langmuir had a pure electron discharge, unaffected by ionization when the nitrogen pressure was reduced to its lowest value of 0.4 micron as described (Langmuir, Rec., Vol. II, pp. 1128, 1302). But Langmuir admits that he was not then conscious of this alleged fact. He testified in this case on that point as follows (Rec., Vol. II, p. 1328):

> "Q380. You did not know at the time or you did not suppose at the time that you had a pure elec-

> tron discharge substantially unaffected by positive ionization, did you?
>
> "A. No, I did not draw that conclusion at that time. I know now but I did not know it then."

It is so clear as to require no argument that there can be no *con*ception of an invention without *per*ception of it (Robinson on Patents, Vol. I, Sec. 79, p. 121).

It should be noted that, in these August experiments, Langmuir merely reached the point, even if his contentions be granted, where pure electron discharge commenced. This condition he was not then interested in, so he introduced more nitrogen gas and retraced his steps. Instead of exploring the new field of pure electron discharge contended to have been opened to him, he closed the door on that field by the introduction of gas, and continued his study of gas clean-up effects.

It follows that Langmuir can be awarded no date earlier than the November 1, 1912, date of Arnold.

We conclude that in view of the work of Lilienfeld, DeForest and Arnold, there is no room for the invention of the definition. Even the fact of *commercial use* implied in the words "working tube" can avail the patentee nothing, for there is no room for doubt; and it is only in cases of grave doubt as to invention accompanied by no direct evidence of prior use, that the factor of commercial use is to be considered. As Judge MORRIS points out (Rec., Vol. III, p. 1964) the radio art was young in 1912. Fleming had no need for this alleged invention. The DeForest audion was not in evidence. There was no long-felt want. The evidence of utility, here, is indicative of nothing more than a proper natural development of the art. Lilienfeld, DeForest and Arnold did the exact thing prior to Langmuir.

The patent is void.

4. The alleged invention is nothing more than a statement of the physical principle of pure electron discharge and therefore not patentable.

The definition of the invention adopted by the Court below and the claims of the patent are broad enough to include modern X-ray tubes. Indeed, respondent contends in this case that the Langmuir patent dominates the Coolidge X-ray tube.

Claim 9 is typical of a group of claims of such breadth. It is as follows:

> "9. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned, or shaped, so as to permit the free passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts."

Analyzing this claim we find:

(1) A discharge tube
(2) Cathode adapted to emit electrons
(3) Anode adapted to receive electrons
(4) Free passage for electrons from cathode to anode
(5) Vacuum such as to permit operation with reproducible results
(6) Substantially unaffected by ionization
(7) With currents of at least 5 milliamperes
(8) With voltages of at least 200 volts

The construction of the tube described is clear. We are merely to have a free passage for electrons from a hot cathode to an anode. The vacuum is simply to be such as is necessary (whatever that may be) to secure "stable and reproducible results," by avoiding ionization under the conditions of operation. These conditions are that the current strength shall be *at least* 5 milliamperes, and that the voltage shall be *at least* 200 volts. It will be seen that there is no upper limit on either the current strength or the voltage.

This claim completely covers the Coolidge X-ray tube and the Lilienfeld perfected X-ray tube, both of which admittedly operate with a pure electron discharge, at currents greatly in excess of 5 milliamperes and with voltages running to many thousands of volts.

The period between the publication of Lilienfeld's 1910 article describing his experimental discharge tube (discussed above in this brief, pages 29 to 33) and the perfection of the Lilienfeld X-ray tube referred to above, was occupied with the usual process of development from the 1910 experimental tube to the finished commercial Lilienfeld X-ray tube.

Respondent's admission with respect to the operation of the perfected Lilienfeld X-ray tube is contained in a footnote on page 99 of its brief on the first hearing in the Circuit Court of Appeals, as follows:

> "A later form of Lilienfeld tube was first described *after* the publication of the Coolidge tube (Vol. III, pp. 1698-1700). This tube did not require ionization for its operation; if properly designed and properly evacuated it would be operable with the Langmuir vacuum.
>
> "This last tube of Lilienfeld's, the only one which, so far as we know, ever went into really practical

> use at all, resembles the Coolidge tube much more closely than it does the tube described in the Lilienfeld-Rosenthal paper. Instead of Coolidge or Langmuir learning something from Lilienfeld, it was Lilienfeld who learned from Coolidge and Langmuir."

Further respondent says, commencing on page 100 of the same brief:

> "If Lilienfeld's publications, plus all the work which Lilienfeld did, did not teach Lilienfeld to build a hot-cathode, pure electron discharge tube—and they did not—that fact alone would outweigh a thousand pages of expert testimony to the effect that they *ought* to have taught him, and anybody else skilled in the art, how to do it (*Schmertz Wire Glass Co.* v. *Pittsburgh Plate Glass Co.*, 168 Fed. 73, 77)." (Italics respondent's.)

Respondent is entirely unwarranted in concluding that the Lilienfeld perfected tube, referred to, owed any part of its being to contributions from either Langmuir or Coolidge. The portions of the record (Vol. III, pp. 1698-1700) cited by respondent, refer to various publications describing the improved Lilienfeld tube, but nowhere is it stated that these were the *first* publications of that kind. Indeed, it is a fact within the available knowledge of counsel who wrote that brief, that this tube was invented by Dr. Lilienfeld before November, 1913, the date of the application in Germany for the Lilienfeld patent covering that pure electronic discharge X-ray tube. That he could not have been assisted by either Coolidge or Langmuir in this development, is shown by the fact that the first publication of their work occurred in December, 1913 (Deft's. Ex. 66, Vol. VI, p. 919; Plff's. Ex. 21, Interf. Ex. 2).

Thus it appears that Lilienfeld's publications and his work did teach him how to build a practical, hot cathode, pure electron discharge X-ray tube, and that Lilienfeld diligently followed up the transformation of his laboratory work into successful commercial products. As respondent so aptly says, these facts speak louder "than a thousand pages of expert testimony."

We see from the foregoing that the interpretation of the patent contended for by respondent and made by the Court below, gives it a scope covering the application of *the principle of pure electron discharge* to practical devices in an art to which Langmuir made no real contribution. In other words, although Lilienfeld disclosed the principle prior to Langmuir, he is, according to respondent's argument, to be prevented from applying that principle to the practical X-ray art, because, forsooth, Langmuir preceded him in the practical application of the principle to quite another art. We submit that this would be a manifestly unjust result, based upon an untenable proposition of law entirely *contra* to the *Corona* case and to the accepted principles underlying our patent structure.

The same result may be reached from a somewhat different aspect.

In the Coolidge tube, admittedly dominated by the Langmuir patent, the voltages employed are so high that practically all of the electrons emitted by the hot cathode are drawn over to the anode (Coolidge, Rec., Vol. III, p. 1556). This is referred to in the patent in suit as operation in the saturation range (p. 2, ll. 77 to 95). But this means that the space charge effect of claims 1 and 10, for example, is without influence on the operation because there is no surplus of electrons on which the space charge can act (Coolidge, Rec., Vol. III, p. 1557). Since the voltages are high, in the saturation range, the discharge does not follow the so-called 3/2 power law of claims such as claim 6. Nor is the straight line logarithmic plot of claim 4 obtained by plotting the discharge of the Coolidge tube. These are stated by respondent to be "earmarks" of the Langmuir invention.

What this means, in simple language, is that none of these complicated phenomena can be accepted as sufficient tests for the presence of the invention, since the invention is claimed to exist in a tube lacking all of them. It follows, therefore, that such things are not of the essence of the invention. But when we look behind them to find the essence of the invention, nothing is left but a vacuum tube having a pure electron discharge, without limitation as to its construction, operation or application to use, other than that the voltages applied shall be above the ionizing voltages. This limitation has no other force than to differentiate from Fleming, who has a pure electron discharge below ionizing voltages, and, therefore, without ionization effects, objectionable or otherwise.

We have, then, a situation where what actually is claimed is the physical principle of pure electron discharge, quite aside from its practical application to any particular art. We have shown above that this principle, this type of discharge, was not new with Langmuir. But wholly apart from this, it is inherently unpatentable subject-matter. It is neither an art, nor a machine, nor a composition of matter. The claim is artfully worded in terms of an article of manufacture, but it defines the article only by the characteristics of its discharge—the principle of its operation.

This is no more patentable than the law of gravitation.

5. Langmuir's only practical application of the principle of pure electron discharge was to the DeForest tube. This application was anticipated by both DeForest and Arnold. Hence claims directed to this use are void.

If we accept the proposition that patentable invention in this case must be limited to the application of the principle of pure electron discharge to a particular practical use, the only such application by Langmuir was to the three electrode DeForest audion. But this application was not even conceived by him until March 21, 1913, long after the same practical use had been made by both DeForest and Arnold. (This invention is claimed only in claims 10, 12, 18, 19, 21 and 22 of the patent.)

It is true that respondent does contend to have developed, as coming within the alleged Langmuir invention, the Coolidge X-ray tube, and the Kenotron high voltage alternating current rectifier, as well as the high vacuum three electrode tube corresponding structurally to the DeForest audion. But we assert that this contention is unfounded.

The Coolidge X-ray tube is the development of Dr. Coolidge, and respondent is estopped to deny that it is Coolidge's invention by having taken out the Coolidge patent thereon (Deft's. Ex. 67, Rec., Vol. VI, p. 941).

The Coolidge X-ray tube, as pointed out above (this brief, p. 40), is a high voltage tube. It is not disputed that it is inherently a rectifier, and that the Kenotron rectifier is an outgrowth of the "Coolidge tube" (Rec., Vol. III, pp. 1528, 1529). The Kenotron rectifier is in fact essentially a Coolidge tube arranged in the high voltage circuit in such a way that the X-rays generated are of low penetrating power and do not get through the glass walls

(Coolidge, Rec., Vol. III, pp. 1529, 1530). There is nothing in this record to indicate that Langmuir had anything to do with its development, and from the logic of the situation, it is clear that he played no such part.

The low voltage rectifiers, say, of the order of a few hundred volts, in commercial use today, such as the Tungar rectifier of respondent, are admittedly gaseous tubes, and are in fact merely structurally improved Fleming valevs. It is admitted in this record (Langmuir, Vol. II, pp. 1351, 1352) that such tubes operate better with gas, and that they are outside of Langmuir's alleged invention.

This leaves us only the high vacuum DeForest tube. Langmuir testified that he first saw a DeForest tube in February, 1913 (Rec., Vol. II, p. 1182). Shortly thereafter he built several such tubes and experimented with them. While there is some contention by respondent that these tubes were high vacuum tubes operating with a pure electron discharge, we believe it is clear from the record that this was not the case. The best evidence of this is to be found in Langmuir's own notebook under date of March 21, 1913, as follows:

> "Now what I intend to do is to construct an audion which will operate entirely and exclusively on the electron discharge. I shall attempt to get the vacuum so good that positive ions are present in negligible amounts." (Plff's. Ex. 131, p. 34, Interf. Ex. U.)

This is a perfectly clear statement of conception of the only possible invention here in issue, but it is, of course, much too late to be of any avail to Langmuir since this had been done in 1912 by both DeForest and Arnold (this brief, pp. 22 to 28).

It is for this reason that we hear so much in this record of Langmuir's earlier experiments during August and November, 1912. But it seems to us that Judge MORRIS has properly characterised the earlier experiments, when he said so accurately in his opinion (Rec., Vol. III, p. 1961):

> "Langmuir made many experiments over a long period of time. Those that were first made were, however, for the purpose of discovering abstract principles and not for the purpose of arriving at practical results. He made discoveries but he did not immediately, or for some time, perceive that they had any practical use. Moreover, the discoveries to which his experiments led him, so far as we are here concerned, were those already made by Lilienfeld and others. * * * But the disclosures of the prior art reveal that Langmuir, great and renowned physicist that he is justly conceded to be, was, in this instance, traveling, all unknown to him, over a field already well explored."

We submit that not only was Langmuir, in his earlier experiments, traveling, all unknown to him, over already well-explored fields, but, in his only practical application of the principle of pure electronic discharge as well, he was completely anticipated by these other workers in the art.

He cannot patent the principle and he is anticipated in his only practical application of that principle, even if such application were not otherwise unpatentable.

CONCLUSION.

Upon the foregoing, we contend that the decree of the Court below should be reversed and the bill of complaint dismissed.

Respectfully submitted,

John F. Neary,
Ramsay Hoguet,
Martin T. Fisher,
Of Counsel for
The Chemical Foundation, Inc.,
Radiological Society of North America,
Radiological Research Institute, Inc.,
Federal Telegraph Company,
As Amici Curiae.

FILE COPY

Office Supreme Co
FILED
JAN 8
CHARLES ELMORE

IN THE

SUPREME COURT OF THE UNITED STATES

OCTOBER TERM, 1930

No. 630

DEFOREST RADIO COMPANY
Petitioner
v.
GENERAL ELECTRIC COMPANY
Respondent

OPINIONS OF JUDGE MORRIS AND JUDGE WOOLLEY

THOMAS G. HAIGHT
SAMUEL E. DARBY, JR.
Counsel for Petitioner

APPEAL PRINTING CO., 33 THAMES ST., NEW YORK CITY

INDEX

PAGE

The Opinion of Judge Morris (District Court of Delaware) 1

The Opinion of Judge Woolley (dissenting from present majority decision of the Third Circuit Court of Appeals) 30

IN THE

District Court of the United States

FOR THE DISTRICT OF DELAWARE.

GENERAL ELECTRIC COMPANY, *Plaintiff*, *v.* DEFOREST RADIO COMPANY, *Defendant.*	Nos 589 and 598. In Equity.

The Opinion of Judge Morris.*

(23 Fed. [2nd] 698)

These two suits of General Electric Company against DeForest Radio Company were tried together. In the first suit all the claims of patent No. 1,558,436, granted to Irving Langmuir, assignor to the plaintiff, October 20, 1925, for "electrical discharge apparatus and process of preparing and using the same" upon an application filed October 16, 1913, and renewed March 14, 1916, are in issue. It is known as the high vacuum tube patent. Infringement is conceded if the claims are valid. Validity is denied for want of invention and novelty and because of prior knowledge and use, for double patenting and upon the ground that Harold D. Arnold, not Langmuir, was the first inventor.

The specification, claims and testimony are so interwoven with scientific theories, more or less abstruse, that it is somewhat difficult to isolate and keep separate from the principles of physics involved Langmuir's conception and idea of means. Yet an analysis of the Langmuir device and its elements discloses that, apart from its functioning and results, [illegible] is nothing more nor less than a Fleming valve or De [illegible] audion, for example, in which a higher vacuum, [illegible] during operation, exists. How much [illegible] the vacuum must be to bring the tube within the patent is not definitely fixed in terms of pressure. The specification states merely that "the evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned." A micron is a pressure equal to a millionth of a meter or a thousandth of a millimeter of mercury. It corresponds to a barometer reading of that value. The normal barometer reading in the open air is about 760 millimeters. The justification for the failure to assign definite pressure limits is that the invention "comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization"—a device in which the residual gases play no part in the operation. The results desired to be obtained are stability and reproducibility of operation and increase of power. The production of these results by the specified manner of functioning is dependent not on the degree of vacuum alone, but upon four coordinating variables—geometry or relation of parts of the tube, temperature of cathode, voltage of anode and degree of vacuum. This fact makes it apparently unavoidable that the claims be functional in form. But they must, of course, be construed to cover the thing. Walker on Patents §163. Claim 26 is comparatively simple. It is:

---

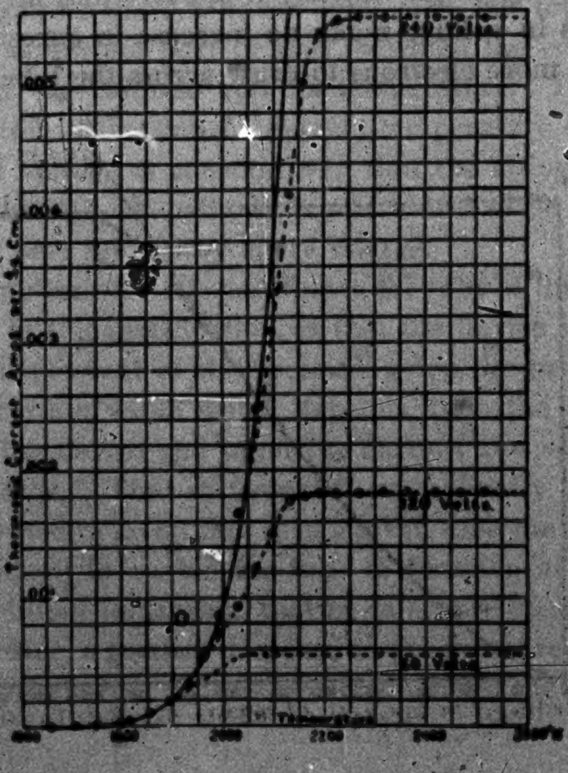
* The opinion of Judge Morris dealt with four Langmuir patents. We are here concerned only with Langmuir patent No. 1,558,436. We have, therefore, only printed that portion of the opinion dealing with this patent.

> "A discharge device comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes, the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge, so that the device is capable of passing a sustained discharge of one tenth of a milliampere at forty volts, without developing any substantial positive ionization effects."

The Fleming and DeForest tubes are "discharge devices comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes." The next clause of the claim—"the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge"—has to do with the manner and degree of evacuation. Underlying this clause are these facts: The glass wall and the electrodes harbour large volumes of occluded gases. Heat is necessary to expel these gases so they may be removed by the pump. If not removed before the tube is sealed off the heat occurring during the operation of the tube expels them, destroying in large degree the vacuum. "The spacing of the electrodes"—one illustration of the geometry of the tube—is a factor because the permissible gas pressure in the tube increases with the proximity of the electrodes to each other. This varying relation is due to the fact that the opportunity for the electrons to collide with gas molecules varies with the length of the path the electrons have to travel. "The energy of the discharge" may be interpreted in terms of power which is the product of the current values and the voltage. The unit of current flow is the ampere or the current which flows at a pressure of one volt through a closed circuit having a resistence of one ohm. The power of a circuit having a pressure of one volt and a current of one ampere is one watt. The power output of the device of claim 26 is .004 of a watt or 4 milliwatts. And increase of energy means an increase in the number and velocity of the electrons passing from cathode to anode and consequently an increase in the number and effect of collisions of electrons with gas molecules. It follows, of course, that if the maximum voltage at which a given tube will function without ionization is increased ionization will occur and the tube fail to function in the manner specified in the patent. "Ionization," by which is meant the conversion of atoms or molecules into ions, is explained by the "Electron Theory." By this all atoms known to chemistry are deemed to be made up of a nucleus endowed with a permanent positive electrical charge around which one or more electrons, each of which has mass or weight and carries, or is, a natural unit of electricity, revolve at inconceivably great speeds in regular orbits in somewhat the same manner as that in which the planets of our solar system revolve about the sun. According to this hypothesis the chief difference between the chemical atoms lies in the number and arrangement of their electrons. Under normal conditions the electrons are maintained within their atoms and in their orbits by the attractive force of the positive nucleus which, electrically, exactly balances and neutralizes the negative charge of the electrons of the atom. Consequently every atom having its normal complement of electrons exhibits no electrical effects. If, however, by impact, or otherwise, an atom loses an electron and becomes an ion it is thrown out of electrical balance. The positively charged nucleus predominates and exhibits a unit positive charge. In thermionic tubes ions are created by the impact upon the gas atoms or molecules of some of the myriads of electrons constituting the current flowing from the hot cathode to the cold anode—the Edison Effect. See Westinghouse Elec. & Mfg. Co. *v.* DeForest Radio Tel. & Tel. Co., 21 Fed. (2d) 918. To dislodge an electron from its atom the colliding electron must have sufficient momentum. The velocity required for this momentum is given to the electrons mainly by the pull or attractive force of the positively charged anode. The strength of the pull increases, other conditions being stable, with the anode voltage. For the gases with which we are here concerned 15 to 25 or 30 volts constitute the ionizing voltages.

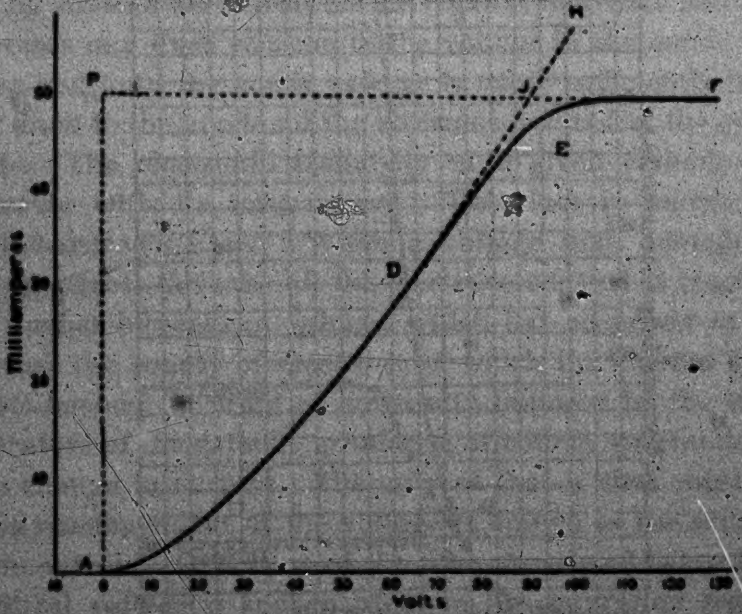
When substantial numbers of atoms or molecules are being converted into positive ions by the electron stream the "ionization effects" forbidden by claim 26 occur. One effect of ionization is an increase in the current across the tube over the value it would have at the same voltage in the particular tube were the vacuum sufficiently high to prevent ionization. Such increase is due to two facts. First, the electrons, being negative charges of electricity, tend in the absence of a countervailing force, violently to repel one another and thus to diminish the number, and so, the value of the current, passing to the anode. Positive ions in the field constitute a countervailing force and consequently expedite the flow of the electrons to the anode. Second, the positively charged ions are drawn with great force to the cathode, the negative electrode, bombard it and thus increase its temperature. As the electron emissivity of the cathode increases with its temperature the ion bombardment of the cathode serves to increase the supply of electrons and consequently the current passing to the anode. This bombardment is so severe that, if continued, it destroys the filamentary cathode. Another effect to which substantial ionization usually gives rise is a blue glow in the tube. This, as I understand it, is accounted for upon the hypothesis that as the electrons are shifted in the atom, by impact of the electrons, from one orbit to another at prodigious speeds they produce waves or vibrations in the ether which constitute light. The ultimate effect or result of ionization is an unstable, non-reproducible and, in a measure, non-controllable current. As it is necessary, in order to prevent the destruction of the cathode and obtain a stable current, to operate gassy tubes below ionization, their power output—the product of current and voltage—was limited. These constitute obvious defects.

These defects are not present in the tube of the patent. It operates without substantial ionization. When there is no substantial ionization the current increases and decreases in a fixed relation to the voltage of the anode unless and until the anode voltage is made sufficiently high to draw to the anode all the electrons emitted at the cathode. The electronic emissivity of a given cathode increases with its temperature. This fact is known as "Richardson's Law." When a voltage high enough to carry across the tube all the electrons emitted is reached a further increase of voltage, which has no power to increase the supply of electrons of which the current consists beyond the limit of emissivity imposed by the temperature of the cathode, produces, of course, substantially no change in current. The current that is thus substantially independent of the voltage is known as the saturation current. Operation of the tube above and below this critical voltage is spoken of as in the saturation region and below saturation respectively. If a tube is operating below saturation an increase of the electron supply by an increase of cathode temperature, but with no increase in voltage, produces no marked change in the current. Decreasing the electrons emitted by the cathode by decreasing the cathode temperature is likewise without effect upon the current, provided, of course, that the decrease in the supply of electrons is limited to the electrons emitted in excess of those pulled across the tube by the given voltage. The fact that if the anode voltage remains stable the current can not be increased by an increase of the cathode temperature, beyond that required to supply the electrons capable of being pulled across the tube at the given voltage is illustrated by the "flat top temperature curve" on the following graph.



The reason that the current does not increase beyond a certain point dependent upon anode voltage with the increase of the temperature of the cathode is that the electrons, all being negatively charged, exert powerful repelling forces on one another. When this force of repulsion equalizes the pull or effect of the voltage on the anode, the anode is without power to draw to itself a greater number of electrons. The current-limiting effect of the electric field of the electrons on one another is known as the "space charge effect." It is space charge which produces the flat top of the temperature emission curve in the foregoing graph.

When the temperature of a cathode is fixed and constant and the voltage is increased the limitation upon the electrons limits the current. This is illustrated by the following graph whereby it appears that the last few increases in voltage make no increase in current—there being no more electrons to draw across the tube.



The curve of this graph, which when plotted on logarithmic paper appears, up to the point approaching saturation, as a straight line, discloses a relation existing between current and voltage. That relation is expressed in the specification thus:

> "In most devices of simple construction which embody my invention, the discharge current passing through a given space with the cathode at a sufficiently high temperature with respect to the voltages employed, varies directly with the 3/2 power [square root of the cube] of the impressed voltages."

"A" to "D" of the curve on the current-voltage chart, in which the temperature is constant, is the space charge part or that in which the current is limited by anode voltage and follows the 3/2 power law. The flat top represents the saturation part or that in which the current is limited by the cathode and its temperature. The converse is true in the first or current-temperature chart in which the voltage is constant. In that the rising part is the part limited by cathode temperature while the flat top is the part limited by space charge.

Another characteristic peculiar to the tube of the patent, as stated in the specification, is that the device is "practically independent of the pressure when the pressure is below a certain value which depends upon the size and shape of the device and upon the current and voltage of the discharge." That statement is undoubtedly true if it be interpreted to mean that if in a given tube the pressure is low enough to enable the tube to function at a given voltage without ionization, that is, as a pure electron discharge device, a further decrease in the pressure will not affect the discharge. It is likewise true that if the pressure is less than that required for a given voltage in a given tube it may be increased up to the pressure immediately below that at which substantial ionization would occur at the given voltage without affecting the discharge. The discharge, however, is in no sense independent of the pressure if the maximum voltage at which a given tube will function without ionization is increased, for ionization would instantly occur and the tube fail to function in the manner specified in the patent. In such instance a decrease in pressure simultaneously with the increase in voltage would be necessary to avoid ionization. In its simplest aspect this is due, of course, to the fact that if ionization is to be avoided above ionization voltages collisions must be avoided between electrons and gas molecules and that the number of collisions in a given tube, dependent upon the relative density of the two, is increased, the pressure being stable, by an increase in the number of electrons pulled to the anode by the increased voltage.

These scientific explanations, arising mainly out of the electron theory, of the functioning of the high vacuum tube change not at all the fact that it differs structurally from the Fleming valve and DeForest audion only in the degree of vacuum maintainable during operation. This was expressly conceded during the pendency of the application in the Patent Office. The fundamental questions here in issue are not changed and their solutions are, I think, but little affected by the theories by which the functioning of the high vacuum tube is accounted for. If it was not known to those skilled in the art how to produce, in a Fleming or DeForest structure, for example, a vacuum sufficiently high to enable the tube to function above ionization voltages without substantial ionization and Langmuir solved the problem and made the necessary disclosure of its solution in his patent, manifestly he would be entitled to a patent for his disclosed method and device as a reward quite apart from his knowledge or lack of it with respect to scientific principles or laws of physics explaining the functioning brought about by the high vacuum. Moreover, independently of whether or not invention was necessary to create a vacuum of the required degree, Langmuir would be entitled, I take it, to a patent for his device regardless of his ability or inability to explain its functioning in principles of physics, if he was the first to appreciate that a high vacuum maintainable during operation in a Fleming or DeForest structure, for example, would constitute means whereby the results produced by the high vacuum tube could be accomplished, provided, of course, he reduced to practice with reasonable diligence the device of his mind.

Upon the question whether the claims for the process of making the high vacuum tube or those for the tube itself, which because of its stability, reproducibility and power has made possible radio broadcasting, modern radio reception and long distance telephony, involve novelty and invention the parties differ widely. The plaintiff asserts, with apparent confidence, that the patent is for invention of a high order—equal to or greater than that of DeForest for the three electrode tube. The defendant, with equal confidence, finds not only all that Langmuir did but all that he discloses with respect to the principles in accordance with which the device functions spread upon the records of the prior art. Since the Fleming valve and the DeForest audion were old and the structure of the tube of the patent differs from these only in the degree of vacuum maintainable during operation the first crucial question is whether claims 30, 31 and 32, directed to the process of making tubes having a vacuum of the required degree are valid. Claim 31 is:

> "In the process of producing a hot cathode discharge device, treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein, continuing these operations until the occluded and original free gas is so thoroughly removed as to enable the finished sealed-off device to operate below saturation in a stable and reproducible manner at a voltage above fifty volts and with a current greater than one milliampere and with the energy of the discharge delivered mainly at one or more anodes."

To find wherein, if at all, this and the other process claims go beyond the discoveries and ideas of others, beyond the use of wise judgment in selecting and combining those discoveries and ideas, or beyond mechanical skill in applying them to practical results, the specification and the prior art must be examined. The specification states:

> "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is prefer-

> ably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. The heating, especially of solid anodes such as shown in Figure 2, may take place in a suitable vacuum furnace, the temperature preferably being raised to 2,500° C. or even higher. Bombardment is a very effective means of removing occluded gas from anodes."

The steps and precautions requisite to successfully evacuate by bombardment are then described after which the specification adds:

> "After the metal has been freed from occluded gas reabsorption of gas will not readily take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated with less electron bombardment of the anode or anodes. * * * It is also true that when the anode has been carefully freed from gas residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated."

The prior art, however, as I understand it, discloses that long before the earliest date claimed for Langmuir it was known not only that large quantities of gas are occluded in the glass walls and electrodes of an electrical discharge device and that unless removed before or during evacuation the gas will be driven out by the heat of operation and thus detrimentally increase the pressure of the vacuum, but also that the occluded gases could be removed and the vacuum created and maintained by the very steps prescribed by Langmuir for removing the occluded and free gases of his device. In May, 1896, the

"American Electrician" published an article by Thomas Duncan in which he said:

> "If an incandescent lamp be exhausted until no air can be seen escaping through the valves of the pump, and the filament then incandesced, considerable quantities of air will be expelled at each operation of the pump, thereby showing that this air has been occluded in the pores of the carbon filament, and could not have been gotten rid of without heating the filament and driving the air out into the vacuous space surrounding it.
>
> "This heating also assists in drawing off the air which clings or adheres against the glass upon the inside of the bulb. If the electrodes are made from aluminum or other porous metal, the secondary terminals from a spark coil can be applied to them, and set in operation in a similar manner to that in which the tube is to be used afterwards. This can not help but be a ready and satisfactory means of eliminating the air occluded within the electrodes."

A résumé of Incandescent Electric Lamp Exhausting by S. E. Doane, published in the "Electrical World and Engineer" of May 21, 1904, says:

> "The exhausting of incandescent electric lamps has developed into a highly specialized branch of the lamp manufacture. * * * The completed lamp must not only be free from gases and vapors, but must also have had those parts capable of giving off gases and vapors, thoroughly freed from them. The only way we knew to accomplish this was to highly heat everything we wished to free from gas. We had three things to heat: the glass, the filaments and the joints between filaments and leading-in wires.
>
> "The glass was heated by an asbestos cone-shaped hood painted black on the inside. The heat from

> the lighted lamp furnished all the heat necessary. The lamps could be heated hot enough to cause the bulb to collapse if the hoods were made too thick. The filaments were also heated sufficiently by the current, * * *."

Dwyer, in his patent No. 596,694, granted January 4, 1898, for a process of producing high vacuums in incandescent electric lamps or similar receptacles during their manufacture recites that in the past such lamps have been exhausted by mechanical pumps, "by chemical processes involving the displacement or absorption of the gases contained in the lamp, or by combinations of these processes." He says that a partial vacuum is readily obtained by a good mechanical or mercurial pump but that complete exhaustion by this means alone is not possible. He then adds:

> "To carry the vacuum still higher, it has been a common practice to heat the lamp-bulb by either an external source of heat, such as a gas-flame, or by an electric current passed through the lamp-filament, or by both of these means combined, so as to expand the gases in the lamp, and also to drive off from the lamp-filament itself and its supports, more particularly the joint between the leading-in wires and the filament, which joint is usually made of some form of hydrocarbon paste, gases occluded therein, while continuing the pumping operation."

Soddy, in his patent No. 859,021 of July 2, 1907, for the employment of certain reagents in the process of producing high vacuum, declares:

> "In the production of high vacua not only has the air to be removed but also the gases occluded or condensed on the walls of the vessel being exhausted and on the contained electrodes or fila-

> ments or other contents of the said vessel, which condensed gases are given up slowly after exhaustion and if not removed during the exhaustion cause the vacuum to deteriorate. * * *
>
> "The heating and expelling of the condensed and occluded gases may be effected in any usual, or suitable, manner of expelling condensed and occluded gases from the walls and contents of vessels being exhausted. The usual manner of effecting such an operation is to heat the vessel while it and its contents are subjected to the same treatment as they are subjected to in after use. In incandescent electric lamps for example an electric current is passed through the filament, and in X-ray bulbs an electric discharge is passed between the electrodes during the continuation of the exhaustion."

Many other references disclose the baking of the walls of the envelope of a discharge device, the heating of the electrodes, incandescing the filament and electron bombardment of metallic electrodes to expel occluded gases. The gas clean-up effect was likewise old at the time Langmuir began his operations. One instance of its disclosure is in patent to Thatcher No. 1,028,636, granted June 4, 1912, application for which was filed March 30, 1910, for method of exhausting vessels, in which it is said in part:

> "I institute the intensive incandescence of the filament proper, that is I bring the current voltage up to a sufficient intensity to produce the blue haze phenomenon, and maintain the same until the blue haze disappears and the desired almost perfect vacuum is attained; * * *"

Dr. E. Leon Chaffee testified (R. Vol. 1, p. 159):

> "It has long been known that the existence of this blue glow improves the vacuum, probably by bom-

> barding the walls with gas ions and consequently causing them to stick to the glass walls. * * *."

These steps of the prior art are the identical steps disclosed by Langmuir. Nor are his disclosures with respect to how these steps are to be employed any more ample or complete with the possible exception of heating by bombardment. But bombardment has no saving power for the claims are not restricted to heating by bombardment. They are broad enough to include any method of "treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein." The plaintiff, however, places some reliance upon the clause in the claims directing continuance of the steps until the desired vacuum is attained and cites Badische *v.* Kalle, 104 Fed. 802. But in that case those skilled in the art were of the opinion that a more prolonged or intense application of the old steps would not accomplish the desired result. Such is not the evidence here as I understand it. Moreover, the tools of the evacuating art were constantly improving. In the early days of the incandescent lamp art manufacturers used the Sprengle pump to obtain their vacua. It gave way to the Geissler pump which, in its turn was superseded or supplemented by chemical evacuating processes. It is, I think, not denied that these old pumps and at least some of the chemical processes left in the tube mercury or other vapors having a pressure too high for the tube of the patent. But if Langmuir makes in his specification any disclosure of steps or means to avoid that result it is by the use of the new, improved Gaede molecular pump. That pump is highly efficient and, when properly used, leaves no free gas or vapor that will prevent the functioning of a thermionic tube above ionization voltages without substantial ionization. But Langmuir is entitled to no credit for that. I think the process claims are invalid.

This conclusion carries with it as a necessary corollary that the device itself, apart from its functioning and use, is lacking in patentable novelty. The inventive quality of the device claims, if any they have, must consequently reside in the discovery of a new principle that thermionic discharges above ionization voltages can be produced without substantial ionization if the vacuum be sufficiently high and the disclosure that the device of the claims constitutes suitable means for putting the principle into practice to obtain useful results, or, in the application of that principle, if known, to a useful purpose—in the realization that the instability, non-reproducibility and lower power output of the gassy tube was due to inadequate vacuum and the conception of a tube with a higher vacuum as a means whereby stability, reproducibility and high power output in thermionic devices might be had. That Langmuir was not the first to discover that a pure electron discharge, a discharge without substantial ionization, can be produced in a thermionic device if the vacuum is sufficiently high was indicated by Richardson's Law, evolved and formulated about 1903. If, perchance, that law was not universally accepted by physicists as being operative in high vacua, as was suggested by Soddy, Pring, Parker and some others, the publications of Lilienfeld in 1910 were clear, complete and specific upon this point. In fact, Langmuir admits (I. R., p. 1378) that Lilienfeld had thermionic discharges above ionization voltages "substantially free from the effects of positive ionization." Moreover, if a thermionic discharge is unaccompanied by substantial ionization all the asserted "earmarks" or characteristics of plaintiff's device are present for they are but incidents flowing from a sufficiently high vacuum for the voltages employed, or, otherwise expressed, from an absence of ionization. These characteristics are, or include, (1) regularity and reproducibility of operation, (2) 3/2 power relation of current to voltage, (3) no blue glow or other visible evidence of discharge, (4) cathode not heated by the discharge, (5) current limited by space-charge effect and (6) discharge independent of pressure in vacuum below certain pressure in the sense hereinbefore stated. As I understand the evidence these "earmarks" are likewise characteristics of the Fleming valve and original DeForest audion when operated at non-ionizing voltages. It thus seems obvious that the merit of the invention, if any, must lie in the realization that the known pure electron discharge to be had in a high vacuum would overcome the special difficulties and limitations of thermionic discharge devices. Whether this realization and the increase of vacuum in structures of the Fleming and DeForest type was a probable natural development of the art or one requiring inventive skill is, like the question of the presence or absence of invention in other cases, not without some difficulty.

One class of evidence which often carries much weight is the necessity for a series of experiments before the result can be arrived at. Such evidence raises a strong inference that the result was not obvious and constitutes a real addition to public knowledge. But for such experiments to be of much value the patentee must have started his experiments with knowledge of the state of the art or his experiments may have succeeded in enabling him to redisclose only what was already known. Langmuir made many experiments over a long period of time. Those that were first made were, however, for the purpose of discovering abstract principles and not for the purpose of arriving at practical results. He made discoveries but he did not immediately, or for some time, perceive that they had any practical use. Moreover, the discoveries to which his experiments led him, so far as we are here concerned, were those already made by Lilienfeld and others. Great credit, bearing upon the issue of invention, is claimed by the plaintiff for Langmuir for discovering from his experiments that electrons will boil out of a hot cathode in a high vacuum, that in a high vacuum the current varies with the 3/2 power of the voltage and other characteristics or incidents of a discharge in a high vacuum without substantial ionization. But disclosures of the prior art reveal that Langmuir, great and renowned physicist that he is justly conceded to be, was, in this instance, travelling, all unknown to him, over a field already well explored. Fleming, the inventor of the Fleming valve, published in the "Scientific American Supplement" for January 20, 1906, an article on the electric conductivity of a vacuum, disclosing not only that electrons are emitted by a hot cathode in a high vacuum but also "that a high vacuum may be a very good conductor, provided that the negative electrode is rendered incandescent. This shows that the obstruction which a high vacuum offers to the passage of electricity is not due to the mere reduction of the matter in the space (that is, to the rarefaction of the gas), but is, in some way or other, largely dependent upon the temperature of the electrodes; the resistance to the passage of electricity through a vacuum can be rendered very small by intensely heating the negative electrode," thus revealing that a current could be had passing from cathode to anode. In addition, Fleming stated: "If we take measurements of the current passing through the vacuum when the negative electrode is an incandescent carbon filament and the other a cold metal plate, and, at the same time, measure the difference of potential between the electrodes, we find that the conductivity, as measured by the ratio of current to voltage, is not constant, but varies with the electromotive force." Furthermore, that Fleming knew the difference between a high and low vacuum is made manifest by his statement: "The vacuum is said to be low when the original normal air pressure in it is reduced to one-thousandth atmosphere, or it may be only to one three-hundredth. It is said to be high when it is reduced to one hundred-millionth of an atmosphere." It is true, as shown by the Fleming curve sheet, that Fleming did not employ in his valve a high vacuum but it is also true that Langmuir, Q212, conceded "There is no advantage in the device of the character of the Fleming valve to go to pressures of less than 50 microns." Both C. D. Child, in an article in the "Physical Review," Vol. 32 (1911), and Lilienfeld, in an article entitled "Conduction of Electricity in Extreme Vacuum," published in "Annalen der Physik," Vol. 32 (1910), disclosed that with the aid of certain simplifying assumptions, such as the ignoring of the initial velocity with which the electrons are boiled out of the cathode, the discharge current varies in accordance with the three-half power of the voltage. This is conclusive evidence, as I understand it, that in a high vacuum the current is under control, stable and reproducible and, since high voltages were employed, that high power levels may be attained by the employment of a high vacuum. "Space charge effect" was, likewise, but a rediscovery. This is made certain by an article by Lilienfeld in "Physikalische Zeitschrift" 1908 in reply to an article by Soddy dealing with the Wehnelt cathode in high vacuum in which Lilienfeld said:—

> "* * * it is not exclusively the electrons emitted from the oxide cathode which, as was often assumed, determined the discharge in high vacua, but that the discharge depends essentially on a second factor. I pointed out more specifically in my second paper this view, that in consequence of the absence of the last traces of gas the number (volume density) of the negative electrons supplying the current becomes great in comparison with the number of gas molecules per unit volume, so that therefore the tendency exists for the formation of the greatest possible negative space charge—which opposes the current transport by the negative electrons.
>
> "The higher the vacuum, the greater the current density, the more prominent this new kind of discharge becomes * * *."

That the discharge in high vacuum devices is practically independent of the pressure when the pressure is below a certain value was discovered by Langmuir after Lilienfeld had made the disclosure in his article of 1910, where he said:

> "* * * from a certain maximum value of the gas density downwards the number of positive charges formed per negative charge, *i. e.*, per negative electron is independent of the gas density.
>
> "Since we usually regard positive charges as originating from molecules (or atoms) we can put this result in the following form: the number of positive charges per molecule increases continually with diminishing gas density in the region of validity of the function K which is independent of the gas density provided other conditions (the potential gradient) are kept constant."

In view of these publications it seems to me that the only permissible inference to be drawn from Langmuir's experiments is not that they constitute evidence of invention but is rather that Langmuir was not abreast of the developments in this particular art when he made his experiments.

Other evidence bearing upon the issue of invention is the great utility of the high vacuum tube. But in 1912 the radio art was young. Fleming did not need for his purposes, as Langmuir testified, a higher vacuum than that employed by him. The DeForest audion was not in wide use. Langmuir did not see one until 1913. Under such circumstances it would be difficult to say that the high vacuum tube satisfied a long felt want or produced results long sought or that the evidence of utility is here indicative of anything more than a proper natural development of the art. Moreover, the fact that falls but little short of a demonstration that the employment of the known pure electron discharge above ionization voltages in tubes of the DeForest type was but the availment of those skilled in the art of the store of knowledge that had been accumulated and lay ready at hand is that when Arnold, who had had long experience with electrical discharges in high vacuum, was shown a DeForest audion for the first time on November 1, 1912, and saw it in operation he immediately realized and said, in effect, that by increasing the vacuum the discharge would be sufficiently stable and at adequate power levels to enable the tube to be employed as a relay device in trans-continental telephony. While not unmindful that invention may sometimes be the result of an instantaneous happy thought, yet the state of the art is strongly confirmative of Arnold's own view at the time that the improvement suggested by him was obvious to one skilled in the art. The act of Arnold turns the scale so overwhelmingly that it lies athwart a finding of invention.

The patent is likewise invalid, in my opinion, because of prior knowledge and use by DeForest. The specification states: "Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts." That, as I understand it, means that at this voltage the current becomes affected by positive ionization and the tube ceases to function as a pure electron discharge device. Yet, prior to August, 1912, the Federal Telegraph Company of California, by which DeForest was then employed, used a B battery of 36 cells, another of 45 cells, or 54 and 67½ volts respectively, with the audion. When used as an amplifier the amplification increases with the voltage. The testimony of Langmuir, XQs761-767, as I understand it, makes it clear that this voltage was employed for amplifying purposes and so with a discharge current substantially unaffected by ionization. That DeForest, though not skilled in the art of evacuating his device, knew the effect thereon of an increased vacuum, though he was very probably unaware of the extent to which it could be carried, is disclosed by his letters of July 26, 1912, and August 14, 1912, to the McCandless Company, the manufacturer of audions for the Federal Telegraph Company. The first letter is:

> "Out of the last lot of 24 audion bulbs which you manufactured for us there are only 4 that came up to proper sensitiveness test. Apparently the vacuum in the other bulbs is too low, because in these latter bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive."

The other letter reads:

> "We took two of the poorest of the discarded 20 to a San Francisco glass-blower, unknown to fame,

> and had him exhaust same to as high a vacuum as his pumps would take. These re-exhausted bulbs now show a sensitiveness equal to those of the first four which proves exclusively that our contention is correct. For the work which we demand from these bulbs they are not sufficiently sensitive and we would be glad therefore if you will re-exhaust them. You certainly should be able to put them in as good condition as the aforesaid San Francisco glass-blower."

The testimony discloses that the glass-blower referred to heated the tubes under an asbestos hood almost to the collapsing point of the tube while they were being exhausted. The references of the prior art which reveal that a lamp may be made to collapse by heating under an asbestos hood leave no room to doubt this testimony. Such heat was sufficient to heat to a certain degree the metal electrodes as well as the walls of the tube, thereby driving off from the electrodes as well as the walls some of the gases occluded therein. The energy of the discharge of the DeForest tube was low. The bombardment was probably not adequate to heat the anode to a temperature even approximating that to which it was raised by the Bunsen burner under the asbestos hood. Consequently, little, if any, occluded gas would escape from the anode and the gas cleanup effect probably tended to improve the vacuum more than it was caused to deteriorate by the molecules of gas that escaped from the anode. The tubes were thus enabled to function substantially above ionization voltages without substantial ionization.

Upon the issue of priority, too, I think the plaintiff must fail. In the contest in the Patent Office between Arnold and Langmuir upon this issue the Examiner of Interferences awarded priority to Langmuir. The Examiners-in-Chief arrived at the same conclusion but for reasons conflicting with those of the Examiner of Interferences. The Commissioner of Patents awarded priority to Arnold. The Court of Appeals of the District of Columbia decided in favor of Langmuir for the reasons stated by the Examiner of Interferences and the Board of Examiners-in-Chief. I am in accord with neither of the divergent views expressed by the Examiner of Interferences and the Board of Examiners-in-Chief but, generally, with the reasoning and conclusion of the Commissioner of Patents. The defendant asserts that Arnold is entitled to the date of November 1, 1912. Upon that date Arnold, who because of his training and experience in the matter of electrical discharges in vacuum and upon the recommendation of Dr. Robert A. Millikan, had been theretofore employed by Western Electric Company to aid in making possible trans-continental telephone service at the opening of the San Francisco Exposition, was shown by Doctors Jewett and Colpitts a DeForest tube that had been brought by DeForest to the Western Electric Company a day or so before. Arnold examined the audion and tested its performance as a repeater of speech currents. It functioned well with weak currents but choked, distorted the speech and blue hazed when increased plate voltage or loud speech currents were applied. Though Arnold had been engaged in perfecting a different device of his own to be employed for telephone relay purposes, he instantly saw that the performance of the tube which made it too unstable in its existing state for a telephone repeater was due to ionization and that this could be removed by increasing the vacuum. This he then disclosed to Colpitts and Jewett. He also understood and then explained to Colpitts that the hot cathode would emit electrons in the high vacuum, that they would be subject to the space charge effect and that it would require high plate potentials to obtain the desired electron flow from cathode to anode. Corroboration of the oral testimony of Arnold, Colpitts and Jewett, if needed, is to be found in the fact that every act of the Telephone Company from that time on is consistent only with the intended use of the audion made more rugged and with a higher vacuum in its trans-continental service. Arnold's conception of the invention, consisting in the full performance of the mental part of the inventive act, was complete. Nothing remained to be done but to give the device practical embodiment with reasonable diligence. If, in view of the fact that those skilled in the evacuating art knew how to reduce to physical form Arnold's mental conception, a physical reduction of his conception to practice was necessary, and I think it was not, McCormick Harvester Mach. Co. *v.* Minneapolis Harvester Works, 42 Fed. 152, 155. Otto *v.* Linford, 46 L. T. (N. S.) 35, this requirement was performed by Arnold with reasonable diligence, thus giving to him an effective date of November 1, 1912. He obtained, knowingly, in that month with audion 7-A a current of 3 milliamperes at 80 volts without substantial ionization. Again, Arnold met the requirements of reduction to practice in April and May of 1913. In the tubes of these experiments 250 volts were impressed upon the plate without ionization effect. The tubes used in Philadelphia in the fall of 1913 functioned well for many hours, one as long as 267 hours as commercial repeaters. The fact that the output energy of one of these tubes was less than that of the usual, original DeForest tube does not negative its being a tube of the patent, for the output energy of claim 26 is likewise less than the output energy of the usual, old DeForest tube. Moreover, it seems to me that other claims of the patent, for example 11, which was an original claim, differs from

26 in the same way and only in the same way that claim 26 differs from the original DeForest device.

Langmuir began his experiments in August of 1912. He now asserts and the defendant denies that he then obtained a pure electron discharge substantially unaffected by positive ionization but concedes, XQ380, that though he now knows that he did then obtain such a discharge he did not know it then. This lack of contemporaneous knowledge denies to his August work any effective value upon the issue of priority. Robinson on Patents, Sec. 79, p. 121. In November Langmuir made other experiments but these he concedes were for the purpose of ascertaining the accuracy and existence of certain laws of physics. I find no evidence that he then thought of applying the scientific principles in which he was interested to any practical result in the useful arts. Consequently, there is no satisfactory evidence that Langmuir had a conception of the device of the patent before the end of November. "It is not while the creative energies are at work shaping and sharpening the idea of means that the conception of the invention becomes perfect. It is when these energies have ceased to act, when the idea stands before the mental vision of the inventor as clearly as a concrete invention before the eyes of an observer, that the conception is complete and the work of reduction is ready to begin." Robinson on Patents, Sec. 379. Tested by this rule even the statements of Langmuir to Coolidge in December, 1912, did not reveal a complete idea of means and, consequently, did not disclose a complete conception within the meaning of the patent law. It was not until March 21, 1913, as I read the record, that Langmuir's conception or idea of means to a useful end began to take shape. He then made a record of it in these words: "Now what I intend to do is to construct an audion which will operate entirely and exclusively on the electron discharge. I shall attempt to get the vacuum so good that positive ions are present in negligible amounts." It is not necessary to inquire when the conception became complete and his idea reduced to practice for Arnold had had the conception long before and had proceeded diligently to reduce it to practice.

The bill of complaint in this case must be dismissed.

(sgd) HUGH M. MORRIS, J.

January 3, 1928.

The Opinion of Judge Woolley.

IN THE
UNITED STATES CIRCUIT COURT OF APPEALS
FOR THE THIRD CIRCUIT.

GENERAL ELECTRIC COMPANY,
Appellant,
v.
DEFOREST RADIO COMPANY,
Appellee.

March Term,
1928.
No. 3799.

WOOLLEY, *Circuit Judge*, dissenting:

I am constrained to dissent from the judgment of the court holding the Langmuir patent No. 1,558,436 valid. I have the same trouble that other tribunals have had throughout the twelve years of the patent prosecution and five years of the patent's life in finding precisely what Langmuir invented. My trouble, like that of others, has been increased by the difficulty which attorneys for the patent have had in defining the invention and by the difference between their definitions and the claims of the patent.

This is more than a mental disturbance, for manifestly a patent to be valid must relate to some invention, something patentably new and useful, and must disclose the invention so that a court, looking through the eyes of those skilled in the art, can see what it is.

The art—really two related arts—is that of wire and wireless telephony, the latter commonly called radio. The invention relates generally to an electron discharge device comprising the familiar vacuum tube in which the customary electric current is carried by negative charges called electrons from the cathode to the anode, sometimes associated with a grid, and relates particularly to a vacuum space so free from gases as to avoid ionization. If the parts and principles of the mechanical construction were new and the gas evacuation old, there might be invention; and also if the structure and its principles were old and the gas evacuation—high vacuum—were new, still there might be invention. But the essential parts and principles of the mechanism, comprising a tube, cathode, anode and grid, were old, and high vacuum in the tube also was old. So the inventor was forced to admit the presence of these old elements, yet, still insisting he had created something new, he was compelled to avoid the common art terms applicable to these elements and particularly that of "high vacuum" in disclosing his invention and use technical terms which, as I understand them, mean the same old things. With this necessarily general preface to a highly complicated situation arising out of a difficult art, I come to the matters in hand.

In an effort to find what Langmuir invented, it is well to begin at the beginning. I shall therefore turn to his application for a patent, for in that instrument must appear the substance of the invention as the basis for subsequent amendments and for the patent as it eventually matured.

A recital of the prosecution of a patent application through the Patent Office is dreary reading yet, in this instance, it shows quite clearly that even the applicant was far from certain what he had invented. Naturally I hesitate to say this about Irving Langmuir, a great physicist, yet, saying it with entire respect, I am convinced that the history of the application establishes that fact and therefore is pertinent to the ever present inquiry: What did Langmuir invent?

The patent issued on October 20, 1925. The application was filed on October 16, 1913; renewed March 14, 1916. These are critical dates. The original application contained five claims; two for process of removing ionizable gas from vacuum electron discharge devices, that is, in plain words, for obtaining a high vacuum, and three for methods of preparing such devices, and no claims for discharge devices themselves. The specification conformed to these claims, referred to the art, stated the problem, disclosed construction adapted to the operative principle of such tubes and showed how they can be "evacuated" of gases by heating the glass walls, heating and bombarding the metal parts thereby expelling occluded gases, and drawing off both free gases and expelled gases "by a suitable evacuating means, for example, a Gaede molecular pump."

It should be noted that when the application was filed in 1913 the radio art was in its infancy but that, in 1925, when the patent issued, the art had attained an amazing growth. It is pertinent to inquire what happened to the application during this span of twelve years during which the mysteries that had enveloped the early art were largely dispelled and replaced by a broad knowledge of its principles.

After the application was filed in 1913 it lay practically dormant for several years, the applicant filing enough amendments by additions and cancellations to keep it alive. Amendments to the specification occurred as follows: two in 1913; eight in 1914; one in 1915; five in 1916; three in 1917; three in 1919 and forty-five in 1925, the year the patent issued.

Amended claims were filed and additions thereto and cancellations thereof made as follows: four in 1913; fifteen in 1914; twenty in 1916; five in 1917; nine in 1919; five in 1921 and forty-two in 1925, the year of the patent.

Analyzing these amendments, it appears that the five original claims (which were for process and method) were at different times wholly cancelled. Late in the year 1913 Langmuir first made claim to invention of a structure or device, that is, to invention of a tube. This he did by four claims. The first was amended four times and cancelled in 1925. The second also was amended four times and cancelled in 1925. The third was amended four times and was not cancelled. The fourth was amended once and cancelled in 1925. Of the thirty-two claims allowed in the issued patent, four are for method and process, being amplifications of the original method and process claims cancelled; twenty-eight are for a device. Of these device claims one was filed by amendment in 1913; one in 1917; nine in 1919; three in 1921 and fourteen in 1925, the year the patent issued. Bearing on the question whether Langmuir knew and disclosed in 1913, or indeed in succeeding years, what he had invented, it is significant to note that during twelve years, and mainly in the latter part of that period when the art had grown and reached a high stature, he rewrote, by sixty-seven amendments, the major part of his specification and cancelled all the original method and process claims and by one hundred amendments added, changed and cancelled claims until finally he was allowed the thirty-two claims of which twenty-eight, the claims for a device, are entirely new. It would be instructive, yet impossible within the permissible bounds of an opinion, to trace the progressive changes from the method and process claims of the original application to the device claims of the matured patent. But device claims having been allowed, they inevitably bring into the case certain devices of the prior art of which two are presently pertinent.

Long before Langmuir applied for a patent, Fleming, an English inventor, brought into a very feeble art a practical electron discharge device, comprising a cathode and anode in a vacuum tube. Also long before Langmuir's application, DeForest improved on Fleming by producing an electron discharge tube which he described as an oscillation detector and called an "audion." The improvement consisted in adding a grid to Fleming's elements. The construction and functions of both devices are given in an elementary way in the opinion in Westinghouse Electric & Mfg. Co. *v.* DeForest Radio T. & T. Co., 21 Fed. (2d) 918, 919. The audion as conceived by Fleming and improved by DeForest at once became and has ever since continued to be the basis of the modern art of transmitting sounds great distances both by wire and through the air. Just here dates are important. A patent for the audion (No. 879,532) issued to DeForest in 1908. The audion vacuum tube was therefore in existence and its principles of operation presumably known by Langmuir when in 1913 he filed his application for a method of evacuating such a tube, although he had not seen one until that year. In 1912 or 1913, the American Telephone & Telegraph Company, committed to the operation of transcontinental telephony by the opening of the San Francisco Fair, acquired rights under the DeForest patent and, first exhausting the gas and heightening its vacuum, used the DeForest audion as an amplifying telephone relay, thus making possible the first transmission of vocal words from coast to coast by wire. In 1917 the DeForest Radio Telephone Company, assignee of the DeForest patent, granted (with certain rights reserved) a license to the Western Electric Company to make, use and sell the invention for certain purposes with the right to grant sub-licenses. In 1920 the General Electric Company, the plaintiff in this suit and the assignee of the Langmuir patent in suit, acquired through mesne conveyances a sub-license to make, use and sell the DeForest audion, DeForest Radio T. & T. Co. *v.* Radio Corporation of America, 20 Fed. (2d) 598, 599, 600, which (probably with a heightened vacuum) it did on a vast scale until the DeForest patent expired in 1925, the year in which the patent in suit, after twelve years of travail in the Patent Office, issued to Langmuir, assignor to the General Electric Company, for an electron discharge tube including the essential parts and now universally accepted principles of the Fleming-DeForest tube. The Langmuir patent now completely covers the field previously occupied by the audion of the expired DeForest patent, and will, on the decree of this court, continue to cover it for twelve years more; hence the importance of this litigation.

Turning to the patent as it issued, the specification must first be looked at, for it contains some references to the behavior of electricity in a vacuum tube, old and well known, which are necessary to an understanding of the case. First there is a description by words and diagrams of mechanism for a vacuum tube. If new, this, it would seem, is unimportant as the specific mechanism is not claimed. Its importance resides in the fact that the patented device comprises the three elements of the general mechanism found in the art—the cathode, anode and grid, variously positioned in a vacuum tube to get the best electrical result—and in the fact that, as I read the record, these three elements, separately and in combination, operate on the same principle in which they operated in the art. Describing their operation, as the art then knew it, Langmuir said:

> "The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the vacuous space. If these electrons when moving above a certain velocity collide with gas molecules they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of electrons and the ions; * * * The cathode under these conditions is disintegrated, * * *, which causes its rapid destruction * * * The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages * * * (It should, for later use, be noted here that Langmuir said nothing about gas being a supposed medium for conducting electrons from one electrode to the other.)
>
> "If for a given cathode temperature the voltage is sufficiently high to cause all the electrons emitted or liberated at the cathode to be drawn away, then a further increase in voltage produces substantially no change in the current. The current thus determined is called the saturation current, and the range of operation in which the current is substantially independent of the voltage or approaches this condition may be called the saturation range

or more briefly designated merely as saturation. If for a given cathode temperature the voltage is not high enough to cause all of the electrons which are emitted or liberated at the cathode to be drawn away, the operation occurs in a range below the saturation range. Operation in this range may be spoken of as operation below saturation."

Predicated on these two definitions of ionization and saturation Langmuir by claim 2, which has been treated in this litigation as a typical claim, said that his invention is:

> "A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range; below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization."

That, as I read it, simply means "high vacuum," for a tube properly fashioned and shaped by skilled workers and highly (thoroughly) evacuated of gases—free and occluded—will in conjunction with a two electron group or with a group of two electrons and a grid produce these results; both groups, then and now, being in common use for different purposes by the art and by the plaintiff itself.

For the purposes of this case, vacuum means gas evacuation, high vacuum means vacuum above the ionization point, and, by the same token, a high vacuum tube means a non-gaseous tube. If the language of the claims means high vacuum, it is prior art, for the art was entirely familiar with the fact and effect of such a vacuum; and if prior art, Langmuir invented nothing.

When the patent came into litigation in this case in the District Court of the United States for the District of Delaware the learned trial judge, having trouble with the claims, endeavored to get from the plaintiff a definition of the invention, asking time and again, as did this court on appeal: If not high vacuum, what is the invention? An answer to this question seemingly had its difficulties. The plaintiff, of course, could not say that the invention was high vacuum alone, or high vacuum in combination with Fleming and DeForest parts alone, for that would be an admission of old art and would instantly avoid the patent. It was forced to admit that the Langmuir device included all these old elements but claimed it included "something else." So, eventually, in order to show this something else—something new—it produced, under the insistence of the trial court, this carefully constructed definition of Langmuir's invention, on which the case was tried below and on which it was first argued and decided in this court on appeal:

> "The Langmuir invention is a coordination of elements having a new functional relation between various factors, producing a new result. It is not a matter merely of maintaining a certain vacuum, far less of *producing* a certain vacuum which will be destroyed the moment the tube begins to operate. It involves primarily a relation between the shape, size and space relation or "geometry" of the parts of the tube and the nature and pressure of the gas therein contained, coordinated and adjusted with respect to the conditions of the electric circuit."

That, I surmise, would be a bad patent claim. However, as it was intended to describe the invention more clearly and more definitely than Langmuir had disclosed it in the patent claims I shall take it as it is written and try to find what it means. I discern in its generalization three factors: (1) gas pressure in the tube; (2) "shape, size and space relation or geometry of the parts of the tube"; and (3) the relation of one to the other.

The first factor of gas pressure, or, more properly, the lack of it, if it means anything, must mean a minimum of gas. This in turn means high vacuum. If it does not mean high vacuum there is no new vacuum factor of invention in the device, for low vacuum was old and that is an end to the case. If it does mean high vacuum then again it is not new, for high vacua, their uses and effect and how to produce them, were long known and practiced in the art.

The second factor, or "geometry," of the physical tube elements is not, so far as the claims reveal, involved in the invention. The physical elements themselves were old. This the plaintiff admits. Though differing in shape from some others, they are not claimed to be inventively novel in themselves. Indeed, each claim describes the invention not so much by its parts as by its characteristics of operation and results—characteristics inherent in any electron discharge tube possessing a high vacuum. Nor was this an inadvertence for when the Examiner, on rejecting certain device claims on prior art references, said:

> "If applicant's device is an improvement over the reference he should define the difference by structural limitations," the applicant (Langmuir) replied by saying:
>
> "The 'structural limitations' in this case are to be found in the *difference of vacuum*."

So, thus far, the invention, with old parts and a high vacuum, gets back to the question whether there was invention in the "difference" between low vacuum and high vacuum, a difference existing in and known to the art.

The third factor, the relation of the two factors of gas pressure and physical parts, appears nowhere in the claim unless it be implicit in the words "the gas content or residue of said tube and the relation of the *parts* of the tube being such" as to produce a certain result. (Gas pressure is scarcely a *part* of a tube.) If it is so implied, Langmuir cannot claim invention by implication. The claim therefore is void for inadequate disclosure. If it is not so implied, there is no claim for the third factor.

Whether I am right or wrong in this analysis of the plaintiff's statement of Langmuir's invention or in my disposition of its elements is not important for the validity of the patent depends not on the plaintiff's conception and definition of the invention but on the claims of the patent.

So I come back to the claims of the Langmuir patent to find Langmuir's invention. But before doing that I am arrested by still another entirely new definition of Langmuir's invention, this time made by the court in its opinion. The court did not adopt the plaintiff's definition of coordinating elements with functional relations but, stating that a non-gaseous electron discharge device did not exist before Langmuir, found the invention to reside in his producing a non-gaseous tube in place of a gaseous tube of the prior art or, in other words, in substituting a high vacuum for a low vacuum, the very thing which all along the plaintiff was forced to avoid in its definition because it was old. Without conceding its predicate, I agree with the court's succinct definition of the invention; but as the invention so defined was old I cannot agree to hold a patent for it valid.

It now appears, and I say this with entire respect, that in interpreting and sustaining the patent broadly for a non-gaseous tube the court has given the plaintiff more than it ever dared to claim. A high vacuum or non-gaseous tube being old, the plaintiff knew that an admission that the invention was a non-gaseous tube and nothing else would defeat the patent. Langmuir also must have known that a non-gaseous tube was old for otherwise, if he had believed he was the first to conceive and make one, he could, and doubtless would, have claimed it in a half dozen words: "A non-gaseous discharge tube," or "an electrical discharge device with a high vacuum tube," whereas in his original application for a patent he made no claim for a tube of that kind or, indeed, for a tube of any kind, the inevitable inference being that at that time he thought all he had invented was a new method or process of gas evacuation, that is, a new way to produce an old thing. But that the plaintiff realized the necessity of claiming for the invention something more than a high vacuum tube or non-gaseous tube is evidenced by its earnest and repeated contentions that Langmuir's invention, while including a non-gaseous tube—high vacuum—admittedly old, included "something else," that something else being disclosed by the remainder of the long claims and interpreted in its quoted definition. The plaintiff nowhere and at no time has claimed that Langmuir invented a non-gaseous tube *per se*. And wisely so, for it well knew that, while not in universal use, non-gaseous tubes were in commercial use before Langmuir for some purposes and that gas evacuations were as thorough as the instrumentalities of the art in 1913 would effect, and that was substantially above the ionization point, which is the crux of this case.

Returning to the patent claims and using claim 2 for convenience, it appears that the invention is an electron discharge tube which is capable of being operated below saturation and above ionization voltages. Langmuir called this a "pure electron discharge device"—"pure" because unaffected by gas ionization which is either entirely absent or negligible.

Electricity is an elusive subject. Therefore I shall, for the immediate purpose, restate in plain words, if I can, the theory of ionization.

Ionization is an effect produced by passing an electric current through gas which remains in a vacuum tube when it has not been thoroughly evacuated. The myriads of electrons, when passing from cathode to anode above a certain velocity, collide with and break up the molecules of gas present and charge the resultant broken parts or ions with positive charges of electricity. Thus electric reaction is inevitable. The ions (with their positive charges of electricity) fight against the electrons (with their negative charges) in the normal flow of the latter from cathode to anode resulting, at high voltages, in a blue glow which is the indication of bad action, a thing to be avoided. The central point of this statement is that ionization occurs at certain voltages in an electron discharge tube when, not being thoroughly evacuated, it contains air or gas, whether gas free in the tube or gas occluded in its parts and liberated by heat during operation. The amount of ionization depends upon the amount of gas present. Langmuir prescribed in his specification that occluded gas should be expelled from the tube parts; from the tube by heating its glass walls; from the cold electrodes by electron bombardment—the liberation of gas by the electric discharge itself; and from the incandescent cathode by the heat of an electric current; all old; and after this, that both the expelled gas and free gas should be pumped out of the tube during the heating process (old) by "a suitable evacuating means (old) for example, a Gaede molecular pump," then a new German invention.

Thus the capital requirement, if not the sole requirement, of Langmuir's claimed invention, is as nearly as possible to withdraw from the tube all gas, free and occluded; in other words, to obtain as high a vacuum as possible. When that is done ionization is avoided and a pure electron discharge follows. Was this new with Langmuir?

Langmuir was met in the Patent Office with the Law Examiner's statement that:

> "It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. *An evacuated tube having therein an incandescent electron emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube were also well known and available to persons skilled in the art.*"

Was that statement of the Law Examiner correct? I think it was. Just here occurs my sharpest departure from the opinion of the court which is based, as I have before stated, on what I am constrained to believe is an erroneous theory or finding that all discharge tubes before Langmuir were gaseous and that Langmuir's invention is a non-gaseous tube.

If that was his invention, clearly he must have been the first to conceive it and reduce it to practice. That the Examiner was right in saying that high vacua in electron discharge tubes were old before Langmuir and that a pure electron discharge—the inevitable result in a high vacuum non-gaseous tube and an impossible result in a gaseous low vacuum tube—also was old is sustained by many prior publications and patents. The same prior publications and patents contradict, I think, the court's holding that Langmuir was first to make and invent a non-gaseous tube. They are so numerous that it would not be permissible to quote them in an opinion. I shall therefore do nothing more than cite a few of them, ranging from 1881 to 1912, found in the record and to be used by anyone who should desire to check up this statement or who may be charged with the duty of retrying the issue. They are: Lilienfeld, Fleming, Doane, VonBaeyer, Bissel & Hagen, Malignani, Edison, Dwyer, Duncan, Leonard, Soddy, Thatcher, Child; illumined by the testimony of Waterman and Chaffee.

On these references I stand; and on them I would hold the patent invalid for want of invention.

Passing from the literature and patents of the prior art as affecting the validity of the patent for want of invention, I come to the question of prior use. The trial court found the patent also invalid because of prior use by DeForest on evidence as to which there is little dispute on the facts as distinguished from inferences. The test is the voltage at which ionization ordinarily occurs in a "gassy" tube. It is given at from 20 to 30 volts. That is not disputed; they are Langmuir's figures.

Prior to August, 1912, DeForest was the electrical engineer of the Federal Telegraph Company of California and was engaged in developing the transmission and reception of messages by radio. In this work he used his oscillation detector or audion then normally having a gas content. It was a "gassy" tube. But desiring to use it not as a detector but as an amplifier, as later it was almost universally used and indeed as made, for that use by the plaintiff itself under license and by the Westinghouse Electric & Manufacturing Company, its sublicensee, he had the audion exhausted of gas as far as it was possible in that day. That is, he sought and obtained as high a vacuum in the tube as existing means would produce. When the vacua were too low and the amplications poor he complained to the manufacturer and had the tubes re-exhausted. During that period (1910, 1911 and 1912) the Federal Telegraph Company used DeForest's amplifying audion at 54 and 67½ volts. This was possible only because he had exhausted the tubes of gas, which otherwise would produce ionization at 20 to 30 volts, and thereby heightened the vacuum above that danger line. This was "high vacuum" within the definition of vacuum above the point of ionization and was therefore high vacuum within the sense of those words as used in this case. It was not so high as that later attained by more modern means, for instance the Gaede molecular pump, which had just come into the art at the time of the patent application, referred to by Langmuir in his application and invented not by him but by Gaede. I agree with the court that DeForest did not then understand the change in operative principle for in later years he expressed views contrary to those advanced both before and after that time. But DeForest did change the vacua of his tubes in changing their function from detectors to amplifiers. Whether he knew the principle of the change is of no consequence. The fact is he did it. And he did it before Langmuir. And by doing it he got rid of the ionization of low vacuum and obtained, and put into commercial practice for nearly three years before Langmuir, the very electron discharge of Langmuir's claimed invention.

What I have said about the device claims applies equally to the method and process claims.

On the subject of validity as involving invention I shall conclude this phase of the discussion by referring very briefly to the claimed advance made in the art by Langmuir's invention, matter with which the plaintiff very earnestly began and ended discussion in its brief and at the argument and matter by which the court was impressed. Admittedly, when invention is in doubt—yet *only* when it is in doubt—favorable reception by the art may be placed in the scale. As the four judges who heard this case have divided evenly on the question of invention, I shall, for that reason only, assume there is doubt as to invention. The plaintiff says that today everybody uses "the Langmuir tube," a name given it not by the art (as the plaintiff frankly admitted at the argument) but by the plaintiff itself; that Langmuir, seeing through the mysteries of the art, made an invention that revolutionized the industry and made possible the transmission of sounds through the air for great distances which without his invention would be impossible.

Much litigation in respect to the radio art has drifted to this circuit. Oddly enough, in every case the plaintiff has claimed for his invention the whole credit for its growth. I am satisfied from the number of cases we have heard that the whole credit for the amazing advance of the radio art cannot be given to any one invention or even to a few of them. In truth, the art is the product of innumerable impulses. The original impulse was, of course, the vacuum tube appearing years ago in the incandescent lamp art. Another impulse given in the incandescent lamp art and transferred to the radio art was that of the Just and Hanaman unstable squirted tungsten filament displacing Edison's bamboo filament; still another was Coolidge's method for obtaining a filament of pure tungsten, strong and stable. Impulses in the radio art itself came from many inventors. At one time there were seven thousand applications for patents pending in the radio section of the Patent Office. To mention only one or two inventions, they include discharge devices of the Fleming two electrode type and the DeForest type with a grid added to Fleming, the feedback circuit invented at different times by DeForest, Armstrong, Langmuir and Meissner. There are many more, without any one of which it has always been said by the particular inventor that the art would have gotten nowhere. And now the plaintiff here says the same of Langmuir. Important and indeed great as some of these inventions were, no one of them is entitled to all credit for what has been accomplished in this great art, for the art has been impelled forward by hundreds of inventors and thousands of skilled workers. What Langmuir claims to have done—procured pure electron discharge above ionization voltages in tubes of the DeForest type—appears to me to be the natural growth of the art, begun by others before Langmuir and by them reduced to practice with means then available, and developed to their later perfection during the twelve years of his patent prosecution through the Patent Office.

I thought after the argument, and still think, the Langmuir patent invalid because of lack of invention and prior use. If I am wrong and the patent really involves invention, then, again, I think it invalid for, as I read the evidence, Langmuir was not the first and original inventor. On this point, to avoid repetition, I refer and subscribe to the opinion of Judge Morris holding on evidence substantially greater than the evidence in the interference proceeding that, if invention, Arnold was the first and original inventor.

And so this court, one judge dissenting, affirmed the decree of the District Court, on its opinion, holding the Langmuir patent invalid.

In due course the plaintiff filed a petition for rehearing based on this proposition:

> "In simple language, Langmuir's invention consisted in taking out the conductor (gas) which was in the Fleming valve and the DeForest audion and putting nothing in its place; he dispensed with what was regarded as an essential element in the operation of the tube (gas) and by doing so made a tube which worked infinitely better."

The petition was allowed and the reargument was based on this entirely new statement of Langmuir's invention made for the first time four years after suit was brought, five years after the patent was issued and seventeen years after the application was filed. Of course if the facts asserted were facts established by the evidence there would be no doubt about what Langmuir did and no doubt that it was invention and, if claimed, no doubt he was entitled to a patent.

The plaintiff rests its proposition upon its own statement that "Both Fleming and DeForest depended upon the conductivity of gas as the fundamental basis of the operation of their tubes." It makes this statement without distinguishing between detectors and amplifiers and supports it by carefully selected quotations from scientific publications in the early days of the art ranging from 1905 to 1912 (one in 1915) when scientists were feeling for the theory of electron movement in electron discharge tubes, some of whom based it on conduction by rarified gases or air, some on conduction by ionized gases, and some not on conduction at all but on free passage of electrons through space in a high vacuum, that is, in the absence of gas or air. And in addition the plaintiff to support its statement points to an adverse criticism by DeForest in 1915 of Langmuir's "extremely high vacuum" quoted in the court's opinion. The plaintiff ignored all the testimony on the subjects of prior art high vacua and pure electron discharge, which means absence of gas as a conductor, their advantages and uses, to which I have previously alluded with citations.

Of course, if the belief and practice of the art were that gas conducts the electrons, that gas therefore is necessary to conduction and Langmuir discovered it to be wrong, that in fact gas is an enemy to conduction, and omitted gas as an element in his tube yet obtained the same or a better result, clearly he made an invention. These are the things which now the plaintiff and also the court say he did. But Langmuir did not say so. If that was his invention he should have disclosed it in his claims for we are called upon to judge the patent on Langmuir's disclosures, not on the plaintiff's definitions of his invention. To be sure, he did refer in his specification to several tubes—the Geisler tube and the Roentgen X-ray tube—"whose operation depends upon gas ionization." He might, more or less correctly, have added to the list detectors with gas content, then and now in common use for certain purposes, whose usefulness depends on their sensitiveness and their sensitiveness on gas content. But he nowhere said in his patent that before his invention electron discharge tubes used for amplifying purposes in order more faithfully to reproduce sounds (one of the purposes of the DeForest audion and the thing we are dealing with in this case) depended on low vacuum or that the art regarded, as an essential element of such a device, gas as a conductor, for he probably knew the contrary was true. To show that the plaintiff's last definition of Langmuir's invention is without foundation in the evidence I refer to, but shall not repeat, what I have said about prior knowledge and prior use of high vacuum tubes. I shall endeavor, very briefly, to show that Langmuir by his own words contradicts the plaintiff's last definition of his invention and refutes the theory on which the court has in part based its judgment.

In Langmuir's original specification he stated that when there was enough gas in the tube to become ionized by the discharge of electrons "The positive ions (gas molecules) *take part* in the *conduction* of current, giving at first erratic readings on measuring instruments connected in circuit," which is what the plaintiff now says. Continuing, he said, that the audion, the DeForest tube, was a device that took advantage of that phenomenon. *But he cancelled the quoted statement before the patent issued.* At the trial he was examined with respect to that statement in his patent application and was asked whether the sentence would be true if it read; "The positive ions take part in the conduction of current by acting as *conductors* or carriers of current." He answered: "In my opinion the sentence would have *no sensible meaning* if the word 'conductor' was left in for *it is inconceivable that ions could be conductors of current.* I will, therefore, confine myself to the case where the positive ions act as 'carriers.' With this correction I can say that the statement would not have been true."

With this cancellation and explanation Langmuir rested. Neither by amendment nor in his testimony did he again advert to a prior art theory of gas conduction which the plaintiff now says "was regarded (by the art) as an essential element of the operation."

In the interference proceeding Langmuir testified with respect to the early work of Lilienfeld, as follows:

> "Lilienfeld proved beyond question, I think, that he obtained discharges in some cases at least, in which the effects that he measured *were not dependent upon gas ionization* * * *
>
> "Lilienfeld probably succeeded in obtaining a discharge *high vacuum substantially free from effects of positive ionization* in the device he described in his 1910 paper * * *
>
> "Lilienfeld in his experiments of 1910 heated the walls of the vessel, *he reduces the gas pressure to a low value*, and in some of his experiments *he heated his electrodes* by *electronic bombardment* * * *
>
> "*Heating of glass and electrodes, and exhaustion to low pressure*, are elements which were used by Lilienfeld and were known *prior* to Lilienfeld's article * * *
>
> "Factor No. 1 which I gave in answer to XQ84, viz., that the bulb should be heated *during* exhaust to a temperature materially higher than the operating temperature, was used by Lilienfeld in much of his work * * *
>
> "Factor No. 4, which is that which I gave in the first part of my answer to XQ87, refers to the lowering of the pressure to such a point *that a further lowering brings about no further change*. In many of Lilienfeld's experiments, this condition *was realized*."

VonBaeyer stated as early as 1909 that his "experiments were of course carried out in the highest possible vacuum to avoid the influence of ionization." Langmuir admitted that "Wehnelt claimed that * * * currents of the order of 10 milliamperes could be obtained even in the highest vacuum."

Referring to an interview with Richardson in 1912 Langmuir said:

> "Richardson * * * expressed himself as confident that even in the highest vacuum thermionic currents could still be obtained."

Langmuir admitted in the interference proceeding that "prior to 1912 (the year before his application) there were some experimenters who took precautions to remove gases from the walls, from vessels and from electrodes."

This, I think, shows that the reargument, based on an incorrect premise, should leave undisturbed the court's first finding that the patent is invalid.

The plaintiff, however, prevailed. The court reversed its previous decision and will now enter a decree holding the patent valid. From the opinion announcing its judgment, in so far as it will reverse the decree of the District Court on the first (Langmuir) patent in suit, I dissent.

This is a long dissenting opinion. In view of the gravity of the Court's decision and its effect upon the art I make no apology for its length. I frankly admit that it is written with the hope that it will arrest the attention of the reviewing court.

A true Copy:

Teste:

Clerk of the United States Circuit Court
of Appeals for the Third Circuit.

FILE COPY

FEB 2 193
CHARLES ELMORE C

Supreme Court of the United States

October Term, 1930.

No. 630.

DeForest Radio Company,
Petitioner,

v.

General Electric Company,
Respondent.

OPINION OF COMMISSIONER OF PATENTS IN ARNOLD *v.* LANGMUIR INTERFERENCE NO. 40,380

Thomas G. Haight,
Samuel E. Darby, Jr.,
Counsel for Petitioner.

Hearing:
Aug. 17, 1923.

IN THE

United States Patent Office

ARNOLD *v.* LANGMUIR.

PATENT INTERFERENCE No. 40,380.

APPEAL FROM EXAMINERS-IN-CHIEF.

ELECTRIC DISCHARGE APPARATUS AND THE PROCESS OF PREPARING THE SAME.

Application of Harold De Forest Arnold filed November 2, 1915, No. 59,210.

Application of Irving Langmuir filed March 14, 1916, No. 84,242, for renewal of application filed October 16, 1913, No. 795,610.

MESSRS. DE WITT C. TANNER and JOHN G. ROBERTS and MR. GEO. E. FOLK for Arnold. MR. CARL A. RICHMOND of counsel.

MR. ALBERT G. DAVIS and MR. ALEXANDER D. LUNT for Langmuir.

This is an appeal by Arnold from a decision of the examiners-in-chief affirming the examiner of interferences awarding priority on all counts to Langmuir.

The issue is a thermionic tube in which there may be a pure electron discharge, as distinguished from a discharge through gas which is ionized, so as to be useful for such purposes as a telephone relay, a wireless detector or amplifier, a rectifier of alternating current and possibly a generator of X-rays. It is the device of defendant in Hewitt *v.* American T. and T. Co., 272 Fed. Rep., 194, and 272 Fed. Rep., 392. The invention is exemplified by a structure such as the well known De Forest audion or Fleming Valve (see Marconi Co. *v.* De Forest Co., 236 Fed. Rep., 942), modified so that there is present during operation too little gas to modify or affect the pure electron discharge from the cathode.

The applications were filed in 1913 (renewed in 1916) and 1915. After the interference was declared, Arnold moved to dissolve on the ground that the issue was unpatentable. In February, 1917, the Commissioner ordered testimony to be taken on the question of patentability and between July, 1917, and January, 1920, over 1650 printed pages of testimony accompanied by a great mass of exhibits were introduced. Much of this testimony should not have been taken since it related to priority alone. Motions were made to amend the issue and some counts were withdrawn. The law examiner rendered a seventeen page opinion settling the counts and finding patentability. Subsequently, by stipulation, other counts were added and the issue fixed into thirteen counts, of which the following are sufficiently illustrative:

> 1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

5. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissas is straight and continuous.

9. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

11. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts.

13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

The counts are ably and clearly analyzed by the examiners-in-chief thus:

> A thermionic tube which operates solely by electron discharges or currents has certain distinctive characteristics by means of which the presence of the invention may be recognized, and the counts have been so worded that each brings out one or more of these characteristics. For example, count 1 specifies that the envelope of the tube is evacuated to such a degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts. Thus the count distinguishes from the prior art, not by features of structure, but by a characteristic which is manifest while the device is operating at or above a certain

voltage. The audion is not evacuated to the high degree that count 1 calls for and, at an impressed voltage of about 30, ionization occurs. Count 5 specifies that the relation of the parts of the tube and the degree of evacuation are such that, when operated in a range below saturation and materially above ionization voltages, the space current is governed by the combined effect of the electric field of the electrons and the potentials applied to the electrodes, the governing or limiting of the current being substantially unaffected by secondary electron emission from the walls of the tube.

When a thermionic tube is operating by a pure electronic discharge at a voltage substantially below saturation, the current varies in substantial accordance with the 3/2 power of the impressed voltage. If the voltages be plotted as abscissas and the currents as ordinates, the result is a curve that gradually rises and turns toward the left—the curve of the 3/2 power. This obtains while there are plenty of electrons emitted from the cathode, at the temperature at which it is heated, to make up the increasing current. But the number of electrons emitted varies with the temperature of the cathode and that temperature is generally maintained constant. Consequently, a voltage will be reached which is capable of forcing the electrons across the space more rapidly than they can be emitted. The result is the flat-topped curve showing saturation. The tubes of the issue are operated at voltages above that of ionization and below that of saturation, and the voltage current curve follows the 3/2 power law. This is one of the characteristics of the tubes; and a tube that has such a characteristic operates by a pure electronic discharge and is a tube of the issue.

Ionization occurs when there is gas within the tube during operation. This gas may be normally free, as when mercury vapors are present, or it may be absorbed or occluded in the electrodes, particularly the anode, and in the glass walls of the tube.

The electrodes and walls act like sponges, taking up the gas when cold and again giving it off when heated during operation. A tube which has gas either in a normal free state or occluded in the electrodes or walls is subject to ionization; and ionization takes place when the voltage rises sufficiently to produce it. About 15 volts is sufficient to give this result. But a tube which operates by ionizing a gas does not respond to the 3/2 power law and is not a tube of the issue. Excessive ionization is usually accompanied by a blue glow or haze; but such a glow is not a reliable test, as both parties admit, since a tube that does not show blue glow may produce ionization to such a degree as to cause it to depart from the 3/2 power characteristic.

Any tube which gives the 3/2 power voltage-current curve must also give the straight-line when the volts and current are plotted on logarithmic paper. These two curves are plotted from the same data and their differences are due simply to the difference in the arrangement of the lines on the paper. If, therefore, the volts and currents be plotted on one kind of paper and the result shows a pure electron discharge, there can be no doubt what the other kind of paper would show. Certain counts, as 6 and 7, call for the straight-line, while count 8 calls for the 3/2 power characteristic.

Other counts refer to the electric field of the electrons (count 2) or to space current due to the electric field of the electrons (count 3). The electrons are supposed to be exceedingly minute pieces of negative electricity, and they react on one another just like a flock of pith balls would react if they were confined in some manner so that they were each within the field of influence of the others. If they were all charged with negative electricity and there were no available positive charge to neutralize them, they would simply create an electric field or space charge. But if at one part of this field a positive charge were created, the negatively charged pith balls would fly across the field to it, thus setting up a current. That is what happens in the tubes of the issue. The electrons are generated or emitted by the heated cathode; and if there is no way of neutralizing them they simply fill the space, charge it negatively, and react on one another. But if the anode be charged positively, the electrons fly across the field to it and become neutralized. This flow of electrons is a current; and, assuming a sufficient emission of electrons, the strength of the current is dependent on the potential difference between the cathode and anode. If this difference is small, comparatively few electrons get through and the others continue to react on one another. If no gas be present in the tube, either free or occluded, the current is governed by the electric field of the electrons and the potential applied to the electrodes. If gas is present and the voltage is above ionization, some of the gas molecules become ionized and rendered positive by having one or more of their negatively charged electrons knocked out of place. These positively charged molecules or ions remain in the field a relatively long time and increase the flow of the electrons. This increases the current more rapidly than the pure electron current would increase and so deviates from the 3/2 power law. This explains the meaning of such counts as 2 to 5, inclusive.

The degree of ionization in a tube varies with the quantity of gas therein. Generally, when ionization occurs the current at a given voltage is larger than it would be at that voltage were no appreciable ionization present. If, therefore, a tube containing some gas were operated and the vacuum therein were gradually increased, as by a pump, the voltage remaining constant, the current would drop as the vacuum improved until ionization became substantially negligible, when the drop in current would cease. This is a test of the invention as defined in such counts as 2 and 3.

The character of the electron discharge is affected by the relation of the parts of the tube. When the passage for the electrons is long, narrow or crooked, the electrons strike the walls of the tube and adhere thereto. This is exemplified by the Lilienfeld experiments in which a long, crooked, capillary-like tube was employed. Only a very minute current was obtained although thousands of volts were employed. Furthermore, it is not possible to remove all the gas, and, when the passage for the electrons is restricted, ionization takes place even in a very high vacuum. Such counts as 5, 8 and 9 call for such a "relation of parts" as render the tube capable of producing a current governed by the combined effect of the electric field of the electrons and the potential applied to the electrodes. Count 9 further states that the current is substantially unaffected by secondary electron emission from the walls of the tube. When the walls are long, crooked or narrowly spaced, the electrons adhere to them, as stated, until they are knocked loose by the electrons of the primary discharge. When thus set free, they constitute a secondary electron emission. The count further states that the current is substantially independent of the cathode temperature. According to Richardson's Law, which is extensively discussed in the records, the electron emission from the cathode increases with the temperature of the latter. But the number passing to the anode, in a tube of the issue, depends upon the impressed voltages. If at a given cathode temperature there are sufficient electrons to furnish the current at the voltage used, an increase of temperature and an increase of electron emission will not increase or otherwise affect the current. Under such conditions, the current is substantially independent of the cathode temperature.

Counts 12 and 13 are the only ones that call for the third electrode. This electrode is generally referred to as the "grid". It is placed between the cathode and anode; and when an electromotive force is applied to it, it modifies the electric field and controls the current passing to the anode. When there is no ionization, this control is certain and the variations in the current follow proportionately and in a reproducible manner the variations of the electromotive force applied to the grid.

The invention in issue is, therefore, a thermionic tube that operates with a pure primary and substantially no secondary discharge at voltages above ionization and below saturation; and such a tube is to be recognized by its response to the characteristics expressed in the several counts. The tubes of counts 12 and 13 have three electrodes, while those of counts 1 to 11 may have two or more, these counts being generic.

The record on the motion and the accompanying exhibits were stipulated in for use on priority, and during 1921 and 1922, upwards of 300 additional pages of testimony were taken. Appeals were promptly taken in what seems to be an honest effort of the parties to hasten a final determination of the case.

The inventions and their development have taken place in the laboratories and shops of the Western Electric Company and the General Electric Company. The parties have had at their disposal unlimited aid, both personal and financial, for the development and investigation of the invention, as well as for the presentation of their cases here. This would lead us to hope and expect to find the issue clearly and simply presented for consideration. It seems, however, that both parties and their counsel have been overpowered with amazement at the abstruse scientific theories that may be evolved to account for the plain simple facts of operation of the invented device. The result is that we are presented here with 379 pages of brief by Langmuir, who has the favorable decision of the examiners-in-chief, and 281 pages by Arnold, in an endeavor, not to controvert that decision, but to show his own priority. Neither brief pays much attention to the decisions below, but both attempt to treat the matter *de novo*, so that this decision may follow the same procedure.

The line between the prior art and the issue is attenuated and if there is patentability, it must be as set out in the decision of the law examiner on the motion, and I do not understand either party to attack that decision here. Arnold alleges that when he made the invention, he thought he was following the prior art and not producing something patentable, and an undercurrent of that attitude seems to tinge his whole case. This is why he filed so late.

I do not find it necessary to go beyond the decision of the law examiner to determine patentability or to interpret the prior art which was elaborately presented to him. He refers to:

Article by Fleming in Scientific American Sup., Jan. 20, 1906, p. 25, 129;

Article by Deininger in the Annalen der Physik, IV, Vol. XXV, p. 288 (1908);

Article by Von Baeyer, Physicalische Zeitschrift for 1909, p. 168;

Article by Gehrts, Annalen der Physik 39, p. 995 (1911);

Article by Child in the Physical Review, Vol. 32, p. 448 (1911);

Articles by Lilienfeld, Annalen der Physik 32, p. 673 (1910); Physicalische Zeitschrift 9, p. 193 (1908);

J. J. Thomson's Conduction of Electricity Through Gases, pp. 222 to 227;

Shottky, Jahrbuch der Radio Activitat, Vol. 12, p. 147 (1915);

Shottky, in Physikalische Zeitschrift, 15, 526 (1914).

After quoting freely from Langmuir's specification, he says:

> It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. An evacuated tube having therein an incandescent electron-emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube, were also well known and available to persons skilled in the art.
>
> * * * * * * * *
>
> The suggestion that the alleged invention represents a mere difference in degree over the prior art loses its force in the presence of the results accomplished (Edison *v.* U. S. Co., 52 F. R. 300, 308; General Electric Co. *v.* Nitro Tungsten Lamp Co., 282 O. G., 195), and the allegation of no invention is overcome by the presumption of invention in the transformation of laboratory experiments, and erratic and unstable devices into reliable, stable and successful commercial products (Marconi *v.* De Forest, 243 F. R. 560).

It will be seen then that the present invention lies not in discovering or producing something new, but in perceiving the practicability of scientific facts known in the laboratory and in making practical useful devices embodying the scientific laws known in the laboratory.

I am struck throughout the record with the care, caution and integrity of the parties and the witnesses. The effort seems to be constantly present to be scrupulously accurate and truthful. The benefits of this are largely lost by the fact that much of the record is made up of sworn statements followed by very little cross examination, some of which is by similar statements made not in the presence of opposing counsel.

Arnold claims conception of the invention "on or about Nov. 1, 1912."

Langmuir's original preliminary statement alleged conception of the invention "all during the month of November, 1912," but when the office objected to that he filed a new statement alleging: "the first device embodying the invention set forth in the issue of the interference was conceived * * * between the middle of the month of July, 1912, and the first day of September, 1912." We will see that his attorneys claim for him conception of the invention in August, 1912, but he meant what he said—not conception of the invention but conception (unperceived) of a structure embodying the invention, but for which he perceived no practical use.

As early as 1884, Thomas A. Edison discovered that in an evacuated incandescent lamp the current did not all go through the filament, but a portion leaked by jumping through the vacuum from one leg of the filament to the other leg. This was referred to as "Edison Current" and now is known as electronic discharge. In 1912, Langmuir was a recognized authority on incandescent lamps and was working in his laboratory on various tungsten lamp problems. In July, 1912, he asked an assistant Sweetser, to do certain experimenting for him. It was known that Edison Current tended to improve the vacuum in a lamp by cleaning up the remaining traces of gas. Of his work between July 20 and September 13, 1912, Sweetser says:

> * * * the primary interest in this experiment was the "clean up." The electron current was observed according to the general purpose of the experiment to determine its effect on the "clean up." As nearly as I can make out from the records, the purpose of the experiment is not to include a study of Edison current except as connected with the "clean up." (Langmuir Record on Motion, p. 734.)

During these operations some peculiar characteristics of the Edison Current were observed and it is alleged by Langmuir's attorney that this was a reduction to practice of the invention, and the examiners-in-chief say it was a conception of the invention. It does not appear that what was done then was of any practical effect in the manufacture of incandescent lamps. The most that Langmuir can say in 1919 is:

> (7) During August, 1912, we made experiments with lower gas pressures, using in many cases initial pressures of about 5 microns of nitrogen, and usually employing 200 to 250 volts on the anode. Under these conditions the residual nitrogen gradually disappeared, and in those cases in which the cathode temperature was rather high, the final pressure obtained was of the order of [illegible]3 microns. Before this lowest pressure was obtained the character of the discharge changed completely, and from the results recorded, and by comparison with experiments subsequently made (November and December, 1912), I can now recognize clearly that with this new type of discharge we actually had a device in which the current was limited by space charge, substantially independently of positive ionisation, at voltages as high as 250 volts. (Langmuir Record on Motion, p. 546.)

But the law examiner held the space charge effect to have been recognized in the prior art. So that by these experiments Langmuir was doing nothing new and adding nothing to the sum of human knowledge. He had neither conceived the invention nor reduced it to practice. It is easy to see why the peculiar words were chosen for use in his preliminary statement.

Langmuir's interest was still paramount in incandescent lamps and he continued looking at Edison Current from that aspect. In November, 1912, he proceeded to experiment with other lamps "exhausted in the regular way that tungsten lamps were exhausted." These lamps had a long filament with four separate leads dividing it into three loops. Sufficient current was applied to the middle loop to burn it out and experiments were performed with Edison Current between the remaining loops. Very elaborate notes are introduced with reference to all these experiments, but there is doubt as to why the middle filament was burnt out. The notes say to separate the other two; the testimony says for that purpose and also to effect "clean up" in the bulb. Probably the latter is true, as such a clean up was not new. Work with this bulb surprised Langmuir by showing some of the effects of pure electronic discharge. He testifies his purpose was "to get an understanding of the fundamental laws involved, and thus *settle once for all whether or not* pure electron currents could be obtained in a practically perfect vacuum." This statement shows clearly that Langmuir had not made the invention before he started the November experiments. There is controversy as to what these experiments proved, but it seems clear that they produced nothing practical. Langmuir was still involved mentally with tungsten illuminating lamps and his report was to a group at the General Electric Laboratory which held weekly "conferences on matters relating to lamps" known as the Lamp Vacuum Committee. The minutes under date of November 21, 1912, show that Langmuir reported his results and then did not insist on a high vacuum, but thought his effect was produced by gas present. "A plausible hypothesis to account for some of these effects is that a small amount of some gas such as argon always remains in the lamp." He makes no suggestion of practical use of what he has discovered. He is merely an experimental scientist traveling the road the prior art considered by the law examiner had already traveled—of course unknown to Langmuir. He says that "after November, 1912, steps were immediately taken to develop applications of this pure electron discharge" (Langmuir Priority Record, p. 120), but the first date I find in the record is December 10, 1912, when Langmuir writes in his notebook what to him indicates that he has suggested to Coolidge that his experiments might have a practical bearing on X-ray tubes. The lower tribunals have rightly refused Langmuir any benefit of the work of Coolidge, because Coolidge was not called to testify. But even if benefit be given, the first date of thought of practical use is December 10, 1912, and Langmuir can have no date of conception prior to this, since the law examiner has held that the invention lies not in laboratory experiments such as Langmuir had performed, but in commercial products. It was even later than this that he learned of De Forests's work with the audion. We need not go further with Langmuir's activities.

On October 30 and 31, 1912, De Forest brought one of his audions to the Western Electric Company and suggested its use as a telephone repeater. It was installed on an experimental telephone line and operated feebly for low sounds which produced small currents.

Prior to this time, Dr. Arnold had been employed by the Western Electric Company to work on telephone repeaters. He was recently from college where he had specialized in the physics relating to electric arcs between metal electrodes at various gas pressures. He had subsequently done graduate work along the same lines and as a part of this work had examined all available prior art literature. His entire life work was along the lines of electronic discharges. The De Forest audion was a device of this character and when the Western Electric people saw that it was not sufficiently useful for their purposes, they called in Arnold and on November 1, 1912, showed him the device in the experimental telephone line. Arnold testifies on pages 12 *et seq.* of Arnold's Priority Record, that on November 1, 1912, he explained that if the De Forest audion were further evacuated so that there would be in it only a pure electronic discharge not interfered with by ionization of the residual gas, the device would answer the purposes of the Western Electric Co. as a telephone repeater. This is confirmed by Colpitts and the other witnesses, they having been sufficiently informed of scientific facts to understand Arnold's suggestion. Arnold was thus able to make a practical or commercial application of the prior art laboratory knowledge. I agree with the examiners-in-chief where they say:

> According to this testimony, Arnold had a conception of a thermionic tube so thoroughly evacuated that it would have a pure electron discharge; and if it clearly appears that he knew how to produce such a tube, we would consider him entitled to November 1, 1912, for conception of the invention in issue.

Further, I am satisfied that Arnold knew how to produce such a tube. The law examiner says of the prior art "methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube, were also known and available to persons skilled in the art." Arnold had worked in this specific art for years and it seems unreasonable to believe he did not know how to produce the vacuum. The testimony is that he did. We have seen that Langmuir relies on the four lead tubes as a reduction and they were "exhausted in the regular way that tungsten lamps were exhausted," which seems to indicate that a novel exhaust was not necessary.

Langmuir in his brief here says:

> The important thing is to get a proper preparation of the tube and its parts; the method by which this is done is not important so far as the issues of this interference are concerned, so long as the result is achieved.

The Langmuir specification describes the device as prepared by evacuation, heat treatment of the glass tube, and heat treatment of the electrodes to eliminate occluded gases. (See also White's Answer to Q. 16, Langmuir Record on Motion, p. 601.) Arnold had developed an "arc repeater" filled with mercury vapor and had found that other vapors interfered with the work. He had therefore had to resort to heating the glass tube and heating the electrodes to eliminate gases other than mercury. At his University laboratory he had been familiar with means for producing high vacua, but the laboratory of the Western Electric Co. had not such means. He looked about and could not find what he wanted in New York and finally ordered by cable from Germany the very vacuum pump recommended in Langmuir's specification. When it arrived he produced tubes which operated practically and the subsequent commercial operations of his company are admittedly reductions to practice. By means of Arnold's devices the first telephone message from New York to San Francisco was sent and the first trans-Atlantic wireless telephone operated.

After Arnold's disclosure on November 1, 1912, any one skilled, as he was, in the art could have produced the device of the issue. If I say a rubber button is a good thing to use in a hose supporter, I have conceived the button, even if I do not know how to make such a button. I may go to a rubber manufacturer and have him reduce my invention to practice and it will be my invention. So here, one skilled in the art could produce the device in issue as soon as told to do so by Arnold.

> He who first conceives and gives expression to the idea of an invention in such clear and intelligent manner that a person skilled in the business could construct the thing, is entitled to a patent, provided he uses reasonable diligence in perfecting it. (McCormick Harvesting Machine Co. *v.* Minneapolis Harvester Works, 42 Fed. Rep., 152, 155.)

Here, the law examiner has held that the prior art taught him to get the required vacuum.

Before the pump arrived Arnold studied the characteristics of De Forest's audions at voltages below those of the issue and he found that one of these had a particularly effective high vacuum and it was successfully operated at voltages which are within the issue, but it is not necessary to hold it a reduction to practice as, in view of all the circumstances, the activities leading up to commercial use are sufficient to negative any lack of diligence on the part of Arnold.

Langmuir objects because Arnold did not proceed at once to use makeshifts to produce the proper vacuum in many bulbs, but I think he was justified in awaiting the arrival of the pump from Germany, especially since he studied the characteristics of what he had and started his associates preparing themselves for the work and did proceed soon after the arrival of the pump.

Adverse comment is made on Arnold's study of the De Forest audion after he says he made the present invention, but that is just what Langmuir had White do in February, 1913 (Langmuir Record on Motion, p. 599, Q. 14).

The condition of the negotiations for patent licenses from Cooper Hewitt and from De Forest sufficiently account for the activities with the "arc repeater".

I have carefully examined the records and tried to weigh every point raised by the arguments or elaborate briefs, but it is impossible to state in an opinion every consideration going to fix a conclusion in the mind.

What I have said shows that Arnold was first to conceive and proceeded diligently to reduce the invention of all the counts, including 12 and 13, which call for a third electrode which Langmuir did not deal with until 1913.

The examiners-in-chief are reversed and priority awarded to Arnold.

Karl Fenning,
Assistant Commissioner.

October 27, 1923.

FILE COPY

FILED
JAN 30 19
CHARLES ELMORE CR
CL

IN THE

SUPREME COURT OF THE UNITED STATES

October Term, 1930

No. 630

DeFOREST RADIO COMPANY
Petitioner
v.
GENERAL ELECTRIC COMPANY
Respondent

OPINIONS

OF THE UNITED STATES CIRCUIT COURT OF APPEALS, THIRD CIRCUIT, OCTOBER 3, 1929, AND NOVEMBER 11, 1930,

AND

OF THE COURT OF APPEALS OF THE DISTRICT OF COLUMBIA IN ARNOLD *v.* LANGMUIR

APPEAL PRINTING CO., 23 THAMES ST., NEW YORK CITY

INDEX

PAGE

The Memorandum Decision of the U. S. C. C. A., 3rd Circuit, October 3, 1929 1

Opinion of that Court, November 11, 1930 2

Opinion of Court of Appeals, D. C., in Interference, Arnold *v.* Langmuir 19

IN THE

United States Circuit Court of Appeals

For the Third Circuit.

General Electric Company, *Appellant,* *v.* The DeForest Radio Company, *Appellee.*	No. 3799. March Term, 1928.

Appeal from the District Court of the United States for the District of Delaware.

(Filed October 3, 1929.)

Before Buffington, Woolley and Davis, *Circuit Judges.*

Per Curiam.

The issues raised on these appeals were fully discussed in the opinion of the learned district judge and we agree with his conclusions. The decrees are, accordingly, affirmed on his opinion.

Buffington, *Circuit Judge*, dissents.

IN THE

UNITED STATES CIRCUIT COURT OF APPEALS,

FOR THE THIRD CIRCUIT.

GENERAL ELECTRIC COMPANY,
Appellant,
v.
THE DEFOREST RADIO COMPANY,
Appellee.

No. 3799.
March Term,
1928.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES FOR THE DISTRICT OF DELAWARE.

Opinion of the Court.

(Filed November 11, 1930.)

Before BUFFINGTON, WOOLLEY and DAVIS, *Circuit Judges.*

BUFFINGTON, *J.*

In the Court below the General Electric Company charged the DeForest Radio Company with the infringement of four patents. On final hearing that Court held one of the patents valid and infringed and the other three invalid. By appropriate steps its so holding was brought before this Court for review. Without entering into detail, we may say that, save as to patent No. 1,558,436, the reasoning, conclusion and decree of the

Court below commend themselves to us and we affirm the same. In the case of patent No. 1,558,436, we feel the Court below committed error in holding the patent invalid and dismissing the bill.

As usual in litigation over a patent of great commercial value, the vast mass of expert speculation, the protracted argument covering days and with briefs that in the aggregate covered several hundred pages, the case, on re-argument, narrowed to the simple question of the patent paternity of what is known commercially as the Langmuir tube. The Court below held the tube had no patent paternity and to that question we now address ourselves. The subject-matter of the patent and the general features of the pertinent art are set forth at length in the comprehensive opinion of the Judge below and by reference thereto we avoid the necessity of present restatement.

Laying aside for the present technical language and scientific discussion and confining ourselves to simple statement, the Langmuir tube is a tube in which for example the gaseous conductor incident to a Fleming valve and a DeForest audion is dispensed with and a vacuum substituted therefor.

In the patent sued on, No. 1,558,436, granted October 20, 1925, to Irving Langmuir, assignor to the General Electric Company for "electrical discharge apparatus and process of preparing and using the same," the specification states:

> "The present invention relates to electrical *vacuum* discharge devices, and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of *gaseous ionization* such as occurring, for example, in the ordinary Roentgen tube.

> "My present invention comprises improvements in electron-discharge apparatus which make possible a *high load capacity* and operation with the *highest voltages*, but the invention is also applicable and useful for moderate loads and moderate voltages."

Existing objectionable incidents to the use of gassy tubes and the erratic, non-determinable action of gas are pointed out as follows:

> "In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a *pure electron* discharge as distinguished from a discharge through *ionized gas.* In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon *gas ionization.* Without a certain *minimum amount of gas* a Roentgen X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.
>
> "The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the *vacuous space.* If these electrons when moving above a certain velocity collide with *gas molecules* they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of the electrons and the ions; these phenomena are in general *erratic and non-reproducible.* The cathode under these conditions is disintegrated, technically it is 'sputtered', which causes its rapid destruction. As *gas ionization* continues at higher voltages a *blue glow* may appear. The bombardment of the cathode by positive ions also

causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. *These voltages are different for different gases.* In the case of gases such as nitrogen, hydrogen, oxygen, argon, helium and neon, they are of the order of magnitude of fifteen to twenty-five volts."

Describing the DeForest audion and differentiating it from the alleged invention of the patent, the specification says:

> "The phenomena above described as being characteristic of devices involving *gas ionization* are taken advantage of in an incandescent cathode device with three electrodes known as the 'Audion.' This device has been used as a receiver for radiotelegraphy and depends in its operation upon the rapid change of the discharge current when *gas ionization begins.* This point depends upon various *accidental* conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts."

Describing the Fleming valve and its limitations, the specification states:

> "Another discharge device previously used to some extent was the *Fleming valve.* This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the voltages at which positive ionization by collision occurs. It was not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects."

Referring to high voltage, the specification makes this statement:

> "No prior hot cathode devices are known to me operating with currents as great as above 5 milliamperes with voltages as high as about 200 volts; indeed no prior discharge devices are known to me operating in a practically usable manner and without substantial positive ionization effects with currents as great as about one-tenth of a milliampere with voltages as high as about forty volts."

Specifying some of the differences and advantages of the alleged invention, the specification states:

> "In devices made in accordance with my invention *gas ionization* is either entirely *absent* or is negligible and a discharge takes place which is *distinct* in its characteristics from the described discharge taking place in an *ionized gas*. The cathode is not heated by the discharge itself. Blue glow, glass fluorescence and in fact all readily visible indications of a discharge are ordinarily absent."

Referring to the evacuation of the tube, the specification sets forth:

> "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes *vapors as well as gases* * * *
>
> "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. * * *

> "It is also true that when the anode has been carefully freed from gas, residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated."

Claim 12, which is,

> "An electrical discharge device, comprising a gas-tight-envelope, an electronemitting cathode, an anode *deprived of ionizable gas* and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that when operated below saturation and materially above the ionization voltages, the current is controlled by *space charge* substantially unaffected by positive ionization."

is typical in character of the alleged invention.

Does the defendant use a tube answering this general description? We think it does and that in giving up the old gaseous tube and using one of the "very high vacuum," a change which it announced in its statements to the public, we have a virtual admission of the essential difference between the two tubes. The tube of this disclosure is aptly described as "non gaseous" and "of a very high vacuum" by the defendant when putting it on the market, as follows:

> "The tube consists of a highly evacuated vessel, cylindrical, rather than bulbular, in shape enclosing the three elements, grid, plate and filament in the form of the old type T tubular DeForest tube with which amateurs are familiar. The plate is of nickel, cylindrical in shape and surrounds a helical grid also of nickel. The filament is a crimped tungsten wire passing through the center of the

> grid exactly as it did in the old style type DeForest tube. The chief difference between this tube and the type T tube of similar mechanical construction is in its evacuation. The old style type T was an *ionic or gaseous tube* very unstable in operation and requiring a variable 'B' battery. It had the decided disadvantage that after continued use the tube would get 'hard' and require more 'B' battery until it reached such a state as to be inoperative. The new 'VT' tube, like the DeForest standard tubes to-day, is purely an electronic tube exhausted to a *very high vacuum*, so that it is non-gaseous and will stand very high plate potentials. When used as a detector, however, a battery of 20 to 40 volts is sufficient to give the proper plate current although voltages of 80 to 100 may be used without detrimental effect upon the tube. The 'B' battery moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work. * * * The gaseous type tubes are, however, no longer being manufactured."

Turning next to the question on which the validity of the patent depends, we inquire first as to its usefulness, for the constitutional power to create the monopoly of a patent in that regard conditioned "to promote the progress of * * * useful arts" and the Congressional enactment in pursuance of the Constitution is that "any person who has * * * discovered any new and useful" etc. For in the final analysis, use, usefulness, is the acid test, the SINE QUA NON of patent grant.

The unusual degree of usefulness of the tube may be assumed. The defendant by its use evidences its usefulness and has, we have seen, adopted it and ceased making "gaseous type tubes," and the Court below, after its exhaustive study of the art, aptly described the tube, and we agree with its estimate, as an agency which "because of its stability, reproducibility and power has made possible radio broadcasting, modern radio reception and long distance telephony."

Seeing then we are here dealing with a progressive step which next to the telegraph, the telephone and the wireless, is probably one of the most far reaching and beneficent in human progress, there can be no question of a non-gaseous, vacuum tube's usefulness. Such being the case, is it novel? The simple fact is that we see such a tube in universal use to-day; we know in the quoted language of the Court below of its "stability"; of its "reproducibility"; of its "power." We know that these elements have, as stated by the Court below, made "possible radio broadcasting, modern radio reception and long distance telephony." Indeed the fact that a non-gaseous vacuum tube makes possible the present improved practice shows that such practice did not exist before the Langmuir tube and that no other device or devices, all important as they may have been in their spheres, did either singly or collectively produce the present practice. The patent office recognized that. In the opinion of The Board of Examiners they found, in affirming the decision of the Examiner of Interferences, that "Langmuir was the first to conceive and the first to reduce."

While all the vast mass of knowledge testified to in these records was open to everyone to use, the simple fact remains that the non-gaseous tube of modern use did not occur to scientists. Every one of the two hundred and sixty-six words in Lincoln's Gettysburg Speech is found in the dictionary; most of them in the Bible. But it remained—not for Noah Webster or even the Prophets of old—but for Abraham Lincoln to take these isolated words and so use them conjointly as to produce the most remarkable combination in literature.

We do not disregard or minimize the all important part of DeForest's audion and Fleming's valve play in the utilization of them in the Langmuir tube, but in spite of such high value, neither of them, in isolation or conjoint use, gave the world the tube here in question and it remained for Langmuir to so couple and coordinate the two by means of eliminating gas and using vacuum as to produce the tube here involved. What scientific credit is due to DeForest or Langmuir or to what patent tribute Langmuir subjected himself in thus using their devices are questions not before us.

Moreover the statement in the Commercial Circular of the DeForest Company that gas was an element of operation, was in accord with the then scientific belief. In 1911 Gernsback, an experienced savant, wrote that in the audion "the operating principle is the shattering of a column of conducting gas by a received electrical impulse."

The function of a gaseous tube as a conductor was stated by the Circuit Court of Appeals of the Second Circuit in 243 Fed. Rep. 565, where Fleming's valve and DeForest's audion were considered, in these words: "The 'gaseous medium' of the audion is nothing but the commercial vacuum of the ordinary electric light bulb—air being a gas, and the bulb containing some residual air. In other words, defendant uses the same 'vacuous vessel' that Fleming does." And in its opinion it stated that it was asserted in that case that the audion was "an apparatus in which the bulb contains a substantial amount of gaseous medium essential to the operation of the device." To the same effect is the testimony of Langmuir, of which we find no contradiction, that

> "In the devices of the old art, in the DeForest audion, the pressure was continually changing. It

> sometimes increased and it sometimes decreased. Both things went on and there was an evolution of gas, water vapor would come off the bulb and be decomposed by the filament and it would generate gas. Gases would come out of the electrodes. Positive ions would bombard the walls and the electrodes and would drive gas off."

It will also be noted this Court in its able and exhaustive statement of the art in 21 Fed. (2) 918, said: "We observe that at the time of both the DeForest and the Armstrong inventions the only audion tubes in use were 'gassy' or 'soft'."

That its action was eccentric, is shown by DeForest's statement:

> "In the first place, anyone who has had considerable experience with numerous audion bulbs must admit that the behavior of different bulbs varies in many particulars, and to an astonishing degree. The wing potential wing current curves for different bulbs, or even for the same bulb at different times, under different conditions (filament temperature, etc.) vary widely.
>
> "What may appear to be a fixed law for one bulb may not hold for another."

On the other hand, the current in Langmuir is practicable, steady, reproducible at any particular voltage.

It further appears that the Langmuir tube has a great advantage when it comes to replacement. When a tube is defective, another of the same type can be bought and placed in the same socket. Not so with the audion. It required frequent replacement and where replacements were made it was necessary to readjust throughout the circuit. In that respect the proof is:

> "XQ35. What practical effect would harmful ionization have upon an audion amplifier such as, for example, as is used in the telephone line?
>
> "A. The worst immediate effect would be as to uniformity of operation, which would make continued adjustments necessary and would interfere with the replacement of one device by another, that is to say, when one tube burned out and another were put in an amount of ionization that would interfere with uniformity of operation would make it necessary to readjust throughout the circuit to take care of the substitute tube."

As to the replacement, the proof is that

> "Another consequence of this uniformity is that replacement of the tubes without changing the apparatus becomes possible. That is particularly important in telephone repeaters and in radio devices both of the receiving and transmitting type. One wants to know that he can replace a burned-out tube with a new tube without having to make substantial changes in the apparatus."

It will also be noted that the whole trend of the art was against the use of a vacuum, and even after Langmuir had shown its use, it was deemed impractical. Thus in a paper of 1914 Wehnelt and Leibreich said that ionization persisted in the best vacuum they could get.

Moreover, it is of great present significance that the then view of DeForest himself was against Langmuir's use of the vacuum, he then stating in a paper read by him before a scientific body: "I believe, however, Dr. Langmuir has, by working into these high vacua and the high potentials necessitated thereby, pursued the less promising of the two paths of research." The record shows no explanation, comment or retraction by him of this statement.

Such being the general state of the case, has the defendant by evidence overcome the prima facies of the patent? We think not. As said by this Court in 159 Fed. Rep. 948, citing the Barbed Wire Case, "the burden of proof upon this part of the case rests upon the defendant, and every reasonable doubt should be resolved against it." And in our view the crux of the case is one of fact, namely, whether the use of a vacuum in the combination of the claim was Langmuir's novel disclosure. We are not concerned with scientific theories and speculations as to what might have been done or what could possibly have been done for, as well said by the Circuit Court of Appeals of the Second Circuit in 298 Fed. Rep. 582, we sit "not as scientists, but as weighers of evidence." But we are concerned with the fact whether the combination of the claim which Langmuir disclosed was new. That some had bombarded anodes of X-ray tubes to get some of the gas out of them; that others had heated bulbs or used pumps to lessen the gas, may all be true, but none of them had produced the commercial tube which Langmuir gave to the public. And such actual contribution in use and not theory and possibility of speculation is, and of right should be, the decisive factor in patent reward. As was said by the Circuit Court of Appeals of the Second Circuit:

> "The keynote of all the decisions is the exent of the benefit conferred upon mankind. Where the court has determined that this benefit is valuable and extensive it will, we think, be difficult to find a well considered case where the patent has been overthrown on the ground of non-patentability."

We regard as of high evidential significance the statements made by the defendant in its circular to the public, already quoted. It will not do to brush aside and ignore it on the suggestion it was the work of some enthusiastic subordinate or sales agent. It was a deliberate statement of a great mechanical company of its ceasing to make and market a superseded article and to thereafter make and market a new and different one. No such change would in business practice be made by subordinates, but was, in the nature of things, the mechanical, scientific and commercial determination of a great business organization. In this statement the defendant recognized a "non-gaseous," highly vacuum tube as new. As we have seen, it differentiated it from its "gaseous" tubes up to then made and publicly announced that such gaseous type tubes would no longer be manufactured. And indeed, that no such non-gaseous, highly vacuum tube existed is shown by the fact that the testimony of experts and the laborious research by the Judge below, whose industry is proverbial, did not disclose any such tube as both parties to this litigation now make and contend for the right to make, existed or had advanced the arts in question to this new standard of theretofore non-attained efficiency.

Such being the case, the defendant is driven to take the position—which found favor with the Court below—that in view of what existed in the prior art, that it required no invention to so utilize these things in the prior art to produce a non-gaseous, highly vacuum tube, and that this great progressive step was due simply to the art's natural advance and improvement.

But in point of fact no such advance toward a non-gaseous tube, as we are now told was to be looked for in the art, was actually made by the art. We would not be misunderstood. Advance, inventive and non-inventive, was being made in the art, but their efforts were in other directions. We would not detract from the great advance made by DeForest and exemplified by his audion and by Fleming with his valve, but great as these steps were—both separately and collectively—and we regard them as the foremost in the advance of the art in the sphere here involved—the gaseous tubes still continued to be used and the art generally regarded gas as incident, if not, indeed, indispensable to their use.

Indeed, had the art followed the caution of DeForest heretofore quoted, we would have no vacuum tube, a situation akin to that referred to by this Court in the Turbine case, 202 Fed. Rep. 932, where we said:

> "Finding, then, as we do, that the disclosures of the Moorehouse patent had no helpful bearing or practical effect on the impulse turbine art, and supported in that conclusion by the fact that its vagueness is such that fair-minded witnesses in this record greatly differ as to what its disclosures really are, we are not warranted in attributing to it any effect in the way of vitiating, or even minimizing, the work of Curtis."

Now as it seems to us, the art, although it did not exactly know how the gas in gaseous tubes acted and just why it was able to so conduct, nevertheless continued to use it and regarded it as the indispensable means of conducting. As against this firmly entrenched teaching and practice of the art, Langmuir's suggestion of eliminating gas as a conductor was a radical change and even more so was not the substitution of some other tangible conductor, but the disclosure of supplanting the tangible gaseous conductor by the intangible conductor of a vacuum. Vacuums, per se, were of course known. DeForest's audion and Fleming's valve were equally known, but the suggestion of dispensing with gas and utilizing a vacuum between the two was as novel in practice as it was unlooked for in result. Indeed, shortly before the patent in suit was applied for and even though the use of a vacuum may possibly have been suggested, the director of the Research Laboratory stated in a paper read before the American Institute of Engineers: "In connection with this work of Fleming's, we have studied the effect of vacuum on the current, and also found that the presence of gas is necessary for this negative discharge." And that Langmuir's use of high vacua did not appeal to so practical and eminent a scientist as DeForest was evidenced by his statement, heretofore quoted, made even after Langmuir had made known his process publicly,—"I believe, however, that Dr. Langmuir has, by working into these extremely high vacua and the high potentials necessitated thereby, pursued the less promising of two paths of research." For the defendant to now contend that the use of these extremely high vacua by Langmuir was simply the natural and to be expected growth of the art is to credit the ordinary art with a scientific capacity which a master of the art like DeForest did not himself possess. If it was an obvious thing, as the Court below believed and decided, for the ordinary art to do away with gas and gaseous tubes and substitute high vacua therefor, surely such an extraordinary mind in that art as DeForest, when confronted with the substitution, would not have pronounced high vacua a mistaken path. Had the ordinary art followed the advice of this super ordinary adviser and leader and discarded the suggestion of high vacua, it would seem so far as the universally used non-gaseous tube is concerned, it would not be in use today.

But it is contended by the defendant and the Court below so held, that all that Langmuir did was simply to vary in degree the prior use of the vacuum and that a mere difference in degree does not constitute invention or, to use the defendant's contention, the Langmuir tube is "nothing more or less than the identical thing of the prior art with possibly a little higher vacuum, depending on the specific use to which the device is to be put." Assuming the correctness of this general proposition, we think it is not applicable to the present case. In considering change in degree, the test is not the quantum or minimum of change made but the quantum of change in function and result which such change, great or small, effects. A great change may effect but a slight change in function and result, while a slight change may effect a radical difference in function and effect. The effect, the practical progress and use in the arts, are the aim and end of patent grants and where great results follow a change, the slightness of the change tends to emphasize and make all the more remarkable, unexpected and inventive the disproportionate result the slight change effects. It was the slight turn of a screw and the closer proximity of the diaphram that made the telephone diaphram the carrier of speech and gave Bell the due reward—not for the slight turn of the screw but for the great effect it wrought. But a vacuum, or indeed change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so co-ordinate and interwork that current flow is not affected by gas. We say not affected by gas because of necessity an absolute vacuum is an impossibility, but the degree of vacuum is such the current flow is no longer objectionably affected by gas. Just what the degree of vacuum shall be is dependent on several elements and, as stated in the patent, cannot be exactly stated. In that regard the specification says: "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned."

So regarding what we believe to be the basic question in the case, we limit ourselves to the foregoing statement of our reasons for our conclusion. But in thus limiting our discussion, we deem it proper to say that the numerous questions and considerations advanced in the case in other particulars, have been duly considered.

The degree of the Court below holding this patent invalid is reversed and the record remitted with instructions to enter a decree that the patent is valid and infringed.

IN THE

COURT OF APPEALS

OF THE DISTRICT OF COLUMBIA.

IRVING LANGMUIR, *Appellant*, *v.* HAROLD D. ARNOLD.	No. 1680. Patent Appeal.

Opinion of the Court.

(Filed June 1, 1925)

(6 Fed. [2nd] 704)

(Before MARTIN, Chief Justice, and ROBB and VAN ORSDEL, Associate Justices)

Appeal from a decision of an Assistant Commissioner of Patents in an interference proceeding awarding priority to the junior party, Arnold, and reversing concurrent decisions of the Examiner of Interferences and the Board of Examiners-in-Chief.

The invention is a thermionic tube adapted to be used as a relay in long distance telephone systems, as a detector or amplifier in wireless systems, or as a rectifier of alternating currents. The issue is expressed in thirteen counts, of which the 1st, 7th and 13th, here reproduced, will serve as examples:

> "1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

"7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltage, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous."

"13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner."

The attitude of the junior party, appellee here, when this interference was declared, is significant. He filed a motion challenging the patentability of the issue and sought and obtained permission to take evidence in support of that motion. The result was the taking of voluminous testimony by the parties on this issue, which by stipulation is in the record here. The Law Examiner, to whom this question was initially referred, sustained the patentability of the issue and his decision is controlling here. We therefore start our inquiry in this appeal with the established fact that, so far as this proceeding is concerned, the issue is patentable; in other words, that something more than mere mechanical skill was involved in the result achieved.

The examiner of Interferences, in an exhaustive opinion, awarded priority to the senior party, Langmuir. The Board, on appeal, directed attention to the fact that, structually considered, the tubes of both parties outwardly are substantially identical with the Fleming valve and the DeForest audion of the prior art; that the invention has been referred to as a "thing compact of glass and metal". The Board then pointed out that this definition, although correct as far as it goes, is inadequate because it applies equally well to the prior art devices, and that to this definition should be added the qualification that the device "operates with a *pure* electronic discharge above the voltage of positive ionization and below saturation", and proceeded: "But how is one to know whether the discharge is purely electronic? In other words, how is one to know whether a tube embodies merely the prior art devices or the invention of the issue? * * * For example, count 1 specifies that the envelope of the tube is evacuated to such a degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts. Thus the count distinguishes from the prior art, not by features of structure, but by a characteristic which is manifest while the device is operating at or above a certain voltage."

Later in its decision the Board suggested that the question to be determined was, who of the parties "first knowingly and understandingly conceived and produced such a tube"; that Arnold, the junior party, did not claim to have conceived the invention prior to November 1, 1912, or to have reduced it to practice prior to the 29th of that month; that Langmuir, on the other hand, alleged conception, disclosure, sketches, written description and successful operation prior to September 1, 1912, followed in November of that year by the successful operation of other devices embodying the invention. The Board then carefully reviewed the testimony in support of Langmuir's contentions and found that he had conceived the invention of counts 1 to 11, inclusive, as early as September 1, 1912, and had reduced the same to practice by November 19th of the same year; that, as to counts 12 and 13, Langmuir had conceived prior to April 8, 1913, and had reduced to practice by April 15th of that year; that Arnold conceived and reduced to practice the invention of all of the counts except counts 1 and 11 on April 25, 1913, and that counts 1 and 11 were not reduced to practice until after Langmuir's filing date.

The attitude of the Assistant Commissioner toward the case was that of the junior party upon the declaration of the interference, namely, that the patentability of the issue was doubtful. He says: "The line between the prior art and the issue is attenuated and if there is patentability, it must be as set out in the decision of the Law Examiner on the motion, and I do not understand either party to attack that decision here. Arnold alleges that when he made the invention, he thought he was following the prior art and not producing something patentable, and an undercurrent of that attitude seems to tinge his whole case. This is why he filed so late." Proceeding from that prostulate, the Assistant Commissioner has accepted as controlling on the question of conception and reduction to practice, on behalf of Arnold, testimony of a vague and general character and which failed to satisfy the lower tribunals, as it also has failed to satisfy us. The decisions of those tribunals are so clear and satisfying that we are content to rest our opinion upon the reasoning there given.

It results that the decision is reversed and priority awarded Langmuir.

Reversed.

Chas. H. Robb,
Associate Justice.

FILE COPY

Office Supreme Court,
FILED
APR 29 193
CHARLES ELMORE CR
CLE

IN THE

Supreme Court of the United States

No. 630 October Term, 1930

DEFOREST RADIO COMPANY
Petitioner

v.

GENERAL ELECTRIC COMPANY
Respondent

ON WRIT OF CERTIORARI TO THE U. S. CIRCUIT COURT OF APPEALS
FOR THE THIRD CIRCUIT

OPINIONS

Of the Patent Office Tribunals and the Court of Appeals, D. C., in the Arnold-Langmuir Interference and of the Courts Below in This Suit

APPEAL PRINTING CO., 30 THAMES ST., NEW YORK CITY

INDEX

IN THE INTERFERENCE ARNOLD *v.* LANGMUIR.

PAGE

Opinion of Law Examiner 1

Opinion of Interference Examiner 18

Opinion of Examiners-in-Chief 48

Opinion of Assistant Commissioner 72

Opinion of Court of Appeals, D. C. 91

IN THE SUIT OF GENERAL ELECTRIC CO. *v.* DEFOREST RADIO CO.

Opinion of Judge Morris, District Court 96

Memorandum of United States Circuit Court of Appeals 125

Opinion of United States Circuit Court of Appeals on Rehearing 126

Dissenting Opinion of Judge Woolley 143

Opinion of the Law Examiner.

February 21, 1921.

(Interference Record p. 2462.)

IN THE UNITED STATES PATENT OFFICE.

Patent Interference No. 40,380.

ARNOLD

v.

LANGMUIR.

Motion to Dissolve. Motion to Amend.

Electric Discharge Apparatus and the Process of Preparing the Same.

Application of Harold de Forest Arnold filed Nov. 2, 1915, No. 59,210.

Application of Irving Langmuir filed March 14, 1916, No. 84,242, renewal of application filed October 16, 1913.

Messrs. DE WITT C. TANNER and JOHN G. ROBERTS and MR. GEORGE E. FOLK for Arnold.

MR. ALBERT G. DAVIS for Langmuir.

The party Arnold moves to dissolve on three grounds which are as follows:

1. That there has been such informality in declaring the interference as will preclude the proper determination of the question of priority of invention.

2. That the party Langmuir has no right to make the claims constituting counts 1, 2, 3 and 7 of the issue of the interference, and hence that the claims are not patentable to him, even if they involve patentable subject matter.

3. That the claims constituting the counts are not patentable to either party.

The first ground will be treated as stating that neither party can make the claims. A supplemental motion to dissolve by Arnold includes additional references which are as follows:

Article by Fleming in Scientific American Sup., Jan. 20, 1906, p. 25,129;

Article by Dininger in the Annalen der Physik, IV, Vol. XXV, p. 288 (1908);

Article by Von Baeyer, Physicalische Zeitschrift for 1909, p. 168;

Article by Gehrts, Annalen der Physik 39, p. 995 (1911);

Article by Child in the Physical Review, Vol. 32, p. 448 (1911);

Articles by Lilienfeld, Annalen der Physik 32, p. 673 (1910); Physikalische Zeitschrift 9, p. 193 (1908);

J. J. Thomson's Conduction of Electricity Through Gases, pp. 222 to 227;

Shottky, Jahrbuch der Radio Activitat, Vol. 12, p. 147 (1915);

Shottky in Physikalische Zeitschrift, 15, 526, (1914).

The procedure in the present contest is exceptional in that a petition for leave to take testimony on the motion to dissolve was granted by the Commissioner on Feb. 23, 1917.

Langmuir moved on Jan. 29, 1917, to amend the issue to include claims 24 to 28 as counts, and subsequently, on May 19, 1919, moved to amend by including claims 1 to 9, inclusive.

After the hearing Langmuir withdrew counts 1, 2, 3, 4, 6 and 7 and claims 24, 25, 27 and 28, leaving for consideration count 5, claim 26 and claims 1 to 9, inclusive. The motion to dissolve is granted as to counts 1, 2, 3, 4, 6 and 7, and the motions to amend are denied as to claims 24, 25, 27 and 28. Count 5, claim 26, and claims 1 to 9, inclusive, which have been retained, are as follows:

Count 5. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

Claim 26. An electrical device comprising the combination of a sealed evacuated envelope, a cathode adapted to be independently heated, and an anode within said envelope, an external circuit connected to said electrodes, and a source of electro-motive force applied to said circuit, the degree of vacuity and the electron emission of the cathode being so related to the potential of said source that the flow of current over a range of voltage materially above the ionization voltage is governed by the electric field of the electrons in the vacuous space and the potential applied to said electrodes, operatively independent of gas ionization.

Claim 1. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the governing or limiting action on the space current due to the electric field of said electrons is substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

Claim 2. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization.

Claim 3. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

Claim 4. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed upon electrodes of the device and when the electron emission has any values such that the space current is below the saturation region at such voltages, that the slope of the line obtained by plotting the logarithms of values of said current as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae shows no increase for increasing voltage values.

Claim 5. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous.

Claim 6. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the tube and when the electron emission has any value such that the space current is below the saturation region at such voltages, that said current varies as the three halves power of said impressed voltages.

Claim 7. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

Claim 8. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, substantially unaffected by positive ionization, the heating effect in the tube due to said current occurring substantially only at one or more of said electrodes.

Claim 9. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least five milliamperes and with voltages of at least 200 volts.

The character of the invention will appear in the following excerpt from Langmuir's specification:

In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a pure electron discharge as distinguished from a discharge through ionized gas. In a Geissler tube, and in a Roentgen or Cookes tube the conduction of current is accompanied by and depends upon gas ionization. Without a certain minimum amount of gas an ordinary X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.

Scientific research has shown that under certain very carefully controlled conditions with extremely low current values of the order of magnitude of .01 of one milliampere or lower and at low voltages, well below 200 volts, an electrical discharge current may take place in an evacuated space between a heated cathode and a cooperating anode without causing the residual gas to take part in the conduction of current. This effect also takes place in a vacuum when an unheated electrode consisting of certain materials, for example, potassium, is subjected to the influence of light, particularly, to ultraviolet rays. The discharge current is carried by negative charges called electrons, which pass through the vacuous space under the influence of the impressed voltage. In the presence of gas these electrons, when moving with proper velocity, collide with gas molecules and give rise to gas ionization which completely changes the phenomena accompanying the discharge. The gas molecules are split up into electrons and larger and more slowly moving positive ions. * * * As gas ionization continues at higher voltages a blue glow may appear. The cathode under these conditions is electrically disintegrated, technically is "sputtered," which causes its rapid destruction. The bombardment of the cathode by positive ions also causes heating of the cathode.

* * * * * * *

In devices made in accordance with my invention gas ionization is either entirely absent or is negligible and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionized gas.

* * * * * * *

The discharge current passing through a given space with the cathode at a sufficiently high temperature so as to give a sufficient electron emission for a given voltage varies directly with the 3/2 power of the impressed voltages, above a minimum voltage depending on the characteristics of each particular device. In other words, the 3/2 power law holds strictly only above a certain minimum voltage for a given device, usually a few volts. If the electron emission is not sufficient, as, for example, when with the cathode at a given temperature the voltage exceeds the value at which all the electrons emitted are utilized, then a further increase in voltage produces substantially no change in current. The discharge is independent of the vacuum, providing the pressure is below the minimum at which gas ionization by collision will take place. As distinguished from discharges in the presence of positive ionization, the pure electron discharge is characterized by regularity and reproducibility with given conditions.

* * * * * * *

As shown in Fig. [illegible] the various parts of the apparatus may be mounted in a tube, or envelope 1, upon a pedestal

2, similar to the mount used in incandescent lamps. The cathode 3 is centrally located and may consist of a short straight filament not shown in Fig. 1, but indicated by the position of terminals 5, 6, and shown plainly in Fig. 3. The cathode shown in Fig. 2 consists of a V-shaped conductor. Either form may be used, the particular form of cathode being ordinarily determined by convenience of construction. Preferably the cathode conductor is held taut by a spring 7 to avoid contact of the cathode conductor with the grid by sagging when the metal is expanded at a high temperature. The filament 3 is mounted between two oppositely disposed supports 9, 9′, in this case constituting a closed loop, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this framework is wound a discharge-varying conductor 10, ordinarily called a grid. The turns of the wire are closely adjacent to each other and are also very closely adjacent to but are out of contact with the incandescent cathode. By means of this grid 10 potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from cathode to anode in proportion to the degree of its charge.

The supporting framework for the cathode and grid is attached to a rod 11, mounted upon the stem of the tube. Adjacent to the cathode and grid is the anode 12 which in the present case has been indicated as consisting of a wire strung in a zigzag manner over hooks 13 upon fork-shaped supports 14 and 15, but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other refractory metals may be used. By constituting the anode a continuous conductor it can be conveniently heated by passage of current during evacuation of the device and for this purpose is attached to leading-in conductors 16 and 17. The grid is indicated in Fig. 1 as being attached to leading-in conductors 18 and 19 at opposite ends, although but one terminal is ordinarily necessary.

* * * * * * *

For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at elevated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. In fact, the heating may take place in a suitable vacuum furnace, the temperature preferably being raised to 2500° C. or even higher. However, heat alone will not remove all the gas liberated by the electron discharge, but this gas is driven out even at ordinary temperatures by the discharge itself. The discharge appears to affect especially the surface of the metal. Heating is a valuable aid in bringing gases from the interior of the metal body into the sphere of action of the discharge but may be omitted when the devices are not heated during normal operation.

The determination of the question of patentability presented by the motion to dissolve is not rendered easier by the testimony of the eminent physicists appearing in the record, since the discussion has not been kept within the scope of the order permitting the taking of testimony and additional publications not mentioned in the motions to dissolve, have been injected into the record from time to time. Under the Commissioner's order testimony cannot be taken to add to the disclosures of the references, but with respect thereto is to be limited to showing the character and meaning of the terms used therein and how these disclosures would have been understood by those skilled in the art at that time. Evidence given in the light of publication subsequent to the alleged anticipating references is not helpful for the present purpose, but is confusing and tends to mislead in that it does not bring out clearly the meaning of terms as understood at the dates of issuance of the references upon which reliance is placed but tends to show the meaning of terms as they would be understood more recently by scientists who have a much larger fund of information, theoretical and experimental, upon which to draw.

The consideration required by the motions will therefore be confined to that part of the prior art actually cited in the motions to dissolve and listed on page 1 of the "Reference Book" submitted by the party Arnold. It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. An exacuated tube having therein an incandescent electron-emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube, were also well known and available to persons skilled in the art. It is well settled, however, that the patentability of a combination is independent of the novelty of any of its constituent elements (Leeds *v.* Catlin, C. D. 1909, 549). There remains for determination the question of the patentability of the combination as a whole.

The importance and the far reaching effect of the improvement are attested by its numerous industrial applications, Langmuir's record, page 586. No argument is necessary to establish utility.

We may lay aside those alleged anticipating disclosures, such as Lenard, Gehrts and Dember, which pertain to photo electric devices using small currents of the order of 10-9 amperes or less. No effort was made at the hearing to include these within the scope of the count or the claims retained and they are avoided by evident limitations, for example, space charge does not govern the flow of current in these devices. It is not seen that any of the remaining references made fully available to the public by proper disclosure the device now claimed in the issue as reformed, or that the proposed combinations of references, with results not suggested by any one of them, were obvious. The fact seems incontrovertible that a substantial and valuable contribution to the art has been made and that, within the limits explicitly stated or necessarily implied in the claims retained, it is entitled to patent protection.

The improved mode of operation of prior devices made possible in a later development of the art by more efficient means does not fairly negative patentability of the device of the issue where the public was not fully advised of all the correlated facts necessary to secure the improved mode of operation.

Richardson investigated experimentally and theoretically the law of emission of electrons. As the claims now stand it is a matter of little moment whether the theory of electron emission was new or old when Langmuir entered the field, since no claims cover broadly the Richardson theory and the claims retained are directed to practical forms of the invention which Richardson did not disclose.

The Von Lieben relay has some features in common with the device of the issue, but it cannot be said that it was available for use without experimentation, by persons skilled in the art, in a manner to satisfy present day requirements.

It is not seen that the Majorana publications present anything definitely anticipating any of the claims herein discussed.

The publication by Child is apparently not urged as a sufficient and complete anticipation in itself. Its interest lies in the fact that the 3/2 power law is clearly disclosed therein. Richardson remarks "There is no doubt that this law represents a fair approximation to the experimental facts in simple arrangements of electrodes such as parallel plates and concentric cylinders. The law is thus of considerable practical interest and Child is entitled to the credit, such as it is, of having given the first theoretical demonstration of it."

The Lilienfeld device with its long, constricted tube is obviously impractical for any commercial purpose. The walls would tend to melt under electron bombardment and would become so hot as to furnish vapors under their own vapor pressure.

The Fleming valve and the DeForest audion apparently depended to some extent upon gas ionization and the inventors did not clearly and fully inform the public how their devices must be designed or treated to get the effective results now demanded in thermionic devices. It was not essential for their purposes that they should understand the theory of operation or use all the precautions later found to be desirable.

The words of Judge Coxe are pertinent at this point:

> "The question is, what does the prior publication say? Not what it might have said or what it should have said. If prior patents and publications can be reconstructed by extrinsic evidence to fit the exigencies of the case, the inquiry will no longer be confined to what the publication communicated to the public, but it will be transferred to an endeavor to ascertain what its author intended to communicate." (Badische Anilin & Soda Fabrik *v.* Kalle, 104 F. R., 802-808.)

As for Thomson, Arnold's own comment may be sufficient:

> "He does not anywhere state that the ionization point depends in a complicated way on the degree of vacuum and the temperature of the filament and nowhere hints that said ionization is highly deleterious to the operation and life of the practical devices utilizing the phenomena of thermionic emission. Finally, he does not anywhere even remotely hint or suggest that the point at which appreciable ionization sets in is precisely the point at which rectification in the two-element device and repeater action in the three-element device becomes imperfect."

The suggestion that the alleged invention represents a mere difference in degree over the prior art loses its force in the presence of the results accomplished (Edison *v.* U. S. Co., 52 F. R., 300, 308; General Electric Co. *v.* Nitro Tungsten Lamp Co., 282 O. G., 195), and the allegation of no invention is overcome by the presumption of invention in the transformation of laboratory experiments, and erratic and unstable devices into reliable, stable, and successful commercial products (Marconi *v.* DeForest, 243 F. R. 560).

The charge of new matter is predicated upon the assertion that many of the criteria set up by Langmuir in his claims are independently disclosed in his original specification and many are not disclosed at all. Some, it is admitted, are capable of being inferred from the original specification and the drawings. These will not be discussed.

In claim 26, the criterion R of Arnold appears which states that the current flow is governed by the electron field or by the same and the electrode potential. This is the "space charge effect" of which there is no direct mention in Langmuir's original specification. However, it is argued by Arnold that the effect had been recognized by many others before Langmuir, including Child, Lenard, Deininger, and Lilienfeld. If it is to be regarded as an effect incidental to a theory of operation known to workers in the art, it is not necessary that mere theory should be set forth in the specification or that an applicant should adhere to the same theory which he originally recited. If on the other hand, it is an essential and novel feature of Langmuir's invention upon which the patentability of certain claims may rest the lack of definite disclosure would support the charge of new matter.

Adopting the first point of view, the space charge effect is held to be not new matter.

Criterion T, that the testing range lies below the voltage at which saturation is obtained is in the nature of a limitation and not an attempt to cover an undisclosed range.

Criterion V, that the discharge is unaffected by secondary electron emission from the tube walls seems to be a necessary result in a properly designed tube, the embodiment in Fig. 1 of the Langmuir drawing being a practical form of tube.

Criterion W, that the current is independent of the cathode temperature appears to be necessarily involved in the operation of the tube when working under the conditions stated in proposed claim 7, and not a function dependent upon something undisclosed.

Criterion X, that the heating effect in the tube shall occur only at an electrode, defines a useful result of the proper design of the tube walls such that the walls of the tube shall not be undesirably heated. There is no substantive new matter in the statement.

The negative limitations in which part of the alleged new matter is included do not appear to demand a specific disclosure in the specification. What is excluded from the scope of the claim by negative limitations, if old, need not be explicitly set forth in the specification, since that which is old is, as it were, written into the specification. (Webster Loom Co. *v.* Higgins, 105 U. S., 580, 586.)

As to the contention that the claims cover merely an effect or result obtained by any means, it is held that the claims define a combination in which one or more of the several elements are qualified by statements of function. The gas content or residue may be accepted as a physical element, the highest attainable vacuum allowing the re-tention of millions of molecules of gas in a cubic centimeter, and the qualification of the gas content in terms of the result obtained sets forth a material modification of one element of the combination to which fairly definite functions are attributed and thereby avoids the criticism that the claims are for an effect or result obtained by any means.

The difficulty of drafting claims satisfactorily defining the invention and free from objectionable statements of function or result, without introducing unnecessary limitations, is recognized. No better form of claim has been suggested, and it seems unavoidable in the present instance that the device must be defined by what it does, rather that what it appears to be. The situation is similar to that in chemical cases where identity in chemical composition is present, attended by marked difference in results produced.

The motions to dissolve are granted as to counts 1, 2, 3, 4, 6 and 7 and denied as to count 5.

The motions to amend are granted as to claim 26 and claims 1 to 9, inclusive, and denied as to claims 24, 25, 27 and 28.

The withdrawal of counts 1, 2, 3, 4, 6 and 7 and claims 24, 25, 27 and 28 by Langmuir is taken as a waiver of appeal, and no limit of appeal is set.

If the party Arnold desires to contest priority as to claim 26 and claims 1 to 9, inclusive, he should present them by suitable amendment within twenty days.

I. P. Disney,
Law Examiner.

February 25, 1921.

Opinion of the Interference Examiner on Priority of Invention.

October 21, 1922.

(Interference Record, p. 2475.)

IN THE UNITED STATES PATENT OFFICE.

Patent Interference No. 40,380.

ARNOLD,

v.

LANGMUIR.

Electric Discharge Apparatus and the Process of Repairing the Same.

Application of Harold DeForest Arnold filed Nov. 2, 1915, Ser. No. 59,210.

Application of Irving Langmuir filed Mar. 14, 1916, Ser. No. 84,242, for renewal of Ser. No. 795,610, filed Oct. 16, 1913.

Messrs. DE WITT C. TANNER and JOHN G. ROBERTS for Arnold.

Messrs. ALBERT G. DAVIS and ALEXANDER D. LUNT for Langmuir.

This interference involves high vacuum tubes. Structurally, the tubes of the issue are similar to the two electrode tube of Fleming and the three electrode tube of DeForest, well known in the art long prior to the dates alleged by either party herein involved. A controversy has arisen as to just what improvement over the prior art is in issue. Arnold, on the one hand, contends it is a mere improvement in the degree of vacuum of devices in the prior art, while Langmuir contends it is a correlation of the physical structure of the tube with relation to the degree of vacuity, resulting in a new device. As will be hereinafter shown, both parties realized the issue by taking an ordinary DeForest audion structure, and removing the gases therein to a probably greater degree than was usual in the commercial audion. Langmuir's correlation may be obtained by taking any usual vacuum tube of the prior art, denuding the walls and electrodes of gas, and removing the gas in the tube by means well known and understood in the prior art, until a vacuum of higher degree is attained, than was originally present in the tube. In other words, by simply removing the occluded gases and increasing the vacuum of the commercial prior art devices to a certain degree, the issue of this interference is fully realized. The degree of vacuum necessary depends largely on the mechanical structure of the tube chosen, and to this extent the issue defines a correlation.

The history of the counts in issue is unusual and has an important bearing on the construction to be placed thereon. A vigorous attack on the issue, as originally framed, was launched by Arnold. Permission was obtained to take testimony before the law examiner on motion to dissolve in order to explain references and the meaning of terms in the art. A voluminous record was presented by both parties on the issue of patentability, and this record has been stipulated as part of the priority record. As a result of these proceedings, and of motions to amend the issue by Langmuir, the issue was reformed to include the following counts held patentable by the law examiner:

Count 1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

Count 2. An electrical device comprising the combination of a sealed evacuated envelope, a cathode adapted to be independently heated, and an anode within said envelope, an external circuit connected to said electrodes, and a source of electromotive force applied to said circuit, the degree of vacuity and the electron emission of the cathode being so related to the potential of said source that the flow of current over a range of voltage materially above the ionization voltage is governed by the electric field of the electrons in the vacuous space and the potential applied to said electrodes, operatively independent of gas ionization.

Count 3. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the governing or limiting action on the space current due to the electric field of said electrons is substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

Count 4. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization.

Count 5. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

Count 6. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed upon electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the slope of the line obtained by plotting the logarithms of values of said current, as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae shows no increase for increasing voltage values.

Count 7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous.

Count 8. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the tube and when the electron emission has any value such that the space current is below the saturation region at such voltages, that said current varies as the three halves power of said impressed voltages.

Count 9. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

Count 10. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gase content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, substantially unaffected by positive ionization, the heating effect in the tube due to said current occurring substantially only at one or more of said electrodes.

Count 11. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts.

Count 12. Apparatus for controlling an electric current comprising a vacuum tube, an anode and an electron emitting cathode in the circuit of said current and within said tube, the degree of evacuation of the tube and the relation of its parts being such that for voltages materially above ionization voltage the current is governed or limited by the electric field of the electrons in said tube substantially unaffected by positive ionization, and a third electrode in said tube by which an auxiliary controlling electromotive force may be superposed to modify the effect of said electric field and control said current in a stable and reproducible manner.

Count 13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

The peculiar relation of the devices in issue to the prior art and the difficulty recognized by the law examiner of distinguishing therefrom in formulating the counts, becomes important in rendering a decision on priority. The decision of the law examiner with respect to patentability will be followed. This, however, does not avoid the necessity for a close analysis of the issue in the light of the record in considering the question of priority. Both Langmuir and Arnold have produced devices which, as previously pointed out, in mechanical structure, have their apparent counterparts in the prior art. Eminent physicists called on behalf of Arnold have expressed opinion that what was accomplished did not amount to invention. The case is of far reaching importance, and in its present form, the issue apparently dominates the entire commercial field of thermionic vacuum tubes. In order to arrive at a conclusion with respect to priority an effort must, therefore, first be made to determine the proper limits of the counts in view of the prior art.

Controversy has arisen concerning proper tests affording a means for distinguishing an improved device from the usual prior art device. The determination of a satisfactory means of recognition is essential. Preliminary inquiry must also be made to ascertain the nature of the improvement in issue, and a criterion must be established affording a standard for comparison.

Taking up first the problem of construing the counts in the light of the prior art, the finding of the law examiner on motion to dissolve is clearly and concisely set forth in the following quotations:

> "* * * It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. An evacuated tube having therein an incandescent electron emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure discharge in a properly designed tube, were also well known and available to persons skilled in the art. * * * and the allegation of no invention is overcome by the presumption of invention in the transformation of laboratory experiments, and erratic and unstable devices into reliable, stable and commercial products."

This view of the state of the art is in apparent accord with the entire record. The principal prior art devices to be here considered are those of Lilienfeld, Fleming and DeForest. For convenience, the reference book presented by Arnold on motion will be considered as disclosing correctly the pertinent portions of the publications therein referred to, since no attack on the authenticity of any extract has been made.

The Lilienfeld device was disclosed fully in printed publications of 1910 and 1911 (R. B. pp. 139 to 166) and consisted of two bulbs, one containing a Wehnelt heated cathode, the other containing a cold anode both connected by a relatively long narrow tube. In the narrow tube were located sounding electrodes to measure potential gradient, the whole being connected to an evacuating system with arrangements to temporarily seal the device off from the pumping system (R. B. pp. 141 to 147; Langmuir p. 353, Q32, section 3, and p. 835, XQ205, L. M. R.). This plainly was a device for experimental purposes only, but was useful for laboratory investigation of laws and theories. Arnold's witness Richardson, referring to Lilienfeld's experiments says (p. 92 R. D.):

> "In Annelen der Physick, Volume 32, page 673, (1910) Lilienfeld investigated the characteristics for a tube with a Wehnelt cathode under condition of vacuum such that further evacuation made no difference to the characteristics * * *."

Speaking of the results attained by Lilienfeld, Richardson attributes to him the experimental determination of the three-halves power law, urged by Langmuir as the principle test for the presence of the issue, in the following words (p. 94, R. D.):

> "Lilienfeld thus arrived at the 3/2 power law as a purely experimental result and he had no theoretical calculations to guide him."

On page 104 R. D., he refers to a "pure electron discharge device such as Lilienfeld's." Respecting the work of Lilienfeld's, Langmuir testifies:

> "(19) Lilienfeld proved beyond question, I think, that he obtained discharges, in some cases at least, in which the effects that he measured were not dependent upon gas ionization * * *." (P. 366, Q32, section 19, L. M. R.)

On page 370, L. M. R.:

> "(24) The heating of the walls of the tube and the fluorescence of the gas furnish absolute proof that the walls are being bombarded by electrons, since Lilienfeld's experiments are made under such conditions that positive and negative ions could not have been present in sufficient numbers to bring about this result."

On page 377, L. M. R.:

> "It should be noted that the 3/2 power law held in Lilienfeld's tube only over a very narrow range of voltage."

On page 507, L. M. R.:

> "(25) Lilienfeld probably succeeded in obtaining a discharge in high vacuum substantially free from effects of positive ionization in the device he described in his 1910 paper (see p. 364 et seq.).

The voltages Lilienfeld used were as high as 6,000 volts (L. M. R. p. 353) and he had generators capable of delivering 10,000 volts (L. M. R. p. 359). According to the replotted diagrams of his results which have not been challenged (R. B. pp. 149 and 150), at 350 volts between the sounding electrodes, approximately 10 milliamperes of current flowed. The Lilienfeld disclosure may, therefore, safely be characterized as a two-electrode high vacuum tube in which the effects of positive ionization are not appreciable with currents of at least five milliamperes at potentials considerably above two hundred volts, but useful only for performance of laboratory experiments. All parties are agreed that ionization potential for gases commonly found in thermionic devices lies between 10 and 20 volts (Langmuir, Q26, Sec. 13, p. 216, L. M. R.; Arnold, p. 15, A. P. R. and Langmuir Brief p. 32). Therefore, Lilienfeld produced and disclosed a high vacuum electron discharge tube unaffected by appreciable ionization at voltages materially above ionizing potentials. Even though this device would be impractical for present day thermionic purposes, and was in fact never intended for use in such a relation, nevertheless, the counts of the issue must be distinguished therefrom, otherwise the terms will be squarely met by a prior art disclosure. Unless distinguished, the counts will not set forth the contribution to the sum of human knowledge (General Electric Co. *v.* Nitro Tungsten Lamp Co., 282 O. G., 195; 266 Fed. Rep. 994) and will not point out the improvement in the manner required by Sec. 4888, R. S.

The Fleming disclosures bear on the production of a two-electrode vacuum tube, which has been used commercially to some extent. The structure of this tube is disclosed in a paper published by Fleming in the Proc. Royal Soc. Vol. 74, pp. 476-487, January 24, 1905, in U. S. Patent No. 803,684 to Fleming, and in a paper published in the Scientific American Supplement No. 1568, pp. 25129-25131, January 20, 1906, pertinent extracts of which are reprinted in Arnold's Reference Book, pp. 47 to 71. The degree of vacuum specified by Fleming in his disclosures is the only element which need be considered, since the remaining elements are unquestionably disclosed. His tube consists of an ordinary incandescent lamp bulb into which has been sealed in the usual way, a plurality of electrodes in the form of filaments, or of a plate and a filament (R. B. pp. 49, 55, 60 and 68). Regarding the degree of vacuum Fleming states in his patent No. 803,684 (R. B. pp. 56 and 57):

> "As a very high degree of vacuum should be obtained in the bulb *a*, and as a considerable quantity of air is occluded in the conductors, these should be heated when the bulb is being exhausted. The filament *b* can be conveniently heated by passing a current through it, while the cylinder *c* can be heated by surrounding the bulb *a* with a resistance-coil through which current is passed, the whole being inclosed in a box lined with asbestos or the like."

In the Royal Soc. paper (R. B. p. 49) referring to the degree of evacuation he states:

> "The bulb must be highly exhausted to about the pressure usual in the case of carbon filament incandescent lamps, and the metal cylinder or plate must be freed from occluded air."

In his Scientific supplement article the following appears:

> "Let this bulb be exhausted as completely as possible so that in it the highest attainable vacuum is made. To achieve this, the filaments must be heated to bright incandescence while exhaustion is going on." (R. B. p. 60)

and on page 65, R. B.

> "If the pressure is great enough electrons may be projected from the negative electrode. If, however, the electrode is surrounded by air molecules at normal pressure, the electrons projected from the metal never attain a very high velocity."

He then goes on to define a high vacuum as "one-hundred millionth of an atmosphere" and defines what he means by "hot" and "cold" and "high" and "low" voltages. It is very clear that Fleming attributes the action of his valve, as early as 1906, entirely to electron flow, and contended that the presence of gas was undesirable, due to the interference with velocity of electrons thereby occasioned. Langmuir himself says (Langmuir, p. 14; L. P. R.):

> "Fleming's idea in wishing to use a high vacuum was undoubtedly based upon a vague desire to avoid ionizing effects."

The definite meansure of Fleming's vacuum, which he considered the "highest obtainable," is given as that of a carbon filament lamp of that period. Long prior to the date of the Royal Soc. paper in 1905, it was customary to heat the bulbs and filaments highly during exhaust to remove occluded gases. Iodine, sulphur, and powdered silver were used to remove mercury and remaining gases (Duncan, pp. 71-72, R. B., May, 1896, De Land, pp. 73-74, R. B., June, 1897, Anonymous, pp. 74-75, R. B., May, 1902; Del Mar, pp. 75-76, R. B., May, 1902; and Doane, pp. 76-77, R. B.). Chemical methods of getting high vacua were also in use (Doane, p. 78-79, R. B., May, 1904). In the Scientific American supplement article, Fleming refers to Sir James Dewar's method of obtaining a high vacuum (Fleming, pp. 59-60, R. B.; Dewar, pp. 3-7, R. B.).

Van der Bijl, testifying in rebuttal for Arnold, made bulbs following Fleming's disclosure, which he exhausted without taking the precaution of heating the bulbs. The filaments were simply glowed during exhaustion. He also made tubes in this manner using tungsten filaments. The results of these experiments are given on pages 104 to 130 of Arnold's rebuttal testimony on motion (Van der Bijl, 98, A. M. R.). The characteristics obtained indicate clearly that a pure electron discharge was obtained at voltages high above the ionization potential. Respecting the precautions taken to obtain a high vacuum, Van der Bijl says (p. 128):

> "In doing so I did not take precautions that a man skilled in the art would have done prior to 1913. In the manufacture of lamps, for example, precautions are taken and have been taken for many years, that are superior to those I took in evacuating these bulbs, and yet these bulbs give pure electron discharge characteristics up to several hundred volts and several milliamperes space current."

and on page 171, A. M. R.:

> "As I have stated before, these tubes were evacuated simply by glowing the filaments to bright incandescence and not baking the bulbs. I used a standard pumping system which is superior to the pumps in use around 1906. In those days the Toepler pump was the one used by some scientists. The Toepler pump is slower, so that my advantage lay in the time of pumping."

Van der Bijl was fully cross-examined regarding these experiments, the manner of making the tubes and the apparatus used in exhausting them. The law examiner on motion held that the Fleming tube was dependent to some extent on gas ionization and the disclosures were not sufficiently clear and full to inform the public how to get the effective results now demanded in thermionic devices. Van der Bijl's experiments and his testimony have not been discussed by the law examiner. It must be assumed, for the purposes of the determination of priority, that these experiments were inconclusive.

A tube made according to Fleming's disclosures, adopting all the precautions in obtaining the usual vacuum in incandescent light bulbs of the prior art, cannot be within the issue. A review of the precautions common in denuding filaments and bulbs of gas during pumping and in removing residual mercury vapors, indicates the extreme precautions necessary to produce a device embodying the issue. Considering the situation, it becomes apparent that the means adopted to procure a vacuum furnishes no reliable guide in determining whether a device corresponding to the issue has been produced.

The remaining important device limiting the field of the counts, is the DeForest audion. DeForest attributed the action of his audion to residual gas and, therefore, the disclosure of his patents may be disregarded. The inquiry must be directed to the characteristics of the device actually in commercial use prior to the work of Langmuir and Arnold. The DeForest audions actually in use in the prior art clearly must limit the scope of the issue. Regarding the DeForest audion, Langmuir testified (L. P. R. p. 39):

> "We should keep in mind, however, that all DeForest audions from 5 to 20 or 30 volts operated substantially unaffected by positive ionization, so that this demonstration could have been made with any audion."

Referring to audions used in tests for telephone repeater service by Kendall, where voltages from 30 to 50 were used in actual practice while considerably higher voltage (about 75 volts corresponding to 52 cells) Langmuir says (L. P. R., pp. 55 and 53):

> "These power outputs do not appear to be appreciably better than might have been expected from many original DeForest audions. Results of this kind could have been obtained by devising methods for making audions of uniform quality, but with no radical improvement in quality."

Arnold exhibit 25 referred to by Langmuir for this data shows, however, that satisfactory telephone conversation was carried on with New York and these tests were immediately prior to installation of commercial service which lasted daily for six months (Kendall, A. P. R. pp. 104 and 105). The test of service as a telephone repeater appears to establish beyond question that the devices were stable and, therefore, substantially unaffected by positive ionization up to at least 41 volts and probably higher. Certainly erratic behavior could not be tolerated under such conditions.

Arnold's testimony with respect to the DeForest audion is substantially in accord with that of Langmuir as follows:

> "* * * since the voltage in those original tubes ran about 40 volts and the current about 150 microamperes * * *." (Arnold p. 12, A. P. R.)

and on p. 15, A. P. R.,

> "* * * the operating range for the new devices should not only exceed the ionization voltage of 10-20 volts, but should indeed exceed the 40 volts at which the DeForest audion operated."

Referring to audion No. 7, before the vacuum had been improved by burning out one filament, Arnold said (p. 23, A. P. R.):

> "* * * the experiment shows that no ionization was produced, the evidence being that no current flowed between plate and grid up to 48 volts."

In view of this testimony it is clear that the DeForest operated as high as 30 volts without appreciable positive ionization and by simply standardizing production according to Langmuir, and without radical improvement in quality, the voltage could be raised as high as 41 to over 50 volts. The counts must, therefore, be limited to devices operating at voltage about 40 or 50 without appreciable ionization.

In deciding the matter of priority it, therefore, becomes evident that the counts must be limited in view of Lilienfeld to a permanently sealed off device more useful than from the standpoint of laboratory experiment or scientific investigation of laws of nature. In view of Fleming and the work of Van der Bijl it is clear that something more than the precuations advocated by Fleming in evacuation is required. If the Fleming disclosures be regarded as insufficient as an anticipation, certainly the suggestion of desirability of a high vacuum in the usual prior art tubes did not require invention. The limits of the DeForest tube are clear. If the majority of counts are to be held not anticipated by this device, then 30 to 50 volts cannot be construed to be materially above the ionization potential of 10 to 20 volts.

Before the matter of priority is discussed, a satisfactory criterion for recognition of a device embodying the issue must be determined. In general, the improvement consists in making the commercial tubes of the prior art stable and operable in a dependable and reproducible manner at materially higher potentials than was before possible for satisfactory operation. The result has been a marked increase in the power of the tubes and in their general usefulness. This result has been accomplished by removing the gases in the tubes to such an extent that the neutralizing effect of positively ionized gases does not materially affect the negative space charge which is due to the mutual repulsion of electrons. The current is then definitely limited in a reproducible manner by the space charge effect, electron emission of the filament, applied potential, and the mechanical structure of the tube, and the tube is reliable at potentials considerably higher than before attainable. Langmuir proposes as a test, a three-halves power law which the volt-ampere characteristic of a tube embodying the issue must follow below the saturation region. Langmuir's own testimony, however, shows the variation from this law, which at best is an approximation (Richardson, Qs8 to 11, R. D.), may be so great that the exponent becomes five-halves, and still the device may embody the issue (Langmuir, XQ134, p. 791, L. M. R.). Even in devices considered by Langmuir as following the 3/2 power law, the deviation is apparent from the diagrams given (pp. 145 to 185, L. M. R.), and Van der Bijl's reply to Q10 (A. M. R., pp. 131, 148). Arnold's criticisms of Langmuir's application of the 3/2 power law (pp. 143-146, Q. P. R.) and Richardson's replies to Qs8 to 13 (R. D. pp. 42 to 77) show that the law is approximately true only for a theoretic device of simple construction, and is seldom realized in practice. As a test in this inquiry it will, therefore, be entirely disregarded except insofar as it is necessarily embodied in the terms of counts 6, 7 and 8.

The appearance of blue glow is a more tangible test for the presence of a serious degree of ionization. When blue glow appears, ionization has gone to the extent of destroying the usefulness of the tube for the potential where the glow appears. Van der Bijl, (p. 142, A. M. R.) referring to the VT-1 tube which is commonly used as a radio detector says:

> "but it was found that these tubes were unsatisfactory at 100 volts because they blue hazed although they were perfectly satisfactory at 45 volts."

This tube was widely in commercial use during the war. Arnold in his testimony, continually refers to the presence or absence of blue haze as a test for ionization (A. P. R. pp. 5 to 62). Jewett testifies that he recognized blue haze was due to ionization (p. 64, A. P. R.) and this was also recognized by Colpitts (p. 71, A. P. R.). Langmuir's witness Dushman plainly relied on blue haze as a test for serious ionization and lack of reproducibility (pp. 141 to 147, L. P. R.). White relied on blue glow (White, Q28, p. 606, L. M. R.). Even counsel for Langmuir was constrained to admit at the oral hearing that it is a test in the following words:

> "It is quite true that if the vacuum is particularly bad ionization may become so violent as to cause blue glow in the tube. It is a good rough preliminary test. It is probably used a good deal in a rough preliminary way in actual manufacturing practices. And you find where Dushman talks about the glow and of what it is he couples it with reproducibility, and reproducibility is of the essence of the invention."

Blue glow or haze, standing alone would unquestionably be too uncertain as a test for presence of the invention. Relatively, however, a rough test may become satisfactorily accurate by comparison. The record shows that the ordinary DeForest audion of the prior art blue hazed at around 40 or 50 volts (Langmuir, p. 71, L. P. R.; White, XQ109, p. 643, L. M. R.; Arnold, p. 12, A. P. R.). Arnold considers a tube which does not blue haze at 68 volts a high vacuum tube. As previously pointed out, Langmuir considers the tubes used by Kendall as telephone repeaters in November, 1913, to be no radical improvement over the DeForest audion. Since these tubes operated at 41 to 50 volts without appreciable ionization, in view of Van der Bijl's testimony relating to the VT-1 tube (p. 142, A. M. R. above quoted), it is probable that blue glow would have appeared below 100 volts. Measuring by Langmuir's standard, a tube which does not show blue glow at voltages about 100 should embody a radical improvement over the DeForest tube of the prior art. Lack of blue glow at potentials above 100 volts will, therefore, be accepted as a test for a tube in which positive ionization is not appreciable at voltages materially above ionization voltages, within the meaning of these terms in the issue. For the purposes of this case it becomes unnecessary to decide whether a tube which shows blue glow below 100 volts embodies the issue.

Having a tangible guide in mind for determination of when the issue is present, an effort must be made to arrive at a conclusion with respect to the nature of the improvement. That an improvement of wide commercial importance has been effected cannot be denied. The presence of blue glow has long been ascribed to be an effect of gas ionization and the effects of ionization had been studied in the prior art. To suggest, therefore, that the effects of gas ionization could be obviated by removing the residual gas was obvious and too absurdly simple, in view of prior knowledge, to arise to the dignity of invention. The result effected was the elimination of erratic behavior in the prior art devices and making them stable and of reproducible characteristics at potentials theretofore unattainable. Thermionic electron emission had been known and studied for years. Therefore, if a skilled worker in the art of thermionic emission, for example Arnold, could have predicted with certainty, that the erratic behavior of the DeForest audion would disappear and a reproducible result obtained at higher voltages than previously attainable, by simply evacuating to a higher degree, then there can be no patentability in this issue over the prior art. So far as this tribunal is concerned the law examiner's decision has settled the matter. Since the existence of patentability has been determined, it must be held that for a person with a knowledge of the prior art to foresee and predict the results of removing the residual gas with certainty, would not have been possible. Any forecast must have been a mere hazard which had to be confirmed by actual test before even conception can be said to have been completed. The improvement must, therefore, be classed as a discovery to be patentable, and of the class concerning which Robinson said:

> "In many inventions the act of conception is clearly distinct, in point of time, from that of reduction; and in these cases the rules given above are easily applied. In many others the work of conception and reduction goes forward almost simultaneously, so nearly so that no date can be fixed as that before which the conception was complete and after which the reduction to practice was begun. This is true in nearly all inventions which are the result of experiment,—where the inventor instead of evolving the entire art or instrument out of his own thought, conjectures that such an act or substance will subserve a given purpose, and having tried it accomplishes the end. The production of a new means by this method is equally with the former, an inventive act, but at no instant before the experiment succeeds can it be said that the conception of the invention exists in the inventor's mind. Until that instant it is mere speculation, at most a probable deduction from facts already known and the same act which reduces it to practice gives to conception its definite and final form. Hence the

> date of conception in such cases is the date, not when the experiments begin, but when they end; and the first to bring the art or instrument into successful operation is the first conceiver of the entire invention." (Robinson, Vol. 1, Sec. 381.)

Adopting this view, conception and reduction to practice must be simultaneous in the present case and the first to reduce to practice must, therefore, prevail.

Arnold's earliest work relied upon was with DeForest audions. Seeing one in operation on November 1, 1912, he immediately suggested to Colpitts that thorough removal of the gas would make it steady and reproducible in operation, as well as enabling higher voltages to be used and higher power obtained (Arnold, p. 13; Colpitts, p. 72, A. P. R.). This disclosure was also made to Jewett who testified as follows (p. 65, A. P. R.):

> "Dr. Arnold said that he could make a tube like these DeForest audions but with greater electron emission and so much better evacuated than erratic behavior due to positive ionization would be eliminated, and the device could be operated at the higher voltages necessary for telephone repeater service without sacrafice of its favorable operational features."

This disclosure of Arnold's, although full and complete, must be treated as a speculation which later was verified by actual experiment. Conception can not be awarded thereon. After this conversation, Pierce was assigned to the task of ascertaining the alternating current characteristics of the audion until November 16, 1912, when upon Arnold's orders, Pierce set to work determining the direct current characterist-s. (Arnold, pp. 20-21; Pierce, pp. 83-84, A. P. R.) Thereafter tests were carried on by Pierce on audion No. 7 until one of the filaments burned out on November 29, 1912 (Pierce, p. 85, A. P. R.). The vaporization of the filament which burned out improved the vacuum in audion No. 7. After the burnout it was labeled No. 7A. This method of obtaining a high vacuum is well recognized today as a clean-up process. Absorption of gases by passing a discharge through a tube was well known to the prior art (Thomson's Conduction of Electricity Through gases, 1906 issue, p. 552). The clean-up effect was well recognized in the carbon lamp art prior to the work of Arnold or Langmuir (Proc. A. T. E. E. Vol. 31, pp. 921, 922, 929, 930, read in June, 1912). It is now urged for Arnold that the clean-up of audion No. 7 was deliberate and for the purpose of improving the vacuum. The tests between November 16 and November 29, however, bear the appearance of tests simply made to obtain the characteristics. Arnold nowhere says that he understood the clean-up effect in 1912, or that Pierce was instructed to improve the vacuum in this manner. It is true that he refers to "bombardment" of the grid and plate and also says (p. 22, A. P. R.),

> "By virtue of the clean-up process which sometimes serves to improve the vacuum, and which was a familiar phenomenon in connection with the exhaustion of incandescent lamp * * * I will explain * * * how we proceeded with audion No. 7 to clean it up * * *."

but this is far from a direct statement that what he did then was done for the purpose of cleaning up the audion. Pierce also refers to the experiments as "bombardment" and says (p. 84, A. P. R.),

> "Having cleaned up both the grid and the plate in the manner already described, some more d. c. tests were made."

He does not say that he was instructed to clean-up the tube or improve the vacuum. Although it was some months before an improved vacuum pump arrived, no further effort to repeat this method of improving the vacuum of other tubes was made. In spite of the anxiety to obtain a high vacuum (Arnold, pp. 34-36, A. P. R.) this simple process was never again resorted to although Trimble was set to work during January of 1913 in an effort to duplicate ordinary DeForest audions (Arnold, pp. 36-37, Trimble, 92-93, A. P. R.). In view of the failure to make direct statements regarding knowledge of the clean-up effect, and subsequent conduct in failing to again resort to such a procedure in the months that followed, it must be held that Arnold did not then appreciate what had occurred. The improvement in audion No. 7A occasioned by the filament evaporation was plainly incidental to other tests and unappreciated. It therefore, becomes unnecessary to determine whether audion No. 7A had become sufficiently improved to embody the issue, since even if it had, Arnold could derive no benefit therefrom.

The work from the end of November until April 25, 1913, so far as Arnold is concerned, was directed to the production of tubes which were similar to the DeForest audion and, therefore, did not embody the improvement (Arnold, pp. 34-49). No claim is made during this interval to actual production of an improved tube. On April 25, 1913, audion 20.2 was evacuated using a new Gaede molecular pump, and tested up to 243 volts at which it "stood up" (Arnold, p. 49, A. P. R.) without the appearance of blue haze (Pierce, p. 88, A. P. R.). On May 12, 1913, audions A-3 and B-3 were evacuated together and in a test showed no blue haze at 240 volts (Arnold, p. 49; Pierce, p. 88, A. P. R.). Langmuir has plotted the characteristics for audions A-3 and B-3 (p. 90, A. P. R.). This data was not attacked by Arnold on rebuttal and is apparently accurate. Audion A-3 clearly had reproducible characteristics up to about 70 volts while B-3 was reproducible up to 50 volts since the rising and falling values correspond below these voltages. Lack of blue haze at 240 volts may, therefore, be relied upon to indicate lack of appreciable ionization at 50 to 70 volts but no higher. Audion 20.2 was, therefore, clearly a reduction to practice of counts 2 to 5 inclusive, 9, 10, 12 and 13, since with the ordinary audion structure secondary electron emission from the walls of the tube is not present in appreciable quantities.

It is, however, apparent that none of Arnold's tubes under consideration operated at 200 volts in a reproducible manner, therefore, counts 1 and 11 were not embodied in these tubes. The characteristics plainly do not follow a theoretic 3/2 power law, nor are the logarithmic plots of the characteristics straight line for any material portion of the curve below saturation. Counts 6, 7 and 8 were, therefore, not reduced to practice by Arnold at this time. No further record of the manufacture of audions better in quality than A-3 appear so far as Arnold is concerned prior to Langmuir's filing date. None capable of operating at 200 volts without appreciable ionization, and none with the peculiar characteristics for the entire range below saturation, demanded by counts 6, 7 and 8, were produced. Arnold is entitled to a date of April 25, 1913, for conception and reduction to practice of counts 2 to 5 inclusive, 9, 10, 12 and 13, but has failed to establish conception of the remaining counts prior to Langmuir's filing date.

Considering Langmuir's case, the investigation in 1912 of clean-up effect in nitrogen lamps with two filaments is the earliest work relied upon. Regarding this work in August of 1912 (Langmuir, pp. 548-550, L. M. R.) Langmuir himself says (p. 546, L. M. R.),

> "by comparison with experiments subsequently made (November and December, 1912) I can now recognize clearly that with this new type of discharge we actually had a device in which the current was limited by space charge substantially independently of positive ionization, at voltages as high as 250 volts."

and on page 55:

> "at that particular time (August, 1912) I did not have any clear understanding of the laws underlying this new type of discharge and I did not know whether, if the vacuum had been still further improved, the currents would not have decreased still further at the lowest possible pressure. In August and September, 1912, however, I was much interested in the subject of thermionic currents in high vacuum, and planned to undertake experiments in order to make a further study of this phenomenon."

According to this testimony, Langmuir did not at that time have any conception of the nature of the device produced and did not realize its value. He was simply interested in phenomena, and planned further study. In September or October, he sought an explanation from Richardson but received none that was satisfactory (Langmuir, pp. 555-556, L. M. R.). A visit by Richardson to the laboratory at Schenectady was arranged. Langmuir testifies with respect to work that followed (pp. 557-558, L. M. R.):

> "(5) After returning to Schenectady I made up my mind that before Richardson visited us I would make a thorough investigation of thermionic cur-

> rents between two filaments in a very high vacuum, in order to get an understanding of the fundamental laws involved and thus settle once and for all whether or not sure electron currents could be obtained in a practically perfect vacuum."

Referring to work of November 19 and November 20, 1912, Langmuir says:

> "The current at these higher temperatures we now know was limited by space charge."

These experiments were admittedly for the sole purpose of scientific investigation of the fundamental law, and Langmuir clearly admits that they were not then understood. At this stage conception of the issue was still manifestly incomplete and certainly no reduction to practice occurred. Langmuir asserts that the Coolidge X-Ray tube was based on his work (p. 574, L. M. R.) and it is urged for him that disclosure to Coolidge was made on December 10, 1912, based on a conversation recorded on pages 156-158 of Langmuir's note book No. 413 (L. Ex. 81). On page 158 in reference to this conversation Langmuir wrote:

> "I also pointed out that the current from a hot cathode is much decreased by the presence of gas."

This, however, is contrary to the now well established knowledge of the general increase in current caused by the presence of gas in sufficient quantities to result in appreciable positive ionization. On January 31, 1913, experiments were still being made on the Edison Effect and Langmuir wrote (p. 206, L. Ex. 81):

> "This fact is strong evidence against Richardson's theory and indicates importance of anode."

"Richardson's theory" apparently was the "Richardson's law" referred to on page 144 (Ex. 81) which was Richardson's law of emission for hot filaments. On February 14, 1913 (p. 236, Ex. 81), the following note by Langmuir appears:

> "The whole field of pure negative electron discharge is a very important one. I think this work in the laboratory at least was started by me last November and that I had very clear ideas on it on November 22, 1912, see p. 144, a couple of weeks before Coolidge made up his first hot cathode tube."

His ideas of the effects of gas on November 22 are given on page 145 (Ex. 81) as follows:

> "but if gas is there the molecules collide with electrons (which have same velocities as those in filament) and slow them up and make them more readily absorbed by anode wires."

On February 14, 1913, Langmuir did not attribute the gas effect to ionization, but apparently, to slowing up of the electrons by collision. These entries do not show disclosure to Coolidge, and even if they showed complete understanding and disclosure, failure to call Coolidge who was available as a witness, must rob them of any value. Langmuir does not testify that he disclosed to Coolidge and he can derive no benefit from the work done by Coolidge. The entries simply show that the work of Coolidge brought to Langmuir a realization of the importance of the development. They do not show that he realized that tubes embodying any counts of the present issue had been produced.

In February, 1913, Langmuir disclosed to White

> "the two general laws which govern the flow of electron current between an anode and a hot cathode in a high vacuum tube." (White, Q7, p. 596, L. M. R.)

Clearly this is not a disclosure of the issue, for the tube then used, was according to White, simply an experimental device to illustrate general laws.

In March, 1913, a three electrode tube according to Langmuir's direction was made by White. This tube was tested and operated above 100 volts without blue glow (White, Qs16 to 18, pp. 601-603, L. M. R.) and has been offered in evidence as Tungsten Wire Audion No. 2 (L. M. R., Ex. 25). The characteristics were obtained about March 18, 1913, and it was rigged up as a wireless detector about March 19, 1913 (Langmuir, p. 124, L. M. R.). This audion was turned over to Dushman for experiment April 8, 1913, and of these experiments Dushman says (pp. 143-144, L. M. R.):

> "Finally I did succeed in getting satisfactory results. On these experiments I used voltages up to 240 on the plate of the audion and obtained perfectly reproducible results. There was no evidence of blue glow or any erratic behavior which would indicate positive ionization in the bulb."

Langmuir made an entry on April 15, 1913, in his note book No. 458 (p. 60) that for several hours Dushman found "beautiful proportionality" but that later the conditions could not be produced. The contemporary records for audion No. 2 were available but not produced (White XQ137, p. 654, L. M. R.) and objection was made that the oral testimony is not the best evidence. The best evidence rule applies only to proof of the contents of written instruments, when the contents are in issue. Here the matter in question is the performance of the audion, not the contents of contemporary records. The oral testimony is, therefore, primary, competent, and admissable. Failure to produce the records which are secondary evidence simply goes to the weight of the oral testimony. The evidence establishes beyond reasonable question that prior to April 15, 1913, Langmuir had produced a three electrode tube which did not show blue glow at voltages above 100. On this date Langmuir had, therefore, conceived and reduced to practice counts 2 to 5 inclusive, 9, 10, 12 and 13.

On July 9, 1913, Dushman sealed off a high power tube which stood 400 watts without blue glow and stood 20,000 volts with 110 milliamperes current flowing (pp. 264, 265, L. Ex. Q; Dushman, p. 146, L. M. R.). Langmuir referred to this as the first successful hot cathode relay (L. Ex. *U*. p. 222). This tube clearly embodied counts 1 and 11 of the issue and Langmuir is entitled to July 9, 1913, as a date of conception and reduction to practice of these counts.

No evidence of the production of any tube, by Langmuir, whose characteristic follows the 3/2 power law or has a straight line characteristic on a logarithmic plot for the entire range below saturation has been adduced prior to Langmuir's filing date. Since it has been held that his application supports such counts as 6, 7 and 8 Langmuir is restricted to his filing date for their conception and reduction to practice.

Being the first to conceive and reduce to practice with respect to all the counts in issue, Langmuir is entitled to prevail.

Priority of invention is hereby awarded to Irving Langmuir, the senior party.

Limit of appeal: November 10, 1922.

W. S. RUCKMAN,
Examiner of Interferences.

October 21, 1922.

Decision of the Examiners-in-Chief.

U. S. Patent Office,
Examiners-in-Chief,
Apr. 21, 1923.

Appeal No. 8640, Paper No. 213.

Decision.

Hearing: February 16, 1923.

Appeal No. 8640.

U. S. Patent Office, April 21, 1923.

Before the Examiners-in-Chief, on Appeal:

In the matter of the interference between the application of Harold de Forest Arnold, filed November 2, 1915, Serial No. 59,210, and the application of Irving Langmuir, filed March 14, 1916, Serial No. 84,242, for renewal of an application, Serial No. 795,610, filed October 16, 1913. Interference No. 40,380.

Electric Discharge Apparatus and the Process of Repairing the Same.

Mr. De Witt C. Tanner and Mr. John G. Roberts for Arnold.

Mr. Albert G. Davis and Mr. Alexander D. Lunt for Langmuir.

This is an appeal by Arnold from the decision of the examiner of interferences awarding priority to Langmuir, the senior party.

The invention in issue is a thermionic tube that is adapted to be used as a relay in long distance telephone systems, as a detector or amplifier in wireless systems, or as a rectifier of alternating currents. Other uses are referred to, as in the case of the Coolidge X-ray tube; but the counts, except 13, are for the tube *per se* irrespective of its uses.

Structurally considered, the tubes of both parties are, or may be, substantially identical with the Fleming Valve or with the DeForest Audion. But these prior art devices are not within the issue, for the reason that they do not exhibit the characteristics required by the counts.

Considerable difficulty has been experienced in formulating a satisfactory issue. After consideration of a motion to dissolve and motions to amend, and after the admission of two new counts (12 and 13) by stipulation, the issue stands with thirteen counts, of which the following are sufficiently illustrative:

1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

5. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous.

9. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

11. A discharge tube having a cathode adopted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts.

13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

The invention has been referred to as a "thing compact of glass and metal." That description is correct as far as it goes, but that it is inadequate is evident from the fact that it applies equally well to the prior art devices. If it were qualified by the statement that it operates with a *pure* electronic discharge above the voltage of positive ionization and below saturation, it would, at least, be improved. But how is one to know whether the discharge is purely electronic? In other words, how is one to know whether a tube embodies merely the prior art devices or the invention in issue? A thermionic tube which operates solely by electron discharges or currents has certain distinctive characteristics by means of which the presence of the invention may be recognized, and the counts have been so worded that each brings out one or more of these characteristics. For example, count 1 specifies that the envelope of the tube is evacuated to such a degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts. Thus the count distinguishes from the prior art, not by features of structure, but by a characteristic which is manifest while the device is operating at or above a certain voltage. The audion is not evacuated to the high degree that count 1 calls for and, at an impressed voltage of about 30, ionization occurs. Count 5 specifies that the relation of the parts of the tube and the degree of evacuation are such that, when operated in a range below saturation and materially above ionization voltages, the space current is governed by the combined effect of the electric field of the electrons and the potentials applied to the electrodes, the governing or limiting of the current being substantially unaffected by secondary electron emission from the walls of the tube.

When a thermionic tube is operating by a pure electronic discharge at a voltage substantially below saturation, the current varies in substantial accordance with the 3/2 power of the impressed voltage. If the voltages be plotted as abscissae and the currents as ordinates, the result is a curve that gradually rises and turns toward the left—the curve of the 3/2 power. This obtains while there are plenty of electrons emitted from the cathode, at the temperature at which it is heated, to make up the increasing current. But the number of electrons emitted varies with the temperature of the cathode and that temperature is generally maintained constant. Consequently, a voltage will be reached which is capable of forcing the electrons across the space more rapidly than they can be emitted. The result is the flat-topped curve showing saturation. The tubes of the issue are operated at voltages above that of ionization and below that of saturation, and the voltage current curve follows the 3/2 power law. This is one of the characteristics of the tubes; and a tube that has such a characteristic operates by a pure electrode discharge and is a tube of the issue.

Ionization occurs when there is gas within the tube during operation. This gas may be normally free, as when mercury vapors are present, or it may be absorbed or occluded in the electrodes, particularly the anode, and in the glass walls of the tube. The electrodes and walls act like sponges, taking up the gas when cold and again giving it off when heated during operation. A tube which has gas either in a normal free state or occluded in the electrodes or walls is subject to ionization; and ionization takes place when the voltage rises sufficient to produce it. About 15 volts is sufficient to give this result. But a tube which operates by ionizing a gas does not respond to the 3/2 power law and is not a tube of the issue. Excessive ionization is usually accompanied by a blue glow or haze; but such a glow is not a reliable test, as both parties admit, since a tube that does not show blue glow may produce ionization to such a degree as to cause it to depart from the 3/2 power characteristic.

Any tube which gives the 3/2 power voltage-current curve must also give the straight-line when the volts and current are plotted on logarithmic paper. These two curves are plotted from the same data and their differences are due simply to the difference in the arrangement of the lines on the paper. If, therefore, the volts and currents be plotted on one kind of paper and the result shows a pure electron discharge, there can be no doubt what the other kind of paper would show. Certain counts, as 6 and 7, call for the straight-line, while count 8 calls for the 3/2 power characteristic.

Other counts refer to the electric field of the electrons (count 2) or to space current due to the electric field of the electrons (count 3). The electrons are supposed to be exceedingly minute pieces of negative electricity, and they react on one another just like a flock of pith balls would react if they were confined in some manner so that they were each within the field of influence of the others. If they were all charged with negative electricity and there were no available positive charges to neutralize them, they would simply create an electric field or space charge. But if at one part of this field a positive charge were created, the negatively charged pith balls would fly across the field to it, thus setting up a current. That is what happens in the tubes of the issue. The electrons are generated or emitted by the heated cathode; and if there is no way of neutralizing them they simply fill the space, charge it negatively and react on one another. But if the anode be charged positively, the electrons fly across the field to it and become neutralized. This flow of electrons is a current; and, assuming a sufficient emission of electrons, the strength of the current is dependent on the potential difference between the cathode and anode. If this difference is small, comparatively few electrons get through and the others continue to react on one another. If no gas be present in the tube, either free or occluded, the current is governed by the electric field of the electrons and the potential applied to the electrodes. If gas is present and the voltage is above ionization, some of the gas molecules become ionized and rendered positive by having one or more of their negatively charged electrons knocked out of place. These positively charged molecules or ions remain in the field a relatively long time and increase the flow of the electrons. This increases the current more rapidly than the pure electron current would increase and so deviates from the 3/2 power law. This explains the meaning of such counts as 2 to 5, inclusive.

The degree of ionization in a tube varies with the quantity of gas therein. Generally when ionization occurs the current at a given voltage is larger than it would be at that voltage were no appreciable ionization present. If, therefore, a tube containing some gas were operated and the vacuum therein were gradually increased, as by a pump, the voltage remaining constant, the current would drop as the vacuum improved until ionization became substantially negligible, when the drop in current would cease. This is a test of the invention as defined in such counts as 2 and 3.

The character of the electron discharge is affected by the relation of the parts of the tube. When the passage for the electrons is long, narrow or crooked, the electrons strike the walls of the tube and adhere thereto. This is exemplified by the Lilienfeld experiments in which a long, crooked, capillary-like tube was employed. Only a very minute current was obtained although thousands of volts were employed. Furthermore, it is not possible to remove all the gas, and, when the passage for the electrons is restricted, ionization takes place even in a very high vacuum. Such counts as 5, 8 and 9 call for such a "relation of parts" as render the tube capable of producing a current governed by the combined effect of the electric field of the electrons and the potential applied to the electrodes. Count 9 further states that the current is substantially unaffected by secondary electron emission from the walls of the tube. When the walls are long, crooked or narrowly spaced, the electrons adhere to them, as stated, until they are knocked loose by the electrons of the primary discharge. When thus set free, they constitute a secondary electron emission. The count further states that the current is substantially independent of the cathode temperature. According to Richardson's Law, which is extensively discussed in the records, the electron emission from the cathode increases with the temperature of the latter. But the number passing to the anode, in a tube of the issue, depends upon the impressed voltages. If at a given cathode temperature there are sufficient electrons to furnish the current at the voltage used, an increase of temperature and an increase of electron emission will not increase or otherwise affect the current. Under such conditions, the current is substantially independent of the cathode temperature.

Counts 12 and 13 are the only ones that call for the third electrode. This electrode is generally referred to as the "grid." It is placed between the cathode and anode; and when an electromotive force is applied to it, it modifies the electric field and controls the current passing to the anode. When there is no ionization, this control is certain and the variations in the current follow proportionately and in a reproducible manner the variations of the electromotive force applied to the grid.

The invention in issue is, therefore, a thermionic tube that operates with a pure primary and substantially no secondary electronic discharge at voltages above ionization and below saturation; and such a tube is to be recognized by its response to the characteristics expressed in the several counts. The tubes of counts 12 and 13 have three electrodes, while those of counts 1 to 11 may have two or more, these counts being generic.

The question for us to determine is who, of the parties involved, first knowingly and understandingly conceived and produced such a tube. This brings us to a consideration of the testimony.

Arnold, the junior party, does not claim to have conceived the invention prior to November 1, 1912, or to have reduced it to practice prior to the 29th of that month. On the other hand, Langmuir alleges conception, disclosure, sketches, written description and successful operation prior to September 1, 1912, followed by the successful operation of other devices embodying the invention in November, 1912. Arnold's testimony, as does his preliminary statement, limits his activities with respect to the invention to a period beginning November 1, 1912. If, therefore, Langmuir has established conception prior to that date and reduction to practice prior to November 29, 1912, or conception prior to November 1, 1912, with due diligence leading up to a subsequent reduction to practice, either actual or constructive, he must prevail, and it will, in that event, be unnecessary to make a detailed analysis of Arnold's proofs. We will, therefore, first take up a consideration of Langmuir's case. Before doing so, however, we wish to state, in a general way, our views as to what constitutes conception or reduction to practice of the invention.

If one, working in some "useful" art, produces a device which is new, of practical utility and such as is unobvious to those skilled in that art, he has made an invention; and it is immaterial that he may not, at the time foresee all its uses, or understand the scientific principle underlying it. He must, however, know that it has some practical utility and must be able to teach those skilled in the art how the device may be reproduced and how it may be used to accomplish some practical and useful result. If he simply notes that it behaves in some novel and characteristic fashion under certain conditions, but has no idea as to how it can be used to accomplish some practical result in relation to the useful arts, he has not gone far enough to entitle himself to a patent. He is purely an investigator. When he has discovered how his device may be made of some practical use, he has completed the inventive act. Further, if in the course of his experimentation, he actually makes a new, useful and unobvious thing but does not know it, or, knowing it, does not know how he did it, he cannot teach others how to make and use the thing. Consequently, he has added nothing to the sum of practical knowledge and has made no invention.

Langmuir's application herein involved is assigned to the General Electric Company, by which he is employed. This Company has an extensive research laboratory which is thoroughly equipped for scientific experimentation. In this laboratory Langmuir did his work. He had an assistant named Sweetser.

It appears, particularly from the record on the motion, that prior to the production of the present invention, Langmuir was familiar with the so-called Edison effect and the Fleming valve and knew that an electron current passed from the heated cathode to the anode in an exhausted tube when potential was applied. He also knew that this current was modified by the presence of gases and that the gases could be eliminated, at least in part, by heat, as by lighting the filaments. This was known as the "clean-up" effect. In the first part of 1912 Sweetser was investigating this effect, and Langmuir kept in close touch with and directed his work. Some devices were made and tested that Langmuir contends embodied the invention in issue and were reductions to practice. It is clear that great care was observed in the preparation of these devices particularly in the heat treatment of the glass and the electrodes, and that charactristics approximating those of the issue were observed. Langmuir had been working on gas-filled lamps for some time, and the tests in August, 1912, had special reference to the clean-up of nitrogen in lamps. For this reason, presumably, nitrogen was introduced into the tube, which was then operated at voltages far above ionization. In the beginning of the run, when the gas pressure was highest, the thermionic current was 18 milliamperes. As the operation proceeded the pressure fell until it reached 1.08 microns without material reduction in current. But below that, the current fell off until, when the pressure reached about .34 microns, the current become substantially constant at about 4.5 milliamperes. The results of the tests were tabulated by Sweetser in Langmuir's Exhibit No. 79. On page 103 of Langmuir's Priority Record is a plot made from Sweetser's data which shows that the current and voltage followed approximately the 3/2 power law. At the time of these tests, however, Langmuir was not familiar with this law.

The August, 1912, experiments were made with a specially prepared thermionic tube which was operated at voltages above that of ionization and below saturation. There was no blue glow and the results showed a close approximation to the 3/2 power law, which is one of the characteristics of the tubes of the issue. But apparently it was an approximation only. However, we cannot agree with the examiner of interferences that Langmuir had no conception of the invention as defined in counts 1 to 11. It is true he did not then forsee all of the marvelous possibilities of the device; but he certainly had in mind a thermionic tube having such a relation of parts and such a degree of vacuum therein that there should be no ionization at 200 volts and in which the space current should be as high as 5 milliamperes. He also knew how to make such a device. If at that time he had been called upon to define the tube he had in mind he would not have employed such terms as space charge, 3/2 power law and logarithmic plot as were subsequently adopted when the counts of the issue were formulated. But these things are not the invention. They are simply characteristics of the invention—ear-marks by which the invention may be recognized. If Langmuir had in mind a tube that would operate with a pure electron discharge at voltages above ionization and below saturation and knew how to produce it, he had the invention in mind. We therefore hold that he is entitled to a date not later than the first of September, 1912, for conception of the invention as defined in counts 1 to 11, inclusive.

In November, 1912, Langmuir prepared three tubes with extraordinary care. They had been made some time before for another purpose but had not been used. No doubt they were selected because of the peculiar arrangement of the filament which was in three sections with four separate leads. Current could be passed through any section singly, through any two adjacent sections or through all sections in series. A two filament tube could be produced only by burning out or otherwise destroying the middle section. The tube was exhausted mechanically to a high vacuum, after which the middle section of the filament was vaporized by running an abnormally high current through it. This had the effect not only of making two electrodes, but of cleaning up the tube and increasing the vacuum to a higher degree than had been obtained before. We cannot doubt that this method was adopted for the express purpose of denuding the tube of all gases that might produce ionization when high voltages were employed.

The tubes thus prepared were tested and the results tabulated. (Langmuir Ex. #81, pages 124 *et seq.*). 250 volts were applied. The cathode was heated increasingly from 1730° to 3320° K. The current increased with the temperature at first, then fell behind and finally became constant. On November 20, 1912, Langmuir wrote in his notebook (p. 126 of Exhibit #81):

> "The Edison current does not increase indefinitely with the temperature but reaches a max. value at about 2700° at which it remains constant. It is roughly proportional to the voltage at the anode."

Again on page 130 he wrote:

> "With the first few runs there was a slight tendency for the Edison current at any given temperature to increase except with very high temperatures. At those very high temperatures the current was absolutely constant (independent of the temperature) and surprisingly independent of all external conditions of gas pressure, temperature of bulb, etc. This limiting current was approximately proportional to the voltage at anode and to area of anode."
>
> "After several runs quite consistent results were obtained on repeating."

This showed that no positive ionization was taking place, and that the discharge was purely electronic. Such a discharge was just what Langmuir was attempting to produce, and he succeeded. It does not seem to us material that Child had previously discussed the phenomenon that Langmuir actually observed. As Arnold admits (brief, page 115), Child made no application of the scientific principal he had discussed. But Langmuir did. He produced a tube which was operated at voltages far above any previously employed in thermionic tubes and obtained a current and an output correspondingly high. As he knew how he did it, he undoubtedly could have done it again and as often as he desired. We can perceive no ground that appears reasonable for holding that the tubes of November, 1912, were not reductions to practice of the invention of counts 1 to 11, inclusive, if Langmuir then knew they had practical utility. He was familiar with the Fleming Valve and of its uses. Certainly it must have been clear to him that his improved valve, with its possibility of use at high voltages and with an output of several watts, had utility. The tests of the tubes which demonstrated the presence of the invention were made on November 19, 1912, and Langmuir is entitled to that date for actual reduction to practice of the invention of counts 1 to 11 inclusive. This holding is made notwithstanding the fact that Langmuir did not at the time test the tubes to determine whether they followed the 3/2 power law or gave a straight-line on a logarithmic plot. As a matter of fact, Langmuir did not work out the mathematical theory of the space charge effect or derive the 3/2 power law until the following February. (Langmuir's Brief, page 153). But any tube built as these tubes were and exhausted to the degree that would prevent ionization at 250 volts would necessarily have responded to the various tests called for in the counts.

It seems logical to discuss at this point Arnold's contention that Langmuir has introduced new matter into his application. On page 15 of his brief Arnold copies count 4 as typical and sets it down in clauses *a* to *f*, clauses *c* and *e* being as follows:

> (*c*) the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation.
>
> * * * * * * * *
>
> (*e*) that the space current is governed or limited by the electric field of said electrons."

These two clauses, Arnold contends, are new matter in Langmuir's case. We do not so regard them. They are merely statements which are descriptive of the invention which is otherwise disclosed. When one fully describes an invention and its uses and it subsequently occurs to him, or he subsequently discovers, that it has some inherent characteristic that he had not pointed out in his original specification, an amendment setting forth this characteristic does not change or add to the invention and is not objectionable as new matter. Nor is it objectionable to include this inherent characteristic in his claims in order to point out his invention and distinguish it from prior art devices. It is our view that the characteristic referred to in Arnold's clauses *c* and *e* is inherent in the thermionic tube Langmuir had fully disclosed and that the description of the same and its inclusion in some of the counts does not import new matter into the application.

This brings us to a consideration of count 12, which is for the three electrode device, and 13, which is for the method of controlling an electric current in that kind of device. They are distinguished from the DeForest audion by the high vacuum and the space charge effect, as are certain of the other counts previously discussed.

Langmuir alleges conception, disclosure, drawings, written description and reduction to practice of the invention of these counts in the period between February 1 and March 15, 1913. These are later than the corresponding dates alleged by Arnold.

While experimenting in November, 1912, Langmuir noticed that the Edison current was affected by the presence of a spark coil or oscillator or by touching the bulb with the fingers. (Langmuir Ex. #81, pp. 135 and 136.) At the bottom of page 127 of his brief Langmuir suggests that this demonstrated the possibility of controlling a current of 250 volts by an electric field and by a principle which is the same as that employed by the three filament tubes. But three electrodes were not then employed or suggested, and there is nothing to indicate that Langmuir regarded the phenomenon he had observed as of any practical value. In any event he can be accorded no date of conception earlier than that alleged.

There is considerable discussion in the Langmuir Records, as well as in the briefs of both parties, of a recorded discussion between Langmuir and Dr. Coolidge respecting the latter's X-ray tube, and Langmuir contends that he reduced counts 12 and 13 to practice with a specially constructed and operated tube of that nature. In the view that we take of this matter it becomes unnecessary for us to pass upon the merits of this contention or upon Arnold's objection to the testimony respecting the X-ray tube.

In February, 1913, Langmuir disclosed and demonstrated the invention of counts 1 to 11, inclusive, to one White, who was another assistant in the Research Laboratory. A tube was then operated at 50 volts while the cathode temperature was increased from a dull red to full incandescence, and White was shown how the electron current increased with the temperature up to a certain point beyond which it became substantially constant. This showed that no ionization was taking place. He was then shown that at a constant temperature of the cathode and an increase of voltage from a low value the current became substantially constant at about 100 volts although the voltage was increased to about 200 (Langmuir Record on Motion, p. 597). Langmuir learned of the DeForest audion sometime about November, 1912; and, at the time of the demonstrations to White, he told the latter that he would procure an audion for him to test. Shortly thereafter an audion was turned over to White who subjected it to the same tests that Langmuir had employed at the earlier demonstration. When he used 50 volts and raised the temperature of the cathode the current did not become stationary, but a blue glow appeared. The results were not reproducible. He then took a three electrode tube that Langmuir had designed, and exhausted it to within a fraction of a micron. He then baked the tube for several hours at a temperature just below the maximum that the glass would stand without softening. He then heated the filament for some time above normal and then operated the plate as a filament. The grid and plate were then subjected to electron bombardment at currents and voltages higher than those under which they were designed to operate, and no blue glow or fluorescence appeared. The tube was then sealed, was tested as a relay, and White found that he

> "could get a good control of the plate current by means of the grid voltage, varying it from several volts negative to several volts positive and using voltages of over 100 on the plate."
>
> (Q17, Langmuir's Record on Motion, p. 602.)

It seems that Langmuir must have had a conception of the invention of counts 12 and 13 in the first half of February, 1913, since he made the demonstrations to White prior to the middle of that month. White fixes this date by an accident to himself which kept him out of the laboratory for about two weeks. However, it is not important that the exact date of conception be fixed, since one of the tubes White had made and tested was turned over to one Dushman on April 8, 1913, for use in measuring very small electric currents. On page 143 of Langmuir's Priority Record Dushman quotes from his notebook No. 464 as follows:

> "Langmuir gave me Audion No. 2 for use in these experiments, also White gave me calibration curve giving relation between Plate EMF and grid EMF for different currents."

He then says:

> "The main difficulties encountered in using the audion were those due to a lack of proper resist-

> ance. In order to obtain the best amplification with the audion, it was necessary to have a nice adjustment between the resistance used in the plate and grid circuits, and the determination of this adjustment consumed a great deal of time. Finally, I did succeed in obtaining very satisfactory results. On these experiments I used voltages up to 240 on the plate of the audion and obtained perfectly reproducible and constant results. There was no evidence of blue glow or any erratic behavior which would indicate positive ionization in the bulb."

Respecting these experiments, Langmuir wrote in his notebook No. 458, page 60 under date of April 15, 1913:

> "Dushman has been using our Tube 2 for magnifying the current of his photo electric cell. He had no trouble getting 1,000 fold magnification and at one time for a couple of hours he found beautiful proportionality between the original current and the magnified current. Later he could not reproduce these conditions."

It appears from Dushman's statement that the troubles were probably due to lack of proper resistances or to leakage somewhere outside the tube and not to the tube itself.

As before the examiner of interferences, Arnold objects to the evidence respecting Dushman's experiments with Audion No. 2 on the ground that, the contemporaneous records not being produced, the oral testimony of the witnesses is not the best evidence. We agree with the reasoning and the conclusion of the examiner of interferences as to this contention and further discussion of the same is deemed unnecessary. It may be pointed out, however, that the production of said records, the existence of which was admitted (White, XQ137, p. 655 of Langmuir's Record on Motion), was not requested and was not refused. Arnold's statements that they were suppressed is therefore considered unwarranted.

In view of all the above, we find that Langmuir had conceived the invention of counts 1 to 11, inclusive, at least as early as September 1, 1912, and had reduced the same to practice by November 19, 1912. As to counts 12 and 13, he had conceived certainly prior to April 8, 1913, and had reduced to practice by April 15, 1913.

Little need be said on the other side of the case as respects counts 1 to 11, since Arnold does not allege conception and reduction to practice until after the corresponding dates, we have awarded to Langmuir. Consequently, Langmuir is entitled to prevail as to these counts for the reason that he was the first to conceive and the first to reduce. Counts 12 and 13, however, call for some consideration of Arnold's proofs.

In 1911 the American Telegraph and Telephone Company and the Western Electric Company were building a transcontinental telephone line, for which they required a better repeater than any that was then available. The latter company, which is the assignee of the Arnold application, employed Arnold to develop for it a repeater that would meet its needs. Arnold conceived the idea of employing the mercury arc, and, by 1912, he had done considerable work in the way of developing a repeater of that type. In the latter part of October, 1912, Dr. DeForest demonstrated his audion to Dr. Jewett and Mr. Colpitts in the laboratory of the Western Electric Company. Arnold was not present at this demonstration; but, on November 1, 1912, he was called in and the same was repeated. The audion appeared to amplify feeble sounds, but broke down and showed blue haze when louder sounds were employed. Furthermore, its available output—said to be less than six milliwatts—was entirely too small for a telephone repeater. According to the testimony, Arnold at once perceived just where the troubles lay, and then and there disclosed the invention in issue to Colpitts and Jewett. He pointed out the necessity of a high vacuum and explained the space charge effect (Colpitts, p. 74 Arnold Priority Record). Jewett testifies (p. 65, same record):

> "Dr. Arnold said that he could make a tube like these DeForest audions but with greater electron emission and so much better evacuated that erratic behavior due to positive ionization would be eliminated, and the device could be operated at the higher voltages necessary for telephone repeater service without sacrifice of its favorable operational features."

According to this testimony, Arnold had a conception of a thermionic tube so thoroughly evacuated that it would have a pure electron discharge; and if it clearly appears that he knew how to produce such a tube we would consider him entitled to November 1, 1912, for conception of the invention in issue. But we are not satisfied that he had such knowledge, and his subsequent acts indicate that he did not have. Unless he could produce the device of the issue and could teach others how to produce the same, he had not a complete conception. Colpitts says (p. 72, Arnold Priority Record) that

> "Arnold assured us that the 'blue haze' and the accompanying erratic and noisy behavior could be overcome by eliminating the residual gas from the tube by methods of heat treatment and pumping with which he had become familiar in his previous work and study."

But he does not say what was to be given the heat treatment, for how long a time or at what temperature. In our consideration of Langmuir's work in August, 1912, we refused to give him a reduction to practice although the heat treatment and pumping had actually been carried on to a high degree. Certainly, the mere suggestion of the employment of a heat treatment and pumping is insufficient to show that Arnold knew how to carry out such treatment to secure the results he had in mind.

On November 16, 1912, Arnold set his assistant Pierce to work determining the characteristics of the audion. One of the filaments of audion No. 7 was burned out on November 29, 1912, and this, of course, improved the vacuum. But this was not done with a purpose and if Arnold knew what had been the effect he apparently failed to appreciate it. In any event, it was not subsequently resorted to, although it was a simple process and one that would seemingly have made the Gaede pump unnecessary. But this pump was ordered from Germany some months later and was received in the spring of 1913. It was used on April 25, 1913, to evacuate audion No. 202. Respecting this operation Arnold testified (p. 50, Priority Record):

> "These tests with the molecular pump were not undertaken by me as tests of the operableness of a high vacuum tube. Of that there had been no doubt in my mind. They were merely tests of the usefulness of the Gaede molecular pump in helping us to attain the high vacuum required. With it thus established that the Gaede pump was capable of producing the required high vacuum repeater tubes, and that they would stand up in service, I ceased to concern myself with this phase of the matter and left the evacuation of devices from that time on in the hands of our laboratory assistants."

This seems to us an admission by Arnold that, prior to April 25, 1913, he was merely speculating on ways and means for securing the vacuum in the tubes necessary for producing the pure electron discharge. Prior to that date, therefore, Arnold had no complete conception of the invention in issue, since he did not know whether the necessary vacuum could be attained.

The examiner of interferences has held that Arnold reduced to practice the invention of counts 2 to 5, inclusive, 9, 10, 12 and 13 on April 25, 1913 when he tested tube 20.2. The data regarding this test are recorded on page 105 of Pierce's notebook (Arnold Exhibit No. 18) and are plotted on Sketch No. E. S. 86907 (Exhibit No. 19). This plot is somewhat puzzling. The long full-line curve seems to follow some power law up to about 24 volts, then to bend over slowly to the right to about 40 volts after which it bends rapidly in the same direction, indicating saturation. But, instead of the current becoming constant under increased voltages, it rapidly drops until at about 210 volts it is but a little more than 3.5 milliamperes where it remains substantially constant up to 240 volts. When, thereafter, the voltage was lowered, the current at once fell and its curve by no means reproduced the curve obtained with the increasing voltages until the 24 volts was again reached. Apparently, therefore, the results were not reproducible except below 24 volts. During this test the filament current was 69 amperes. When the same tube was tested with a filament current of .64 amperes the results were much the same, the ascending and descending-voltage curves coinciding only below 16 volts. Those parts of both curves where reproducible results were apparently obtained do not follow the 3/2 power law, being much too steep. This seems to indicate ionization. If the 3/2 power law is an accurate test of the presence of the invention of the issue, as the parties agree, then Arnold's 20.2 tube did not embody the issue. However, the same exhibit (No. 19) shows a plot in dotted lines of Audion B which appears to follow substantially the 3/2 power law and which indicates substantial reproducibility up to 100 volts. The data from which this plot was made was obtained April 25, 1913, and recorded on page 107 of Pierce's Notebook (Exhibit No. 18). In view of this data and plot, we find that Arnold conceived and reduced to practice the invention of all the counts except 1 and 11 on April 25, 1913. As to these two counts, we agree with the examiner of interferences that they were not reduced to practice until after Langmuir's filing date.

As to all the counts, therefore, Langmuir was the first to conceive and the first to reduce. The decision of the examiner of interferences awarding priority to Langmuir is accordingly affirmed.

Limit of Appeal: May 11, 1923.

S. E. Fouts,
R. E. Marine,
E. S. Henry,
Examiners-in-Chief.

Opinion of Assistant Commissioner of Patents.

October 27, 1923.

(Interference Record p. 2509.)

IN THE UNITED STATES PATENT OFFICE.

Patent Interference No. 40,380.

ARNOLD

v.

LANGMUIR.

Appeal from Examiners-in-Chief.

Electric Discharge Apparatus and the Process of Preparing the Same.

Application of Harold De Forest Arnold filed November 2, 1915, No. 59,210.

Application of Irving Langmuir filed March 14, 1916, No. 84,242, for renewal of application filed October 16, 1913, No. 795,610.

Messrs. De Witt C. Tanner and John G. Roberts and Mr. Geo. E. Folk for Arnold. Mr. Carl A. Richmond of counsel.

Mr. Albert G. Davis and Mr. Alexander D. Lunt for Langmuir.

This is an appeal by Arnold from a decision of the examiners-in-chief affirming the examiner of interferences awarding priority on all counts to Langmuir.

The issue is a thermionic tube in which there may be a pure electron discharge as distinguished from a discharge through gas which is ionized, so as to be useful for such purposes as a telephone relay, a wireless detector or amplifier, a rectifier of alternating current and possibly a generator of X-rays. It is the device of defendant in Hewitt *v.* American T. and T. Co., 272 Fed. Rep., 194, and 272 Fed. Rep., 392. The invention is exemplified by a structure such as the well known De Forest audion or Fleming Valve (see Marconi Co. *v.* De Forest Co., 236 Fed. Rep., 942), modified so that there is present during operation too little gas to modify or affect the pure electron discharge from the cathode.

The applications were filed in 1913 (renewed in 1916) and 1915. After the interference was declared, Arnold moved to dissolve on the ground that the issue was unpatentable. In February, 1917, the Commissioner ordered testimony to be taken on the question of patentability and between July, 1917, and January, 1920, over 1,650 printed pages of testimony accompanied by a great mass of exhibits were introduced. Much of this testimony should not have been taken since it related to priority alone. Motions were made to amend the issue and some counts were withdrawn. The law examiner rendered a seventeen page opinion settling the counts and finding patentability. Subsequently, by stipulation, other counts were added and the issue fixed into thirteen counts, of which the following are sufficiently illustrative:

1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode, and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts.

5. A discharge tube having electrodes at least one of which is adapted to emit electrons, the gas content or

residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that in that range the space current is governed by the combined effect of the electric field of said electrons and the potentials applied to said electrodes, the governing or limiting of the current being substantially unaffected by positive ionization and by secondary electron emission from the walls of the tube.

7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltages, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissæ is straight and continuous.

9. A discharge device comprising a tube and electrodes therein one of which is an electron emitting cathode, the degree of evacuation of said device and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission is such that the space current is below the saturation region at such voltages, that said current is substantially independent of the cathode temperature and unaffected by secondary electron emission from the walls of the tube.

11. A discharge tube having a cathode adapted to emit electrons, an anode adapted to receive electrons and tube walls fashioned or shaped so as to permit the free passage of the useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of operation with stable and reproducible results substantially unaffected by positive ionization, with currents of at least 5 milliamperes and with voltages of at least 200 volts.

13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner.

The counts are ably and clearly analyzed by the examiners-in-chief thus:

A thermionic tube which operates solely by electron discharges or currents has certain distinctive characteristics by means of which the presence of the invention may be recognized, and the counts have been so worded that each brings out one or more of these characteristics. For example, count 1 specifies that the envelope of the tube is evacuated to such a degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts. Thus the count distinguishes from the prior art, not by features of structure, but by a characteristic which is manifest while the device is operating at or above a certain voltage. The audion is not evacuated to the high degree that count 1 calls for, and at an impressed voltage of about 30, ionization occurs. Count 5 specifies that the relation of the parts of the tube and the degree of evacuation are such that, when operated in a range below saturation and materially above ionization voltages, the space current is governed by the combined effect of the electric field of the electrons and the potentials applied to the electrodes, the governing or limiting of the current being substantially unaffected by secondary electron emission from the walls of the tube.

When a thermionic tube is operating by a pure electronic discharge at a voltage substantially below saturation, the current varies in substantial accordance with the 3/2 power of the impressed voltage. If the voltages be plotted as abscissas and the currents as ordinates, the result is a curve that gradually rises and turns toward the left—the curve of the 3/2 power. This obtains while there are plenty of electrons emitted from the cathode, at the temperature at which it is heated, to make up the increasing current. But the number of electrons emitted varies with the temperature of the cathode and that temperature is generally maintained constant. Consequently, a voltage will be reached which is capable of forcing the electrons across the space more rapidly than they can be emitted. The result is the flat-topped curve showing saturation. The tubes of the issue are operated at voltages above that of ionization and below that of saturation, and the voltage current curve follows the 3/2 power law. This is one of the characteristics of the tubes; and a tube that has such a characteristic operates by a pure electronic discharge and is a tube of the issue.

Ionization occurs when there is gas within the tube during operation. This gas may be normally free, as when mercury vapors are present, or it may be absorbed or occluded in the electrodes, particularly the anode, and in the glass walls of the tube. The electrodes and walls act like sponges, taking up the gas when cold and again giving it off when heated during operation. A tube which has gas either in a normal free state or occluded in the electrodes or walls is subject to ionization; and ionization takes place when the voltage rises sufficiently to produce it. About 15 volts is sufficient to give this result. But a tube which operates by ionizing a gas does not respond to the 3/2 power law and is not a tube of the issue. Excessive ionization is usually accompanied by a blue glow or haze; but such a glow is not a reliable test, as both parties admit, since a tube that does not show blue glow may produce ionization to such a degree as to cause it to depart from the 3/2 power characteristic.

Any tube which gives the 3/2 power voltage-current curve must also give the straight-line when the volts and current are plotted on logarithmic paper. These two curves are plotted from the same data and their differences are due simply to the difference in the arrangement of the lines on the paper. If, therefore, the volts and currents be plotted on one kind of paper and the result shows a pure electron discharge, there can be no doubt what the other kind of paper would show. Certain counts, as 6 and 7, call for the straight-line, while count 8 calls for the 3/2 power characteristics.

Other counts refer to the electric field of the electrons (count 2) or to space current due to the electric field of the electrons (count 3). The electrons are supposed to be exceedingly minute pieces of negative electricity, and they react on one another just like a flock of pith balls would react if they were confined in some manner so that they were each within the field of influence of the others. If they were all charged with negative electricity and there were no available positive charge to neutralize them, they would simply create an electric field or space charge. But if at one part of this field a positive charge were created, the negatively charged pith balls would fly across the field to it, thus setting up a current. That is what happens in the tubes of the issue. The electrons are generated or emitted by the heated cathode; and if there is no way of neutralizing them they simply fill the space, charge it negatively, and react on one another. But if the anode be charged positively, the electrons fly across the field to it and become neutralized. This flow of electrons is a current; and, assuming a sufficient emission of electrons, the strength of the current is dependent on the potential difference between the cathode and anode. If this difference is small, comparatively few electrons get through and the others continue to react on one another. If no gas be present in the tube, either free or occluded, the current is governed by the electric field of the electrons and the potential applied to the electrodes. If gas is present and the voltage is above ionization, some of the gas molecules become ionized and rendered positive by having one or more of their negatively charged electrons knocked out of place. These positively charged molecules or ions remain in the field a relatively long time and increase the flow of the electrons. This increases the current more rapidly than the pure electron current would increase and so deviates from the 3/2 power law. This explains the meaning of such counts as 2 to 5, inclusive.

The degree of ionization in a tube varies with the quantity of gas therein. Generally, when ionization occurs the current at a given voltage is larger than it would be at that voltage were no appreciable ionization present. If, therefore, a tube containing some gas were operated and the vacuum therein were gradually increased, as by a pump, the voltage remaining constant, the current would drop as the vacuum improved until ionization became substantially negligible, when the drop in current would cease. This is a test of the invention as defined in such counts as 2 and 3.

The character of the electron discharge is affected by the relation of the parts of the tube. When the passage for the electrons is long, narrow or crooked, the electrons strike the walls of the tube and adhere thereto. This is exemplified by the Lilienfeld experiments in which a long, crooked capilliary-like tube was employed. Only a very minute current was obtained although thousands of volts were employed. Furthermore, it is not possible to remove all the gas, and, when the passage for the electrons is restricted, ionization takes place even in a very high vacuum. Such counts as 5, 8 and 9 call for such a "relation of parts" as render the tube capable of producing a current governed by the combined effect of the electric field of the electrons and the potential applied to the electrodes. Count 9 further states that the current is substantially unaffected by secondary electron emission from the walls of the tube. When the walls are long, crooked or narrowly spaced, the electrons adhere to them, as stated, until they are knocked loose by the electrons of the primary discharge. When thus set free, they constitute a secondary electron emission. The count further states that the current is substantially independent of the cathode temperature. According to Richardson's Law, which is extensively discussed in the records, the electron emission from the cathode increases with the temperature of the latter. But the number passing to the anode, in a tube of the issue, depends upon the impressed voltages. If at a given cathode temperature there are sufficient electrons to furnish the current at the voltage used, an increase of temperature and an increase of electron emission will not increase or otherwise affect the current. Under such conditions, the current is substantially independent of the cathode temperature.

Counts 12 and 13 are the only ones that call for the third electrode. This electrode is generally referred to as the "grid." It is placed between the cathode and anode; and when an electromotive force is applied to it, it modifies the electric field and controls the current passing to the anode. When there is no ionization, this control is certain and the variations in the current follow proportionately and in a reproducible manner the variations of the electromotive force applied to the grid.

The invention in issue is, therefore, a thermionic tube that operates with a pure primary and substantially no secondary discharge at voltages above ionization and below saturation; and such a tube is to be recognized by its response to the characteristics expressed in the several counts. The tubes of counts 12 and 13 have three electrodes, while those of counts 1 to 11 may have two or more, these counts being generic.

The record on the motion and the accompanying exhibits were stipulated in for use on priority, and during 1921 and 1922, upwards of 300 additional pages of testimony were taken. Appeals were promptly taken in what seems to be an honest effort of the parties to hasten a final determination of the case.

The inventions and their development have taken place in the laboratories and shops of the Western Electric Company and the General Electric Company. The parties have had at their disposal unlimited aid, both personal and financial, for the development and investigation of the invention, as well as for the presentation of their cases here. This would lead us to hope and expect to find the issue clearly and simply presented for consideration. It seems, however, that both parties and their counsel have been overpowered with amazement at the abstruse scientific theories that may be evolved to account for the plain simple facts of operation of the invented device. The result is that we are presented here with 379 pages of brief by Langmuir, who has the favorable decision of the examiners-in-chief, and 281 pages by Arnold, in an endeavor, not to controvert that decision, but to show his own priority. Neither brief pays much attention to the decisions below, but both attempt to treat the matter *de novo*, so that this decision may follow the same procedure.

The line between the prior art and the issue is attenuated and if there is patentability, it must be as set out in the decision of the law examiner on the motion, and I do not understand either party to attack that decision here. Arnold alleges that when he made the invention, he thought he was following the prior art and not producing something patentable, and an undercurrent of that attitude seems to tinge his whole case. This is why he filed so late.

I do not find it necessary to go beyond the decision of the law examiner to determine patentability or to interpret the prior art which was elaborately presented to him. He refers to:

Article by Fleming in Scientific American Sup., Jan. 20, 1906, p. 25,129;

Article by Deininger in the Annalen der Physik, IV, Vol. XXV, p. 288 (1908);

Article by Von Baeyer, Physicalische Zeitschrift for 1909, p. 168;

Article by Gehrts, Annalen der Physik 39, p. 995 (1911);

Article by Child in the Physical Review, Vol. 32, p. 448 (1911);

Articles by Lilienfeld, Annalen der Physik 32, p. 673 (1910); Physicalische Zeitschrift 9, p. 193 (1908);

J. J. Thomson's Conduction of Electricity Through Gases, pp. 222 to 227;

Shottky, Jahrbuch der Radio Activitat, Vol. 12, p. 147 (1915);

Shottky in Physikalische Zeitschrift, 15,526 (1914).

After quoting freely from Langmuir's specification, he says:

It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. An evacuated tube having therein an incandescent electron-emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube, were also well known and available to persons skilled in the art.

* * * * * * *

The suggestion that the alleged invention represents a mere difference in degree over the prior art loses its force in the presence of the results accomplished (Edison *v.* U. S. Co., 52 F. R. 300, 308; General Electric Co. *v.* Nitro Tungsten Lamp Co., 282 O. G., 195), and the allegation of no invention is overcome by the presumption of invention in the transformation of laboratory experiments, and erratic and unstable devices into reliable, stable and successful commercial products (Marconi *v.* De Forest, 243 F. R. 560).

It will be seen then that the present invention lies not in discovering or producing something new, but in perceiving the practicability of scientific facts known in the laboratory and in making practical, useful devices embodying the scientific laws known in the laboratory.

I am struck throughout the record with the care, caution and integrity of the parties and the witnesses. The effort seems to be constantly present to be scrupulously accurate and truthful. The benefits of this are largely lost by the fact that much of the record is made up of sworn statements followed by very little cross examination, some of which is by similar statements made not in the presence of opposing counsel.

Arnold claims conception of the invention "on or about Nov. 1, 1912."

Langmuir's original preliminary statement alleged conception of the invention "all during the month of November, 1912," but when the office objected to that he filed a new statement alleging: "the first device embodying the invention set forth in the issue of the interference was conceived * * * between the middle of the month of July, 1912, and the first day of September, 1912." We will see that his attorneys claim for him conception of the invention in August, 1912, but he meant what he said —not conception of the invention but conception (unperceived) of a structure embodying the invention, but for which he perceived no practical use.

As early as 1884, Thomas A. Edison discovered that in an evacuated incandescent lamp the current did not all go through the filament, but a portion leaked by jumping through the vacuum from one leg of the filament to the other leg. This was referred to as "Edison Current" and now is known as electronic discharge. In 1912, Langmuir was a recognized authority on incandescent lamps and was working in his laboratory on various tungsten lamp problems. In July, 1912, he asked an assistant, Sweetser, to do certain experimenting for him. It was known that Edison Current tended to improve the vacuum in a lamp by cleaning up the remaining traces of gas. Of his work between July 20 and September 13, 1912, Sweetser says:

> * * * the primary interest in this experiment was the "clean up." The electron current was observed according to the general purpose of the experiment to determine its effect on the "clean up." As nearly as I can make out from the records, the purpose of the experiment is not to include a study of Edison current except as connected with the "clean up." (Langmuir Record on Motion, p. 734.)

During these operations some peculiar characteristics of the Edison current were observed and it is alleged by Langmuir's attorney that this was a reduction to practice of the invention, and the examiners-in-chief say it was a conception of the invention. It does not appear that what was done then was of any practical effect in the manufacture of incandescent lamps. The most that Langmuir can say in 1919 is:

> (7) During August, 1912, we made experiments with lower gas pressures, using in many cases initial pressures of about 5 microns of nitrogen, and usually employing 200 to 250 volts on the anode. Under these conditions the residual nitrogen gradually disappeared, and in those cases in which the cathode temperature was rather high,

the final pressure obtained was of the order of 0.3 microns. Before this lowest pressure was obtained, the character of the discharge changed completely, and from the results recorded, and by comparison with experiments subsequently made (November and December, 1912), I can now recognize clearly that with this new type of discharge we actually had a device in which the current was limited by space charge, substantially independently of positive ionization, at voltages as high as 250 volts. (Langmuir Record on Motion, p. 546.)

But the law examiner held the space charge effect to have been recognized in the prior art. So that by these experiments Langmuir was doing nothing new and adding nothing to the sum of human knowledge. He had neither conceived the invention nor reduced it to practice. It is easy to see why the peculiar words were chosen for use in his preliminary statement.

Langmuir's interest was still paramount in incandescent lamps and he continued looking at Edison Current from that aspect. In November, 1912, he proceeded to experiment with other lamps "exhausted in the regular way that tungsten lamps were exhausted." These lamps had a long filament with four separate leads dividing it into three loops. Sufficient current was applied to the middle loop to burn it out and experiments were performed with Edison Current between the remaining loops. Very elaborate notes are introduced with reference to all these experiments, but there is doubt as to why the middle filament was burnt out. The notes say to separate the other two; the testimony says for that purpose and also to effect "clean up" in the bulb. Probably the latter is true, as such a clean up was not new. Work with this bulb surprised Langmuir by showing some of the effects of pure electronic discharge. He testifies his purpose was "to get an understanding of the fundamental laws involved, and thus *settle once for all whether or not* pure electron currents could be obtained in a practically perfect vacuum." This statement shows clearly that Langmuir had not made the invention before he started the November experiments. There is controversy as to what these experiments proved, but it seems clear that they produced nothing practical. Langmuir was still involved mentally with tungsten illuminating lamps and his report was to a group at the General Electric Laboratory which held weekly "conferences on matters relating to lamps" known as the Lamp Vacuum Committee. The minutes under date of November 21, 1912, show that Langmuir reported his results and then did not insist on a high vacuum, but thought his effect was produced by gas present. "A plausible hypothesis to account for some of these effects is that a small amount of some gas such as argon always remains in the lamp." He makes no suggestion of practical use of what he has discovered. He is merely an experimental scientist traveling the road the prior art considered by the law examiner had already traveled—of course unknown to Langmuir. He says that "after November, 1912, steps were immediately taken to develop applications of this pure electron discharge" (Langmuir Priority Record, p. 120), but the first date I find in the record is December 10, 1912, when Langmuir writes in his notebook what to him indicates that he has suggested to Coolidge that his experiments might have a practical bearing on X-ray tubes. The lower tribunals have rightly refused Langmuir any benefit of the work of Coolidge, because Coolidge was not called to testify. But even if benefit be given, the first date of thought of practical use is December 10, 1912, and Langmuir can have no date of conception prior to this, since the law examiner has held that the invention lies not in laboratory experiments such as Langmuir had performed, but in commercial products. It was even later than this that he learned of DeForest's work with the audion. We need not go further with Langmuir's activities.

On October 30 and 31, 1912, DeForest brought one of his audions to the Western Electric Company and suggested its use as a telephone repeater. It was installed on an experimental telephone line and operated feebly for low sounds which produced small currents.

Prior to this time, Dr. Arnold had been employed by the Western Electric Company to work on telephone repeaters. He was recently from college where he had specialized in the physics relating to electric arcs between metal electrodes at various gas pressures. He had subsequently done graduate work along the same lines and as a part of this work had examined all available prior art literature. His entire life work was along the lines of electronic discharges. The DeForest audion was a device of this character and when the Western Electric people saw that it was not sufficiently useful for their purposes, they called in Arnold and on November 1, 1912, showed him the device in the experimental telephone line. Arnold testifies on pages 12 *et seq.* of Arnold's Priority Record, that on November 1, 1912, he explained that if the DeForest audion were further evacuated so that there would be in it only a pure electronic discharge not interfered with by ionization of the residual gas, the device would answer the purposes of the Western Electric Co. as a telephone repeater. This is confirmed by Colpitts and the other witnesses, they having been sufficiently informed of scientific facts to understand Arnold's suggestion. Arnold was thus able to make a practical or commercial application of the prior art laboratory knowledge. I agree with the examiners-in-chief where they say:

> According to this testimony, Arnold had a conception of a thermionic tube so thoroughly evacuated that it would have a pure electron discharge; and if it clearly appears that he knew how to produce such a tube, we would consider him entitled to November 1, 1912, for conception of the invention in issue.

Further, I am satisfied that Arnold knew how to produce such a tube. The law examiner says of the prior art "methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube, were also known and available to persons skilled in the art." Arnold had worked in this specific art for years and it seems unreasonable to believe he did not know how to produce the vacuum. The testimony is that he did. We have seen that Langmuir relies on the four lead tubes as a reduction and they were "exhausted in the regular way that tungsten lamps were exhausted," which seems to indicate that a novel exhaust was not necessary.

Langmuir in his brief here says:

> The important thing is to get a proper preparation of the tube and its parts; the method by which this is done is not important so far as the issues of this interference are concerned, so long as the result is achieved.

The Langmuir specification describes the device as prepared by evacuation, heat treatment of the glass tube, and heat treatment of the electrodes to eliminate occluded gases. (See also White's Answer to Q16, Langmuir Record on Motion, p. 601.) Arnold had developed an "arc repeater" filled with mercury vapor and had found that other vapors interfered with the work. He had therefore had to resort to heating the glass tube and heating the electrodes to eliminate gases other than mercury. At his University laboratory he had been familiar with means for producing high vacua, but the laboratory of the Western Electric Co. had not such means. He looked about and could not find what he wanted in New York and finally ordered by cable from Germany the very vacuum pump recommended in Langmuir's specification. When it arrived he produced tubes which operated practically and the subsequent commercial operations of his company are admittedly reductions to practice. By means of Arnold's devices the first telephone message from New York to San Francisco was sent and the first trans-Atlantic wireless telephone operated.

After Arnold's disclosure on November 1, 1912, any one skilled, as he was, in the art could have produced the device of the issue. If I say a rubber button is a good thing to use in a hose supporter, I have conceived the button, even if I do not know how to make such a button. I may go to a rubber manufacturer and have him reduce my invention to practice and it will be my invention. So here, one skilled in the art could produce the device in issue as soon as told to do so by Arnold.

He who first conceives and gives expression to the idea of an invention in such clear and intelligent manner that a person skilled in the business could construct the thing, is entitled to a patent, provided he uses reasonable diligence in perfecting it. (McCormick Harvesting Machine Co. *v.* Minneapolis Harvester Works, 42 Fed. Rep., 152, [illegible]5.)

Here, the law examiner has held that the prior art taught him to get the required vacuum.

Before the pump arrived Arnold studied the characteristics of DeForest's audions at voltages below those of the issue and he found that one of these had a particularly effective high vacuum and it was successfully operated at voltages which are within the issue, but it is not necessary to hold it a reduction to practice as, in view of all the circumstances, the activities leading up to commercial use are sufficient to negative any lack of diligence on the part of Arnold.

Langmuir objects because Arnold did not proceed at once to use makeshifts to produce the proper vacuum in many bulbs, but I think he was justified in awaiting the arrival of the pump from Germany, especially since he studied the characteristics of what he had and started his associates preparing themselves for the work and did proceed soon after the arrival of the pump.

Adverse comment is made on Arnold's study of the DeForest audion after he says he made the present invention, but that is just what Langmuir had White do in February, 1913 (Langmuir Record on Motion, p. 599, Q14).

The condition of the negotiations for patent licenses from Cooper Hewitt and from DeForest sufficiently account for the activities with the "arc repeater."

I have carefully examined the records and tried to weigh every point raised by the arguments or elaborate briefs, but it is impossible to state in an opinion every consideration going to fix a conclusion in the mind.

What I have said shows that Arnold was first to conceive and proceeded diligently to reduce the invention of all the counts, including 12 and 13, which call for a third electrode which Langmuir did not deal with until 1913.

The examiners-in-chief are reversed and priority awarded to Arnold.

KARL FENNING,
Assistant Commissioner.

October 27, 1923.

IN THE

COURT OF APPEALS

OF THE DISTRICT OF COLUMBIA.

IRVING LANGMUIR, *Appellant,* *v.* HAROLD D. ARNOLD.	No. 1680. Patent Appeal.

Opinion of the Court.

(Filed June 1, 1925)

(6 Fed. [2nd] 704)

(Before MARTIN, Chief Justice, and ROBB and VAN ORSDEL, Associate Justices)

Appeal from a decision of an Assistant Commissioner of Patents in an interference proceeding awarding priority to the junior party, Arnold, and reversing concurrent decisions of the Examiner of Interferences and the Board of Examiners-in-Chief.

The invention is a thermionic tube adapted to be used as a relay in long distance telephone systems, as a detector or amplifier in wireless systems, or as a rectifier of alternating currents. The issue is expressed in thirteen counts, of which the 1st, 7th and 13th, here reproduced, will serve as examples:

"1. A high vacuum electron discharge device comprising an envelope, an incandescent cathode and an anode, the space in said envelope being evacuated to such degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts."

"7. A discharge device comprising a tube and electrodes therein one of which is adapted to emit electrons, the degree of evacuation and the relation of the parts of the device being such that the device is capable of being so operated, when voltages materially higher than ionization voltages are impressed on electrodes of the device and when the electron emission has any value such that the space current is below the saturation region at such voltage, that the line obtained by plotting the logarithms of any values of said current below the saturation region as ordinates against the logarithms of the corresponding values of said impressed voltages as abscissae is straight and continuous."

"13. The method of controlling an electric current in one circuit by an electromotive force in another circuit which consists in causing said current at voltages materially above ionization voltages to pass as a discharge across a vacuous space between an electron emitting cathode and an anode, maintaining a high vacuum in said space, governing or limiting the current by a space charge effect in said space substantially unaffected by positive ionization, and superimposing the effect of said electromotive force on said space charge effect to control said current in a stable and reproducible manner."

The attitude of the junior party, appellee here, when this interference was declared, is significant. He filed a motion challenging the patentability of the issue and sought and obtained permission to take evidence in support of that motion. The result was the taking of voluminous testimony by the parties on this issue, which by stipulation is in the record here. The Law Examiner, to whom this question was initially referred, sustained the patentability of the issue and his decision is controlling here. We therefore start our inquiry in this appeal with the established fact that, so far as this proceeding is concerned, the issue is patentable; in other words, that something more than mere mechanical skill was involved in the result achieved.

The examiner of Interferences, in an exhaustive opinion, awarded priority to the senior party, Langmuir. The Board, on appeal, directed attention to the fact that, structurally considered, the tubes of both parties outwardly are substantially identical with the Fleming valve and the DeForest audion of the prior art; that the invention has been referred to as a "thing compact of glass and metal". The Board then pointed out that this definition, although correct as far as it goes, is inadequate because it applies equally well to the prior art devices, and that to this definition should be added the qualification that the device "operates with a *pure* electronic discharge above the voltage of positive ionization and below saturation", and proceeded: "But how is one to know whether the discharge is purely electronic? In other words, how is one to know whether a tube embodies merely the prior art devices or the invention of the issue? * * * For example, count 1 specifies that the envelope of the tube is evacuated to such a degree that the passage of current produces no appreciable positive ionization when the impressed voltage is as high as 200 volts. Thus the count distinguishes from the prior art, not by features of structure, but by a characteristic which is manifest while the device is operating at or above a certain voltage."

Later in its decision the Board suggested that the question to be determined was, who of the parties "first knowingly and understandingly conceived and produced such a tube"; that Arnold, the junior party, did not claim to have conceived the invention prior to November 1, 1912, or to have reduced it to practice prior to the 29th of that month; that Langmuir, on the other hand, alleged conception, disclosure, sketches, written description and successful operation prior to September 1, 1912, followed in November of that year by the successful operation of other devices embodying the invention. The Board then carefully reviewed the testimony in support of Langmuir's contentions and found that he had conceived the invention of counts 1 to 11, inclusive, as early as September 1, 1912, and had reduced the same to practice by November 19th of the same year; that, as to counts 12 and 13, Langmuir had conceived prior to April 8, 1913, and had reduced to practice by April 15th of that year; that Arnold conceived and reduced to practice the invention of all of the counts except counts 1 and 11 on April 25, 1913, and that counts 1 and 11 were not reduced to practice until after Langmuir's filing date.

The attitude of the Assistant Commissioner toward the case was that of the junior party upon the declaration of the interference, namely, that the patentability of the issue was doubtful. He says: "The line between the prior art and the issue is attenuated and if there is patentability, it must be as set out in the decision of the Law Examiner on the motion, and I do not understand either party to attack that decision here. Arnold alleges that when he made the invention, he thought he was following the prior art and not producing something patentable, and an undercurrent of that attitude seems to tinge his whole case. This is why he filed so late." Proceeding from that prostulate, the Assistant Commissioner has accepted as controlling on the question of conception and reduction to practice, on behalf of Arnold, testimony of a vague and general character and which failed to satisfy the lower tribunals, as it also has failed to satisfy us. The decisions of those tribunals are so clear and satisfying that we are content to rest our opinion upon the reasoning there given.

It results that the decision is reversed and priority awarded Langmuir.

Reversed.

CHAS. H. ROBB,
Associate Justice.

IN THE

DISTRICT COURT OF THE UNITED STATES

FOR THE DISTRICT OF DELAWARE.

GENERAL ELECTRIC COMPANY,
Plaintiff,

v.

DEFOREST RADIO COMPANY,
Defendant.

Nos. 589 and 598
In Equity.

The Opinion of Judge Morris.*

(23 Fed. [2nd] 698)

These two suits of General Electric Company against DeForest Radio Company were tried together. In the first suit all the claims of patent No. 1,558,436, granted to Irving Langmuir, assignor to the plaintiff, October 20, 1925, for "electrical discharge apparatus and process of preparing and using the same" upon an application filed October 16, 1913, and renewed March 14, 1916, are in issue. It is known as the high vacuum tube patent. Infringement is conceded if the claims are valid. Validity is denied for want of invention and novelty and because of prior knowledge and use, for double patenting and upon the ground that Harold D. Arnold, not Langmuir, was the first inventor.

The specification, claims and testimony are so interwoven with scientific theories, more or less abstruse, that it is somewhat difficult to isolate and keep separate from the principles of physics involved Langmuir's conception and idea of means. Yet an analysis of the Langmuir device and its elements discloses that, apart from its functioning and results it is nothing more nor less than a Fleming valve or DeForest audion, for example, in which a higher vacuum, maintainable during operation, exists. How much higher the vacuum must be to bring the tube within the patent is not definitely fixed in terms of pressure. The specification states merely that "the evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned." A micron is a pressure equal to a millionth of a meter or a thousandth of a millimeter of mercury. It corresponds to a barometer reading of that value. The normal barometer reading in the open air is about 760 millimeters. The justification for the failure to assign definite pressure limits is that the invention "comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the cathode, independently of gaseous ionization"—a device in which the residual gases play no part in the operation. The results desired to be obtained are stability and reproducibility of operation and increase of power. The production of these results by the specified manner of functioning is dependent not on the degree of vacuum alone, but upon four coordinating variables—geometry or relation of parts of the tube, temperature of cathode, voltage of anode and degree of vaccum. This fact makes it apparently unavoidable that the claims be functional in form. But they must, of course, be construed to cover the thing. Walker on Patents §163. Claim 26 is comparatively simple. It is:

---

* The opinion of Judge Morris dealt with four Langmuir patents. We are here concerned only with Langmuir patent No. 1,558,436. We have, therefore, only printed that portion of the opinion dealing with this patent.

> "A discharge device comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes, the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge, so that the device is capable of passing a sustained discharge of one tenth of a milliampere at forty volts, without developing any substantial positive ionization effects."

The Fleming and DeForest tubes are "discharge devices comprising a sealed off envelope and electrodes therein, the envelope being shaped and the electrodes located so that the energy of the discharge is delivered mainly upon one or more of the electrodes." The next clause of the claim—"the inner wall of the envelope and electrodes being so free from occluded gas and the pressure in the tube being sufficiently low, with respect to the spacing of the electrodes and the energy of the discharge"—has to do with the manner and degree of evacuation. Underlying this clause are these facts: The glass wall and the electrodes harbour large volumes of occluded gases. Heat is necessary to expel these gases so they may be removed by the pump. If not removed before the tube is sealed off the heat occurring during the operation of the tube expels them, destroying in large degree the vacuum. "The spacing of the electrodes"—one illustration of the geometry of the tube—is a factor because the permissible gas pressure in the tube increases with the proximity of the electrodes to each other. This varying relation is due to the fact that the opportunity for the electrons to collide with gas molecules varies with the length of the path the electrons have to travel. "The energy of the discharge" may be interpreted in terms of power which is the product of the current values and the voltage. The unit of current flow is the ampere or the current which flows at a pressure of one volt through a closed circuit having a resistance of one ohm. The power of a circuit having a pressure of one volt and a current of one ampere is one watt. The power output of the device of claim 26 is .004 of a watt or 4 milliwatts. And increase of energy means an increase in the number and velocity of the electrons passing from cathode to anode and consequently an increase in the number and effect of collisions of electrons with gas molecules. It follows, of course, that if the maximum voltage at which a given tube will function without ionization is increased ionization will occur and the tube fail to function in the manner specified in the patent. "Ionization," by which is meant the conversion of atoms or molecules into ions, is explained by the "Electron Theory." By this all atoms known to chemistry are deemed to be made up of a nucleus endowed with a permanent positive electrical charge around which one or more electrons, each of which has mass or weight and carries, or is, a natural unit of electricity, revolve at inconceivably great speeds in regular orbits in somewhat the same manner as that in which the planets of our solar system revolve about the sun. According to this hypothesis the chief difference between the chemical atoms lies in the number and arrangement of their electrons. Under normal conditions the electrons are maintained within their atoms and in their orbits by the attractive force of the positive nucleus which, electrically, exactly balances and neutralizes the negative charge of the electrons of the atom. Consequently every atom having its normal complement of electrons exhibits no electrical effects. If, however, by impact, or otherwise, an atom loses an electron and becomes an ion it is thrown out of electrical balance. The positively charged nucleus predominates and exhibits a unit positive charge. In thermionic tubes ions are created by the impact upon the gas atoms or molecules of some of the myriads of electrons constituting the current flowing from the hot cathode to the cold anode—the Edison Effect. See Westinghouse Elec. & Mfg. Co. *v.* DeForest Radio Tel. & Tel. Co., 21 Fed. (2d) 918. To dislodge an electron from its atom the colliding electron must have sufficient momentum. The velocity required for this momentum is given to the electrons mainly by the pull or attractive force of the positively charged anode. The strength of the pull increases, other conditions being stable, with the anode voltage. For the gases with which we are here concerned 15 to 25 or 30 volts constitute the ionizing voltages.

When substantial numbers of atoms or molecules are being converted into positive ions by the electron stream the "ionization effects" forbidden by claim 26 occur. One effect of ionization is an increase in the current across the tube over the value it would have at the same voltage in the particular tube were the vacuum sufficiently high to prevent ionization. Such increase is due to two facts. First, the electrons, being negative charges of electricity, tend in the absence of a countervailing force, violently to repel one another and thus to diminish the number, and so, the value of the current, passing to the anode. Positive ions in the field constitute a countervailing force and consequently expedite the flow of the electrons to the anode. Second, the positively charged ions are drawn with great force to the cathode, the negative electrode, bombard it and thus increase its temperature. As the electron emissivity of the cathode increases with its temperature the ion bombardment of the cathode serves to increase the supply of electrons and consequently the current passing to the anode. This bombardment is so severe that, if continued, it destroys the filamentary cathode. Another effect to which substantial ionization usually gives rise is a blue glow in the tube. This, as I understand it, is accounted for upon the hypothesis that as the electrons are shifted in the atom, by impact of the electrons, from one orbit to another at prodigious speeds they produce waves or vibrations in the ether which constitute light. The ultimate effect or result of ionization is an unstable, non-reproducible and, in a measure, non-controllable current. As it is necessary, in order to prevent the destruction of the cathode and obtain a stable current, to operate gassy tubes below ionization, their power output—the product of current and voltage—was limited. These constitute obvious defects.

These defects are not present in the tube of the patent. It operates without substantial ionization. When there is no substantial ionization the current increases and decreases in a fixed relation to the voltage of the anode unless and until the anode voltage is made sufficiently high to draw to the anode all the electrons emitted at the cathode. The electronic emissivity of a given cathode increases with its temperature. This fact is known as "Richardson's Law." When a voltage high enough to carry across the tube all the electrons emitted is reached a further increase of voltage, which has no power to increase the supply of electrons of which the current consists beyond the limit of emissivity imposed by the temperature of the cathode, produces, of course, substantially no change in current. The current that is thus substantially independent of the voltage is known as the saturation current. Operation of the tube above and below this critical voltage is spoken of as in the saturation region and below saturation respectively. If a tube is operating below saturation an increase of the electron supply by an increase of cathode temperature, but with no increase in voltage, produces no marked change in the current. Decreasing the electrons emitted by the cathode by decreasing the cathode temperature is likewise without effect upon the current, provided, of course, that the decrease in the supply of electrons is limited to the electrons emitted in excess of those pulled across the tube by the given voltage. The fact that if the anode voltage remains stable the current can not be increased by an increase of the cathode temperature, beyond that required to supply the electrons capable of being pulled across the tube at the given voltage is illustrated by the "flat top temperature curve" on the following graph.

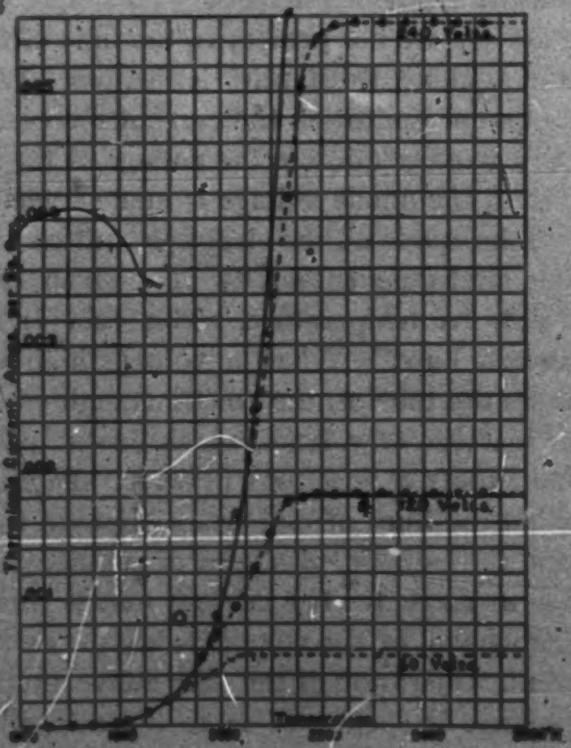
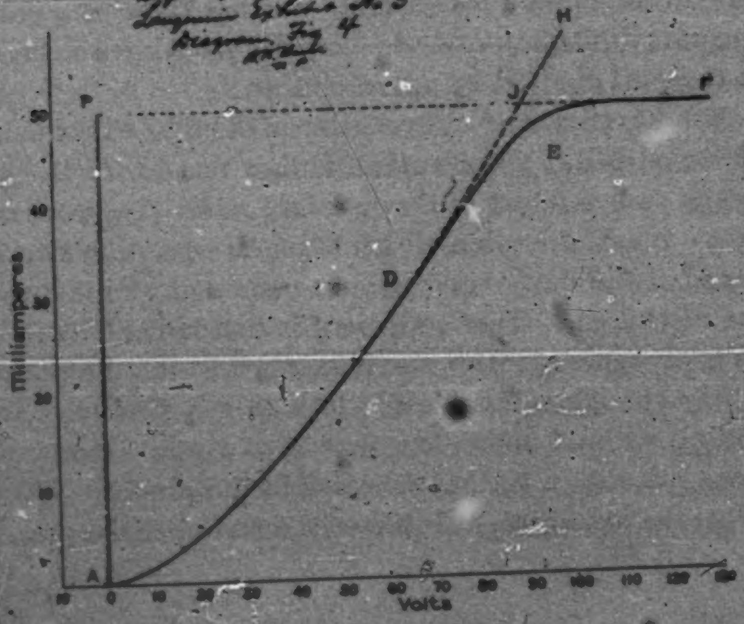


Fig. 1.

The reason that the current does not increase beyond a certain point dependent upon anode voltage with the increase of the temperature of the cathode is that the electrons, all being negatively charged, exert powerful repelling forces on one another. When this force of repulsion equalizes the pull or effect of the voltage on the anode, the anode is without power to draw to itself a greater number of electrons. The current-limiting effect of the electric field of the electrons on one another is known as the "space charge effect." It is space charge which produces the flat top of the temperature emission curve in the foregoing graph.

When the temperature of a cathode is fixed and constant and the voltage is increased the limitation upon the electrons limits the current. This is illustrated by the following graph whereby it appears that the last few increases in voltage make no increase in current—there being no more electrons to draw across the tube.

Arnold
vs } Int. No. 48380
Langmuir
Langmuir Exhibit No. 5
Diagram Fig 4



The curve of this graph, which when plotted on logarithmic paper appears, up to the point approaching saturation, as a straight line, disclosed a relation existing between current and voltage. That relation is expressed in the specification thus:

> "In most devices of simple construction which embody my invention, the discharge current passing through a given space with the cathode at a sufficiently high temperature with respect to the voltages employed, varies directly with the 3/2 power [square root of the cube] of the impressed voltages."

"A" to "D" of the curve on the current-voltage chart, in which the temperature is constant, is the space charge part or that in which the current is limited by anode voltage and follows the 3/2 power law. The flat top represents the saturation part or that in which the current is limited by the cathode and its temperature. The converse is true in the first or current-temperature chart in which the voltage is constant. In that the rising part is the part limited by cathode temperature while the flat top is the part limited by space charge.

Another characteristic peculiar to the tube of the patent, as stated in the specification, is that the device is "practically independent of the pressure when the pressure is below a certain value which depends upon the size and shape of the device and upon the current and voltage of the discharge." That statement is undoubtedly true if it be interpreted to mean that if in a given tube the pressure is low enough to enable the tube to function at a given voltage without ionization, that is, as a pure electron discharge device, a further decrease in the pressure will not affect the discharge. It is likewise true that if the pressure is less than that required for a given voltage in a given tube it may be increased up to the pressure immediately below that at which substantial ionization would occur at the given voltage without affecting the discharge. The discharge, however, is in no sense independent of the pressure if the maximum voltage at which a given tube will function without ionization is increased, for ionization would instantly occur and the tube fail to function in the manner specified in the patent. In such instance a decrease in pressure simultaneously with the increase in voltage would be necessary to avoid ionization. In its simplest aspect this is due, of course, to the fact that if ionization is to be avoided above ionization voltages collisions must be avoided between electrons and gas molecules and that the number of collisions in a given tube, dependent upon the relative density of the two, is increased, the pressure being stable, by an increase in the number of electrons pulled to the anode by the increased voltage.

These scientific explanations, arising mainly out of the electron theory, of the functioning of the high vacuum tube change not at all the fact that it differs structurally from the Fleming valve and DeForest audion only in the degree of vacuum maintainable during operation. This was expressly conceded during the pendency of the application in the Patent Office. The fundamental questions here in issue are not changed and their solutions are, I think, but little affected by the theories by which the functioning of the high vacuum tube is accounted for. If it was not known to those skilled in the art how to produce, in a Fleming or DeForest structure, for example, a vacuum sufficiently high to enable the tube to function above ionization voltages without substantial ionization and Langmuir solved the problem and made the necessary disclosure of its solution in his patent, manifestly he would be entitled to a patent for his disclosed method and device as a reward quite apart from his knowledge or lack of it with respect to scientific principles or laws of physics explaining the functioning brought about by the high vacuum. Moreover, independently of whether or not invention was necessary to create a vacuum of the required degree, Langmuir would be entitled, I take it, to a patent for his device regardless of his ability or inability to explain its functioning in principles of physics, if he was the first to appreciate that a high vacuum maintainable during operation in a Fleming or DeForest structure, for example, would constitute means whereby the results produced by the high vacuum tube could be accomplished, provided, of course, he reduced to practice with reasonable diligence the device of his mind.

Upon the question whether the claims for the process of making the high vacuum tube or those for the tube itself, which because of its stability, reproducibility and power has made possible radio broadcasting, modern radio reception and long distance telephony, involve novelty and invention the parties differ widely. The plaintiff asserts, with apparent confidence, that the patent is for invention of a high order—equal to or greater than that of DeForest for the three electrode tube. The defendant, with equal confidence, finds not only all that Langmuir did but all that he discloses with respect to the principles in accordance with which the device functions spread upon the records of the prior art. Since the Fleming valve and the DeForest audion were old and the structure of the tube of the patent differs from these only in the degree of vacuum maintainable during operation, the first crucial question is whether claims 30, 31 and 32, directed to the process of making tubes having a vacuum of the required degree are valid. Claim 31 is:

> "In the process of producing a hot cathode discharge device, treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein, continuing these operations until the occluded and original free gas is so thoroughly removed as to enable the finished sealed-off device to operate below saturation in a stable and reproducible manner at a voltage above fifty volts and with a current greater than one milliampere and with the energy of the discharge delivered mainly at one or more anodes."

To find wherein, if at all, this and the other process claims go beyond the discoveries and ideas of others, beyond the use of wise judgment in selecting and combining those discoveries and ideas, or beyond mechanical skill in applying them to practical results, the specification and the prior art must be examined. The specification states:

> "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapors as well as gases. Chemical evacuating means such as electrically vaporized calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at ele-

> vated temperature during the normal operation of the device. In this case the temperature is preferably carried close to brilliant incandescence. In the case of the structure shown in Fig. 1, the heating may take place by passing an electrical current through the wire 12. The heating, especially of solid anodes such as shown in Figure 2, may take place in a suitable vacuum furnace, the temperature preferably being raised to 2,500° C. or even higher. Bombardment is a very effective means of removing occluded gas from anodes."

The steps and precautions requisite to successfully evacuate by bombardment are then described after which the specification adds:

> "After the metal has been freed from occluded gas reabsorption of gas will not readily take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated with less electron bombardment of the anode or anodes. * * * It is also true that when the anode has been carefully freed from gas residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated."

The prior art, however, as I understand it, discloses that long before the earliest date claimed for Langmuir it was known not only that large quantities of gas are occluded in the glass walls and electrodes of an electrical-discharge device and that unless removed before or during evacuation the gas will be driven out by the heat of operation and thus detrimentally increase the pressure of the vacuum, but also that the occluded gases could be removed and the vacuum created and maintained by the very steps prescribed by Langmuir for removing the occluded and free gases of his device. In May, 1896, the "American Electrician" published an article by Thomas Duncan in which he said:

> "If an incandescent lamp be exhausted until no air can be seen escaping through the valves of the pump, and the filament then incandesced, considerable quantities of air will be expelled at each operation of the pump, thereby showing that this air has been occluded in the pores of the carbon filament, and could not have been gotten rid of without heating the filament and driving the air out into the vacuous space surrounding it.
>
> "This heating also assists in drawing off the air which clings or adheres against the glass upon the inside of the bulb. If the electrodes are made from aluminum or other porous metal, the secondary terminals from a spark coil can be applied to them, and set in operation in a similar manner to that in which the tube is to be used afterwards. This can not help but be a ready and satisfactory means of eliminating the air occluded within the electrodes."

A résumé of Incandescent Electric Lamp Exhausting by S. E. Doane, published in the "Electrical World and Engineer" of May 21, 1904, says:

> "The exhausting of incandescent electric lamps has developed into a highly specialized branch of the lamp manufacture. * * * The completed lamp must not only be free from gases and vapors, but must also have had those parts capable of giving off gases and vapors, thoroughly freed from them. The only way we knew to accomplish this was to highly heat everything we wished to free

> from gas. We had three things to heat: the glass, the filaments and the joints between filaments and leading-in wires.
>
> "The glass was heated by an asbestos cone-shaped hood painted black on the inside. The heat from the lighted lamp furnished all the heat necessary. The lamps could be heated hot enough to cause the bulb to collapse if the hoods were made too thick. The filaments were also heated sufficiently by the current, * * *."

Dwyer, in his patent No. 596,694, granted January 4, 1898, for a process of producing high vacuums in incandescent electric lamps or similar receptacles during their manufacture recites that in the past such lamps have been exhausted by mechanical pumps, "by chemical processes involving the displacement or absorption of the gases contained in the lamp, or by combinations of these processes." He says that a partial vacuum is readily obtained by a good mechanical or mercurial pump but that complete exhaustion by this means alone is not possible. He then adds:

> "To carry the vacuum still higher, it has been a common practice to heat the lamp-bulb by either an external source of heat, such as a gas-flame, or by an electric current passed through the lamp-filament, or by both of these means combined, so as to expand the gases in the lamp, and also to drive off from the lamp-filament itself and its supports, more particularly the joint between the leading-in wires and the filament, which joint is usually made of some form of hydrocarbon paste, gases occluded therein, while continuing the pumping operation."

Soddy, in his patent No. 859,021 of July 2, 1907, for the employment of certain reagents in the process of producing high vacuum, declares:

> "In the production of high vacua not only has the air to be removed but also the gases occluded or condensed on the walls of the vessel being exhausted and on the contained electrodes or filaments or other contents of the said vessel, which condensed gases are given up slowly after exhaustion and if not removed during the exhaustion cause the vacuum to deteriorate. * * *
>
> "The heating and expelling of the condensed and occluded gases may be effected in any usual, or suitable, manner of expelling condensed and occluded gases from the walls and contents of vessels being exhausted. The usual manner of effecting such an operation is to heat the vessel while it and its contents are subjected to the same treatment as they are subjected to in after use. In incandescent electric lamps for example an electric current is passed through the filament, and in X-ray bulbs an electric discharge is passed between the electrodes during the continuation of the exhaustion."

Many other references disclose the baking of the walls of the envelope of a discharge device; the heating of the electrodes, incandescing the filament and electron bombardment of metallic electrodes to expel occluded gases. The gas clean-up effect was likewise old at the time Langmuir began his operations. One instance of its disclosure is in patent to Thatcher No. 1,028,636, granted June 4, 1912, application for which was filed March 30, 1910, for method of exhausting vessels, in which it is said in part:

> "I institute the intensive incandescence of the filament proper, that is, I bring the current voltage up to a sufficient intensity to produce the blue haze phenomenon, and maintain the same until the blue haze disappears and the desired almost perfect vacuum is attained; * * *."

Dr. E. Leon Chaffee testified (R. Vol. 1, p. 159):

> "It has long been known that the existence of this blue glow improves the vacuum, probably by bombarding the walls with gas ions and consequently causing them to stick to the glass walls. * * *"

These steps of the prior art are the identical steps disclosed by Langmuir. Nor are his disclosures with respect to how these steps are to be employed any more ample or complete with the possible exception of heating by bombardment. But bombardment has no saving power for the claims are not restricted to heating by bombardment. They are broad enough to include any method of "treating the interior surface of the envelope and the operating parts to liberate therefrom occluded gas, and removing from the envelope gas liberated by said treatment and free gas originally contained therein." The plaintiff, however, places some reliance upon the clause in the claims directing continuance of the steps until the desired vacuum is attained and cites Badische *v.* Kalle, 104 Fed. 802. But in that case those skilled in the art were of the opinion that a more prolonged or intense application of the old steps would not accomplish the desired result. Such is not the evidence here as I understand it. Moreover, the tools of the evacuating art were constantly improving. In the early days of the incandescent lamp art manufacturers used the Sprengle pump to obtain their vacua. It gave way to the Geissler pump which, in its turn was superseded or supplemented by chemical evacuating processes. It is, I think, not denied that these old pumps and at least some of the chemical processes left in the tube mercury or other vapors having a pressure too high for the tube of the patent. But if Langmuir makes in his specification any disclosure of steps or means to avoid that result it is by the use of the new, improved Gaede molecular pump. That pump is highly efficient and, when properly used, leaves no free gas or vapor that will prevent the functioning of a thermionic tube above ionization voltages without substantial ionization. But Langmuir is entitled to no credit for that. I think the process claims are invalid.

This conclusion carries with it as a necessary corollary that the device itself, apart from its functioning and use, is lacking in patentable novelty. The inventive quality of the device claims, if any they have, must consequently reside in the discovery of a new principle that thermionic discharges above ionization voltages can be produced without substantial ionization if the vacuum be sufficiently high and the disclosure that the device of the claims constitutes suitable means for putting the principle into practice to obtain useful results, or, in the application of that principle, if known, to a useful purpose—in the realization that the instability, non-reproducibility and lower power output of the gassy tube was due to inadequate vacuum and the conception of a tube with a higher vacuum as a means whereby stability, reproducibility and high power output in thermionic devices might be had. That Langmuir was not the first to discover that a pure electron discharge, a discharge without substantial ionization, can be produced in a thermionic device if the vacuum is sufficiently high was indicated by Richardson's Law, evolved and formulated about 1903. If, perchance, that law was not universally accepted by physicists as being operative in high vacua, as was suggested by Soddy, Pring, Parker and some others, the publications of Lilienfeld in 1910 were clear, complete and specific upon this point. In fact, Langmuir admits (I. R. p. 1378) that Lilienfeld had thermionic discharges above ionization voltages "substantially free from the effects of positive ionization." Moreover, if a thermionic discharge is unaccompanied by substantial ionization all the asserted "earmarks" or characteristics of plaintiff's device are present for they are but incidents flowing from a sufficiently high vacuum for the voltages employed, or, otherwise expressed, from an absence of ionization. These characteristics are, or include, (1) regularity and reproducibility of operation, (2) 3/2 power relation of current to voltage, (3) no blue glow or other visible evidence of discharge, (4) cathode not heated by the discharge, (5) current limited by space-charge effect and (6) discharge independent of pressure in vacuum below certain pressure in the sense hereinbefore stated. As I understand the evidence these "earmarks" are likewise characteristics of the Fleming valve and original DeForest audion when operated at nonionizing voltages. It thus seems obvious that the merit of the invention, if any, must lie in the realization that the known pure electron discharge to be had in a high vacuum would overcome the special difficulties and limitations of thermionic discharge devices. Whether this realization and the increase of vacuum in structures of the Fleming and DeForest type was a probable natural development of the art or one requiring inventive skill is, like the question of the presence or absence of invention in other cases, not without some difficulty.

One class of evidence which often carries much weight is the necessity for a series of experiments before the result can be arrived at. Such evidence raises a strong inference that the result was not obvious and constitutes a real addition to public knowledge. But for such experiments to be of much value the patentee must have started his experiments with knowledge of the state of the art or his experiments may have succeeded in enabling him to redisclose only what was already known. Langmuir made many experiments over a long period of time. Those that were first made were, however, for the purpose of discovering abstract principles and not for the purpose of arriving ~~at~~ practical results. He made discoveries but he did not immediately, or for some time, perceive that they had any practical use. Moreover, the discoveries to which his experiments led him, so far as we are here concerned, were those already made by Lilienfeld and others. Great credit, bearing upon the issue of invention, is claimed by the plaintiff for Langmuir for discovering from his experiments that electrons will boil out of a hot cathode in a high vacuum, that in a high vacuum the current varies with the 3/2 power of the voltage and other characteristics or incidents of a discharge in a high vacuum without substantial ionization. But disclosures of the prior art reveal that Langmuir, great and renowned physicist that he is justly conceded to be, was, in this instance, travelling, all unknown to him, over a field already well explored. Fleming, the inventor of the Fleming valve, published in the "Scientific American Supplement" for January 20, 1906, an article on the electric conductivity of a vacuum, disclosing not only that electrons are emitted by a hot cathode in a high vacuum but also "that a high vacuum may be a very good conductor, provided that the negative electrode is rendered incandescent. This shows that the obstruction which a high vacuum offers to the passage of electricity is not due to the mere reduction of the matter in the space (that is, to the rarefaction of the gas), but is, in some way or other, largely dependent upon the temperature of the electrodes; the resistance to the passage of electricity through a vacuum can be rendered very small by intensely heating the negative electrode," thus revealing that a current could be had passing from cathode to anode. In addition, Fleming stated: "If we take measurements of the current passing through the vacuum when the negative electrode is an incandescent carbon filament and the other a cold metal plate, and, at the same time, measure the difference of potential between the electrodes, we find that the conductivity, as measured by the ratio of current to voltage, is not constant, but varies with the electromotive force." Furthermore, that Fleming knew the difference between a high and low vacuum is made manifest by his statement: "The vacuum is said to be low when the original normal air pressure in it is reduced to one-thousandth atmosphere, or it may be only to one three-hundredth. It is said to be high when it is reduced to one hundred-millionth of an atmosphere." It is true, as shown by the Fleming curve sheet, that Fleming did not employ in his valve a high vacuum but it is also true that Langmuir, Q212, conceded "There is no advantage in the device of the character of the Fleming valve to go to pressures of less than 50 microns." Both C. D. Child, in an article in the "Physical Review," Vol. 32 (1911), and Lilienfeld, in an article entitled "Conduction of Electricity in Extreme Vacuum," published in "Annalen der Physik," Vol. 32 (1910), disclosed that with the aid of certain simplifying assumptions, such as the ignoring of the initial velocity with which the electrons are boiled out of the cathode, the discharge current varies in accordance with the three-half power of the voltage. This is conclusive evidence, as I understand it, that in a high vacuum the current is under control, stable and reproducible and, since high voltages were employed, that high power levels may be attained by the employment of a high vacuum. "Space charge effect" was, likewise, but a rediscovery. This is made certain by an article by Lilienfeld in "Physikalische Zeitschrift" 1908 in reply to an article by Soddy dealing with the Wehnelt cathode in high vacuum in which Lilienfeld said:—

> "* * * it is not exclusively the electrons emitted from the exide cathode which, as was often assumed, determined the discharge in high vacua, but that the discharge depends essentially on a second factor. I pointed out more specifically in my second paper this view, that in consequence of the absence of the last traces of gas the number (volume density) of the negative electrons supplying the current becomes great in comparison with the number of gas molecules per unit volume, so that therefore the tendency exists for the formation of the greatest possible negative space charge—which opposes the current transport by the negative electrons.
>
> "The higher the vacuum, the greater the current density, the more prominent this new kind of discharge becomes * * *."

That the discharge in high vacuum devices is practically independent of the pressure when the pressure is below a certain value was discovered by Langmuir after Lilienfeld had made the disclosure in his article of 1910, where he said:

> "* * * from a certain maximum value of the gas density downwards the number of positive charges formed per negative charge, *i. e.*, per negative electron is independent of the gas density.
>
> "Since we usually regard positive charges as originating from molecules (or atoms) we can put

> this result in the following form: the number of positive charges per molecule increases continually with diminishing gas density in the region of validity of the function K which is independent of the gas density provided other conditions (the potential gradient) are kept constant."

In view of these publications it seems to me that the only permissible inference to be drawn from Langmuir's experiments is not that they constitute evidence of invention but is rather that Langmuir was not abreast of the developments in this particular art when he made his experiments.

Other evidence bearing upon the issue of invention is the great utility of the high vacuum tube. But in 1912 the radio art was young. Fleming did not need for his purposes, as Langmuir testified, a higher vacuum than that employed by him. The DeForest audion was not in wide use. Langmuir did not see one until 1913. Under such circumstances it would be difficult to say that the high vacuum tube satisfied a long-felt want or produced results long sought or that the evidence of utility is here indicative of anything more than a proper natural development of the art. Moreover, the fact that falls but little short of a demonstration that the employment of the known pure electron discharge above ionization voltages in tubes of the DeForest type was but the availment of those skilled in the art of the store of knowledge that had been accumulated and lay ready at hand is that when Arnold, who had had long experience with electrical discharges in high vacuum, was shown a DeForest audion for the first time on November 1, 1912, and saw it in operation he immediately realized and said, in effect, that by increasing the vacuum the discharge would be sufficiently stable and at adequate power levels to enable the tube to be employed as a relay device in transcontinental telephony. While not unmindful that invention may sometimes be the result of an instantaneous happy thought, yet the state of the art is strongly confirmative of Arnold's own view at the time that the improvement suggested by him was obvious to one skilled in the art. The act of Arnold turns the scale so overwhelmingly that it lies athwart a finding of invention.

The patent is likewise invalid, in my opinion, because of prior knowledge and use by DeForest. The specification states: "Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts." That, as I understand it, means that at this voltage the current becomes affected by positive ionization and the tube ceases to function as a pure electron discharge device. Yet, prior to August, 1912, the Federal Telegraph Company of California, by which DeForest was then employed, used a B battery of 36 cells, another of 45 cells, or 54 and 67½ volts respectively, with the audion. When used as an amplifier the amplification increases with the voltage. The testimony of Langmuir, XQs761-767, as I understand it, makes it clear that this voltage was employed for amplifying purposes and so with a discharge current substantially unaffected by ionization. That DeForest, though not skilled in the art of evacuating his device, knew the effect thereon of an increased vacuum, though he was very probably unaware of the extent to which it could be carried, is disclosed by his letters of July 26, 1912, and August 14, 1912, to the McCandless Company, the manufacturer of audions for the Federal Telegraph Company. The first letter is:

> "Out of the last lot of 24 audion bulbs which you manufactured for us there are only 4 that came

up to proper sensitiveness test. Apparently the vacuum in the other bulbs is too low, because in these latter bulbs we notice that the blue arc or cathode beam starts suddenly at 15 or 20 volts, under which condition the bulb is not sensitive."

The other letter reads:

"We took two of the poorest of the discarded 20 to a San Francisco glass-blower, unknown to fame, and had him exhaust same to as high a vacuum as his pumps would take. These re-exhausted bulbs now show a sensitiveness equal to those of the first four which proves exclusively that our contention is correct. For the work which we demand from these bulbs they are not sufficiently sensitive and we would be glad therefore if you will re-exhaust them. You certainly should be able to put them in as good condition as the aforesaid San Francisco glass-blower."

The testimony discloses that the glass-blower referred to heated the tubes under an asbestos hood almost to the collapsing point of the tube while they were being exhausted. The references of the prior art which reveal that a lamp may be made to collapse by heating under an asbestos hood leave no room to doubt this testimony. Such heat was sufficient to heat to a certain degree the metal electrodes as well as the walls of the tube, thereby driving off from the electrodes as well as the walls some of the gases occluded therein. The energy of the discharge of the DeForest tube was low. The bombardment was probably not adequate to heat the anode to a temperature even approximating that to which it was raised by the Bunsen burner under the asbestos hood. Consequently, little, if any, occluded gas would escape from the anode and the gas clean-up effect probably tended to improve the vacuum more than it was caused to deteriorate by the molecules of gas that escaped from the anode. The tubes were thus enabled to function substantially above ionization voltages without substantial ionization.

Upon the issue of priority, too, I think the plaintiff must fail. In the contest in the Patent Office between Arnold and Langmuir upon this issue the Examiner of Interferences awarded priority to Langmuir. The Examiners-in-Chief arrived at the same conclusion but for reasons conflicting with those of the Examiner of Interferences. The Commissioner of Patents awarded priority to Arnold. The Court of Appeals of the District of Columbia decided in favor of Langmuir for the reasons stated by the Examiner of Interferences and the Board of Examiners-in-Chief. I am in accord with neither of the divergent views expressed by the Examiner of Interferences and the Board of Examiners-in-Chief but, generally, with the reasoning and conclusion of the Commissioner of Patents. The defendant asserts that Arnold is entitled to the date of November 1, 1912. Upon that date Arnold, who because of his training and experience in the matter of electrical discharges in vacuum and upon the recommendation of Dr. Robert A. Millikan, had been theretofore employed by Western Electric Company to aid in making possible transcontinental telephone service at the opening of the San Francisco Exposition, was shown by Doctors Jewett and Colpitts a DeForest tube that had been brought by DeForest to the Western Electric Company a day or so before. Arnold examined the audion and tested its performance as a repeater of speech currents. It functioned well with weak currents but choked, distorted the speech and blue hazed when increased plate voltage or loud speech currents were applied. Though Arnold had been engaged in perfecting a different device of his own to be employed for telephone relay purposes, he instantly saw that the performance of the tube which made it too unstable in its existing state for a telephone repeater was due to ionization and that this could be removed by increasing the vacuum. This he then disclosed to Colpitts and Jewett. He also understood and then explained to Colpitts that the hot cathode would emit electrons in the high vacuum, that they would be subject to the space charge effect and that it would require high plate potentials to obtain the desired electron flow from cathode to anode. Corroboration of the oral testimony of Arnold, Colpitts and Jewett, if needed, is to be found in the fact that every act of the Telephone Company from that time on is consistent only with the intended use of the audion made more rugged and with a higher vacuum in its transcontinental service. Arnold's conception of the invention, consisting in the full performance of the mental part of the inventive act, was complete. Nothing remained to be done but to give the device practical embodiment with reasonable diligence. If, in view of the fact that those skilled in the evacuating art knew how to reduce to physical form Arnold's mental conception, a physical reduction of his conception to practice was necessary, and I think it was not, McCormick Harvester Mach. Co. *v.* Minneapolis Harvester Works, 42 Fed. 152, 155. Otto *v.* Linford, 46 L. T. (N. S.) 35, this requirement was performed by Arnold with reasonable diligence, thus giving to him an effective date of November 1, 1912. He obtained, knowingly, in that month with audion 7-A a current of 3 milliamperes at 80 volts without substantial ionization. Again, Arnold met the requirements of reduction to practice in April and May of 1913.

in the tubes of these experiments 250 volts were impressed upon the plate without ionization effect. The tubes used in Philadelphia in the fall of 1913 functioned well for many hours, one as long as 267 hours as commercial repeaters. The fact that the output energy of one of these tubes was less than that of the usual, original DeForest tube does not negative its being a tube of the patent, for the output energy of claim 26 is likewise less than the output energy of the usual, old DeForest tube, Moreover, it seems to me that other claims of the patent, for example 11, which was an original claim, differs from 26 in the same way and only in the same way that claim 26 differs from the original DeForest device.

Langmuir began his experiments in August of 1912. He now asserts and the defendant denies that he then obtained a pure electron discharge substantially unaffected by positive ionization but concedes, XQ380, that though he now knows that he did then obtain such a discharge he did not know it then. This lack of contemporaneous knowledge denies to his August work any effective value upon the issue of priority. Robinson on Patents, Sec. 79, p. 121. In November Langmuir made other experiments but these he concedes were for the purpose of ascertaining the accuracy and existence of certain laws of physics. I find no evidence that he then thought of applying the scientific principles in which he was interested to any practical result in the useful arts. Consequently, there is no satisfactory evidence that Langmuir had a conception of the device of the patent before the end of November. "It is not while the creative energies are at work shaping and sharpening the idea of means that the conception of the invention becomes perfect. It is when these energies have ceased to act, when the idea stands before the mental vision of the inventor as clearly as a concrete invention before the eyes of an observer, that the conception is complete and the work of reduction is ready to begin." Robinson on Patents, Sec. 379. Tested by this rule even the statements of Langmuir to Coolidge in December, 1912, did not reveal a complete idea of means and, consequently, did not disclose a complete conception within the meaning of the patent law. It was not until March 21, 1913, as I read the record, that Langmuir's conception or idea of means to a useful end began to take shape. He then made a record of it in these words: "Now what I intend to do is to construct an audion which will operate entirely and exclusively on the electron discharge. I shall attempt to get the vacuum so good that positive ions are present in negligible amounts." It is not necessary to inquire when the conception became complete and his idea reduced to practice for Arnold had had the conception long before and had proceeded diligently to reduce it to practice.

The bill of complaint in this case must be dismissed.

(sgd) Hugh M. Morris, J.

January 3, 1928.

IN THE

UNITED STATES CIRCUIT COURT OF APPEALS,

FOR THE THIRD CIRCUIT.

GENERAL ELECTRIC COMPANY, *Appellant,* *v.* THE DEFOREST RADIO COMPANY, *Appellee.*	No. 3799. March Term, 1928.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES FOR THE DISTRICT OF DELAWARE.

(Filed October 3, 1929.)

Before BUFFINGTON, WOOLLEY and DAVIS, *Circuit Judges.*

Per Curiam.

The issues raised on these appeals were fully discussed in the opinion of the learned district judge and we agree with his conclusions. The decrees are, accordingly, affirmed on his opinion.

BUFFINGTON, *Circuit Judge,* dissents.

IN THE

UNITED STATES CIRCUIT COURT OF APPEALS,

FOR THE THIRD CIRCUIT.

GENERAL ELECTRIC COMPANY,
Appellant,
v.
THE DEFOREST RADIO COMPANY,
Appellee.

No. 3799.
March Term,
1928.

APPEAL FROM THE DISTRICT COURT OF THE UNITED STATES FOR THE DISTRICT OF DELAWARE.

Opinion of the Court.

(Filed November 11, 1930.)

Before BUFFINGTON, WOOLLEY and DAVIS, *Circuit Judges.*

BUFFINGTON, *J.*

In the Court below the General Electric Company charged the DeForest Radio Company with the infringement of four patents. On final hearing that Court held one of the patents valid and infringed and the other three invalid. By appropriate steps its so holding was brought before this Court for review. Without entering into detail, we may say that, save as to patent No.

1,558,436, the reasoning, conclusion and decree of the Court below commend themselves to us and we affirm the same. In the case of patent No. 1,558,436, we feel the Court below committed error in holding the patent invalid and dismissing the bill.

As usual in litigation over a patent of great commercial value, the vast mass of expert speculation, the protracted argument covering days and with briefs that in the aggregate covered several hundred pages, the case, on reargument, narrowed to the simple question of the patent paternity of what is known commercially as the Langmuir tube. The Court below held the tube had no patent paternity and to that question we now address ourselves. The subject-matter of the patent and the general features of the pertinent art are set forth at length in the comprehensive opinion of the Judge below and by reference thereto we avoid the necessity of present restatement.

Laying aside for the present technical language and scientific discussion and confining ourselves to simple statement, the Langmuir tube is a tube in which for example the gaseous conductor incident to a Fleming valve and a DeForest audion is dispensed with and a vacuum substituted therefor.

In the patent sued on, No. 1,558,436, granted October 20, 1925, to Irving Langmuir, assignor to the General Electric Company for "electrical discharge apparatus and process of preparing and using the same," the specification states:

> "The present invention relates to electrical *vacuum* discharge devices, and it comprises devices in which the electrical current is carried by negative charges called electrons, emanating from the

> cathode, independently of *gaseous ionization* such as occurring, for example, in the ordinary Roentgen tube.
>
> "My present invention comprises improvements in electron-discharge apparatus which make possible a *high load capacity* and operation with the *highest voltages,* but the invention is also applicable and useful for moderate loads and moderate voltages."

Existing objectionable incidents to the use of gassy tubes and the erratic, non-determinable action of gas are pointed out as follows:

> "In order to distinguish electron discharge devices made in accordance with my invention from the prior art, I will explain briefly the character of a *pure electron* discharge as distinguished from a discharge through *ionized gas.* In a Geissler tube, and in a Roentgen or Crookes tube the conduction of current is accompanied by and depends upon *gas ionization.* Without a certain *minimum amount of gas* a Roentgen X-ray tube ceases to operate and as this minimum is approached the resistance of the tube steadily increases.
>
> "The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the *vacuous space.* If these electrons when moving above a certain velocity collide with *gas molecules* they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of the electrons and the ions; these phenomena are in general *erratic and non-reproducible.* The cathode under these conditions is disinte-

> grafed, technically it is 'sputtered', which causes its rapid destruction. As *gas ionization* continues at higher voltages a *blue glow* may appear. The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages. *These voltages are different for different gases.* In the case of gases such as nitrogen, hydrogen, oxygen, argon, helium and neon, they are of the order of magnitude of fifteen to twenty-five volts."

Describing the DeForest audion and differentiating it from the alleged invention of the patent, the specification says:

> "The phenomena above described as being characteristic of devices involving *gas ionization* are taken advantage of in an incandescent cathode device with three electrodes known as the 'Audion.' This device has been used as a receiver for radiotelegraphy and depends in its operation upon the rapid change of the discharge current when *gas ionization begins.* This point depends upon various *accidental* conditions which cause such irregularities in the operation of various devices apparently identical that sometimes only one of a considerable number can be used. Ordinarily the gas ionization in the audion begins to be important somewhere between 20 and 30 volts."

Describing the Fleming valve and its limitations, the specification states:

> "Another discharge device previously used to some extent was the *Fleming valve.* This was a two-electrode tube which, so far as I am aware, was always used at voltages well below the volt-

> ages at which positive ionization by collision occurs. It was not evacuated in such a manner as to permit it to be used at voltages materially above these ionization voltages without manifesting substantial positive ionization effects."

Referring to high voltage, the specification makes this statement:

> "No prior hot cathode devices are known to me operating with currents as great as above 5 milliamperes with voltages as high as about 200 volts; indeed no prior discharge devices are known to me operating in a practically usable manner and without substantial positive ionization effects with currents as great as about one-tenth of a milliampere with voltages as high as about forty volts."

Specifying some of the differences and advantages of the alleged invention, the specification states:

> "In devices made in accordance with my invention *gas ionization* is either entirely *absent* or is negligible and a discharge takes place which is *distinct* in its characteristics from the described discharge taking place in an *ionized gas*. The cathode is not heated by the discharge itself. Blue glow, glass fluorescence and in fact all readily visible indications of a discharge are ordinarily absent."

Referring to the evacuation of the tube, the specification sets forth:

> "For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube preferably while still heated is carried out by means of a suitable evacuating means, for

> example, a Gaede molecular pump, which removes *vapors as well as gases* * * *
>
> "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. * * *
>
> "It is also true that when the anode has been carefully freed from gas, residual free gas, even if present in a sufficient amount to cause some gas ionization when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated."
>
> Claim 12, which is,
>
> "An electrical discharge device, comprising a gas-tight-envelope, an electronemitting cathode, an anode *deprived of ionizable gas* and a discharge controlling conductor, the space in the envelope being evacuated to a pressure not substantially in excess of a few hundred thousandths of a millimeter of mercury, said device being characterized by the fact that when operated below saturation and materially above the ionization voltages, the current is controlled by *space charge* substantially unaffected by positive ionization."

is typical in character of the alleged invention.

Does the defendant use a tube answering this general description? We think it does and that in giving up the old gaseous tube and using one of the "very high vacuum," a change which it announced in its statements to the public, we have a virtual admission of the essential difference between the two tubes. The tube of this disclosure is aptly described as "non gaseous" and "of a very high vacuum" by the defendant when putting it on the market, as follows:

> "The tube consists of a highly evacuated vessel, cylindrical, rather than bulbular, in shape enclos-

> ing the three elements, grid, plate and filament in the form of the old type T tubular DeForest tube with which amateurs are familiar. The plate is of nickel, cylindrical in shape and surrounds a helical grid also of nickel. The filament is a crimped tungsten wire passing through the center of the grid exactly as it did in the old style type DeForest tube. The chief difference between this tube and the type T tube of similar mechanical construction is in its evacuation. The old style type T was an *ionic or gaseous tube* very unstable in operation and requiring a variable 'B' battery. It had the decided disadvantage that after continued use the tube would get 'hard' and require more 'B' battery until it reached such a state as to be inoperative. The new 'VT' tube, like the DeForest standard tubes to-day, is purely an electronic tube exhausted to a *very high vacuum*, so that it is non-gaseous and will stand very high plate potentials. When used as a detector, however, a battery of 20 to 40 volts is sufficient to give the proper plate current although voltages of 80 to 100 may be used without detrimental effect upon the tube. The 'B' battery moreover, is not critical in adjustment and, therefore, a fixed battery may be used and is used for all practical work. * * * The gaseous type tubes are, however, no longer being manufactured."

Turning next to the question on which the validity of the patent depends, we inquire first as to its usefulness, for the constitutional power to create the monopoly of a patent in that regard conditioned "to promote the progress of * * * useful arts" and the Congressional enactment in pursuance of the Constitution is that "any person who has * * * discovered any new and useful" etc. For in the final analysis, use, usefulness, is the acid test, the sine qua non of patent grant.

The unusual degree of usefulness of the tube may be assumed. The defendant by its use evidences its usefulness and has, we have seen, adopted it and ceased making "gaseous type tubes," and the Court below, after its exhaustive study of the art, aptly described the tube, and we agree with its estimate, as an agency which "because of its stability, reproducibility and power has made possible radio broadcasting, modern radio reception and long distance telephony."

Seeing then we are here dealing with a progressive step which next to the telegraph, the telephone and the wireless, is probably one of the most far reaching and beneficent in human progress, there can be no question of a non-gaseous, vacuum tube's usefulness. Such being the case, is it novel? The simple fact is that we see such a tube in universal use to-day; we know in the quoted language of the Court below of its "stability"; of its "reproducibility"; of its "power." We know that these elements have, as stated by the Court below, made "possible radio broadcasting, modern radio reception and long distance telephony." Indeed the fact that a non-gaseous vacuum tube makes possible the present improved practice shows that such practice did not exist before the Langmuir tube and that no other device or devices, all important as they may have been in their spheres, did either singly or collectively produce the present practice. The patent office recognized that. In the opinion of The Board of Examiners they found, in affirming the decision of the Examiners of Interferences, that "Langmuir was the first to conceive and the first to reduce."

While all the vast mass of knowledge testified to in these records was open to everyone to use, the simple fact remains that the non-gaseous tube of modern use did not occur to scientists. Every one of the two hundred and sixty-six words in Lincoln's Gettysburg Speech is found in the dictionary; most of them in the Bible. But it remained—not for Noah Webster or even the Prophets of old—but for Abraham Lincoln to take these isolated words and so use them conjointly as to produce the most remarkable combination in literature.

We do not disregard or minimize the all important part of DeForest's audion and Fleming's valve play in the utilization of them in the Langmuir tube, but in spite of such high value, neither of them, in isolation or conjoint use, gave the world the tube here in question and it remained for Langmuir to so couple and coordinate the two by means of eliminating gas and using vacuum as to produce the tube here involved. What scientific credit is due to DeForest or Langmuir or to what patent tribute Langmuir subjected himself in thus using their devices are questions not before us.

Moreover the statement in the Commercial Circular of the DeForest Company that gas was an element of operation, was in accord with the then scientific belief. In 1911 Gernsback, an experienced savant, wrote that in the audion "the operating principle is the shattering of a column of conducting gas by a received electrical impulse."

The function of a gaseous tube as a conductor was stated by the Circuit Court of Appeals of the Second Circuit in 243 Fed. Rep. 565, where Fleming's valve and DeForest's audion were considered, in these words: "The 'gaseous medium' of the audion is nothing but the commercial vacuum of the ordinary electric light bulb—air being a gas, and the bulb containing some residual air. In other words, defendant uses the same 'vacuous vessel' that Fleming does." And in its opinion it stated that it was asserted in that case that the audion was "an apparatus in which the bulb contains a substantial amount of gaseous medium essential to the operation of the device." To the same effect is the testimony of Langmuir, of which we find no contradiction, that

> "In the devices of the old art, in the DeForest audion, the pressure was continually changing. It sometimes increased and it sometimes decreased. Both things went on and there was an evolution of gas, water vapor would come off the bulb and be decomposed by the filament and it would generate gas. Gases would come out of the electrodes. Positive ions would bombard the walls and the electrodes and would drive gas off."

It will also be noted this Court in its able and exhaustive statement of the art in 21 Fed. (2) 918, said: "We observe that at the time of both the DeForest and the Armstrong inventions the only audion tubes in use were 'gassy' or 'soft'."

That its action was eccentric, is shown by DeForest's statement:

> "In the first place, anyone who has had considerable experience with numerous audion bulbs must admit that the behavior of different bulbs varies in many particulars, and to an astonishing degree. The wing potential wing current curves for different bulbs, or even for the same bulb at different times, under different conditions (filament temperature, etc.) vary widely.
>
> "What may appear to be a fixed law for one bulb may not hold for another."

On the other hand, the current in Langmuir is practicable, steady, reproducible at any particular voltage.

It further appears that the Langmuir tube has a great advantage when it comes to replacement. When a tube is defective, another of the same type can be bought and placed in the same socket. Not so with the audion. It required frequent replacement and where replacements were made it was necessary to readjust throughout the circuit. In that respect the proof is:

> "XQ35. What practical effect would harmful ionization have upon an audion amplifier such as, for example, as is used in the telephone line?
>
> "A. The worst immediate effect would be as to uniformity of operation, which would make continued adjustments necessary and would interfere with the replacement of one device by another, that is to say, when one tube burned out and another were put in an amount of ionization that would interfere with uniformity of operation would make it necessary to readjust throughout the circuit to take care of the substitute tube."

As to the replacement, the proof is that

> "Another consequence of this uniformity is that replacement of the tubes without changing the apparatus becomes possible. That is particularly important in telephone repeaters and in radio devices both of the receiving and transmitting type. One wants to know that he can replace a burned-out tube with a new tube without having to make substantial changes in the apparatus."

It will also be noted that the whole trend of the art was against the use of a vacuum, and even after Langmuir had shown its use, it was deemed impractical. Thus in a paper of 1914 Wehnelt and Leibreich said that ionization persisted in the best vacuum they could get.

Moreover, it is of great present significance that the then view of DeForest himself was against Langmuir's use of the vacuum, he then stating in a paper read by him before a scientific body: "I believe, however, Dr. Langmuir has, by working into these high vacua and the high potentials necessitated thereby, pursued the less promising of the two paths of research." The record shows no explanation, comment or retraction by him of this statement.

Such being the general state of the case, has the defendant by evidence overcome the prima facies of the patent? We think not. As said by this Court in 159 Fed. Rep. 948, citing the Barbed Wire Case, "the burden of proof upon this part of the case rests upon the defendant, and every reasonable doubt should be resolved against it." And in our view the crux of the case is one of fact, namely, whether the use of a vacuum in the combination of the claim was Langmuir's novel disclosure. We are not concerned with scientific theories and speculations as to what might have been done or what could possibly have been done for, as well said by the Circuit Court of Appeals of the Second Circuit in 298 Fed. Rep. 582, we sit "not as scientists, but as weighers of evidence." But we are concerned with the fact whether the combination of the claim which Langmuir disclosed was new. That some had bombarded anodes of X-ray tubes to get some of the gas out of them; that others had heated bulbs or used pumps to lessen the gas, may all be true, but none of them had produced the commercial tube which Langmuir gave to the public. And such actual contribution in use and not theory and possibility of speculation is, and of right should be, the decisive factor in patent reward. As was said by the Circuit Court of Appeals of the Second Circuit:

> "The keynote of all the decisions is the extent of the benefit conferred upon mankind. Where the court has determined that this benefit is valuable

> and extensive it will, we think, be difficult to find a well considered case where the patent has been overthrown on the ground of non-patentability."

We regard as of high evidential significance the statements made by the defendant in its circular to the public, already quoted. It will not do to brush aside and ignore it on the suggestion it was the work of some enthusiastic subordinate or sales agent. It was a deliberate statement of a great mechanical company of its ceasing to make and market a superseded article and to thereafter make and market a new and different one. No such change would in business practice be made by subordinates, but was, in the nature of things, the mechanical, scientific and commercial determination of a great business organization. In this statement the defendant recognized a "non-gaseous," highly vacuum tube as new. As we have seen, it differentiated it from its "gaseous" tubes up to then made and publicly announced that such gaseous type tubes would no longer be manufactured. And indeed, that no such non-gaseous, highly vacuum tube existed is shown by the fact that the testimony of experts and the laborious research by the Judge below, whose industry is proverbial, did not disclose any such tube as both parties to this litigation now make and contend for the right to make, existed or had advanced the arts in question to this new standard of theretofore non-attained efficiency.

Such being the case, the defendant is driven to take the position—which found favor with the Court below—that in view of what existed in the prior art, that it required no invention to so utilize these things in the prior art to produce a non-gaseous, highly vacuum tube, and that this great progressive step was due simply to the art's natural advance and improvement.

But in point of fact no such advance toward a non-gaseous tube, as we are now told was to be looked for in the art, was actually made by the art. We would not be misunderstood. Advance, inventive and non-inventive, was being made in the art, but their efforts were in other directions. We would not detract from the great advance made by DeForest and exemplified by his audion and by Fleming with his valve, but great as these steps were—both separately and collectively—and we regard them as the foremost in the advance of the art in the sphere here involved—the gaseous tubes still continued to be used and the art generally regarded gas as incident, if not, indeed, indispensable to their use.

Indeed, had the art followed the caution of DeForest heretofore quoted, we would have no vacuum tube, a situation akin to that referred to by this Court in the Turbine case, 202 Fed. Rep. 932, where we said:

> "Finding, then, as we do, that the disclosures of the Moorehouse patent had no helpful bearing or practical effect on the impulse turbine art, and supported in that conclusion by the fact that its vagueness is such that fair-minded witnesses in this record greatly differ as to what its disclosures really are, we are not warranted in attributing to it any effect in the way of vitiating, or even minimizing, the work of Curtis."

Now as it seems to us, the art, although it did not exactly know how the gas in gaseous tubes acted and just why it was able to so conduct, nevertheless continued to use it and regarded it as the indispensable means of conducting. As against this firmly entrenched teaching and practice of the art, Langmuir's suggestion of eliminating gas as a conductor was a radical change and even more so was not the substitution of some other tangible conductor, but the disclosure of supplanting the tangible gaseous conductor by the intangible conductor of a vacuum. Vacuums, per se, were of course known. DeForest's audion and Fleming's valve were equally known, but the suggestion of dispensing with gas and utilizing a vacuum between the two was as novel in practice as it was unlooked for in result. Indeed, shortly before the patent in suit was applied for and even though the use of a vacuum may possibly have been suggested, the director of the Research Laboratory stated in a paper read before the American Institute of Engineers: "In connection with this work of Fleming's, we have studied the effect of vacuum on the current, and also found that the presence of gas is necessary for this negative discharge." And that Langmuir's use of high vacua did not appeal to so practical and eminent a scientist as DeForest was evidenced by his statement, heretofore quoted, made even after Langmuir had made known his process publicly,—"I believe, however, that Dr. Langmuir has, by working into these extremely high vacua and the high potentials necessitated thereby, pursued the less promising of two paths of research." For the defendant to now contend that the use of these extremely high vacua by Langmuir was simply the natural and to be expected growth of the art is to credit the ordinary art with a scientific capacity which a master of the art like DeForest did not himself possess. If it was an obvious thing, as the Court below believed and decided, for the ordinary art to do away with gas and gaseous tubes and substitute high vacua therefor, surely such an extraordinary mind in that art as DeForest, when confronted with the substitution, would not have pronounced high vacua a mistaken path. Had the ordinary art followed the advice of this super ordinary adviser and leader and discarded the suggestion of high vacua, it would seem so far as the universally used non-gaseous tube is concerned, it would not be in use today.

But it is contended by the defendant and the Court below so held, that all that Langmuir did was simply to vary in degree the prior use of the vacuum and that a mere difference in degree does not constitute invention or, to use the defendant's contention, the Langmuir tube is "nothing more or less than the identical thing of the prior art with possibly a little higher vacuum, depending on the specific use to which the devices is to be put." Assuming the correctness of this general proposition, we think it is not applicable to the present case. In considering change in degree, the test is not the quantum or minimum of change made but the quantum of change in function and result which such change, great or small, effects. A great change may effect but a slight change in function and result, while a slight change may effect a radical difference in function and effect. The effect, the practical progress and use in the arts, are the aim and end of patent grants and where great results follow a change, the slightness of the change tends to emphasize and make all the more remarkable, unexpected and inventive the disproportionate result the slight change effects. It was the slight turn of a screw and the closer proximity of the diaphram that made the telephone diaphram the carrier of speech and gave Bell the due reward—not for the slight turn of the screw but for the great effect it wrought. But a vacuum, or indeed change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so co-ordinate and interwork that current flow is not affected by gas. We say not affected by gas because of necessity an absolute vacuum is an impossibility, but the degree of vacuum is such the current flow is no longer objectionably affected by gas. Just what the degree of vacuum shall be is dependent on several elements and, as stated in the patent, cannot be exactly stated. In that regard the specification says: "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned."

So regarding what we believe to be the basic question in the case, we limit ourselves to the foregoing statement of our reasons for our conclusions. But in thus limiting our discussion, we deem it proper to say that the numerous questions and considerations advanced in the case in other particulars, have been duly considered.

The degree of the Court below holding this patent invalid is reversed and the record remitted with instructions to enter a decree that the patent is valid and infringed.

The Opinion of Judge Woolley.

IN THE

UNITED STATES CIRCUIT COURT OF APPEALS

For the Third Circuit.

General Electric Company, *Appellant,* *v.* DeForest Radio Company, *Appellee.*	March Term, 1928. No. 3799.

Woolley, *Circuit Judge,* dissenting:

I am constrained to dissent from the judgment of the court holding the Langmuir patent No. 1,558,436 valid. I have the same trouble that other tribunals have had throughout the twelve years of the patent prosecution and five years of the patent's life in finding precisely what Langmuir invented. My trouble, like that of others, has been increased by the difficulty which attorneys for the patent have had in defining the invention and by the difference between their definitions and the claims of the patent.

This is more than a mental disturbance, for manifestly a patent to be valid must relate to some invention, something patentably new and useful, and must disclose the invention so that a court, looking through the eyes of those skilled in the art, can see what it is.

The art—really two related arts—is that of wire and wireless telephony, the latter commonly called radio. The invention relates generally to an electron discharge device comprising the familiar vacuum tube in which the customary electric current is carried by negative charges called electrons from the cathode to the anode, sometimes associated with a grid, and relates particularly to a vacuum space so free from gases as to avoid ionization. If the parts and principles of the mechanical construction were new and the gas evacuation old, there might be invention; and also if the structure and its principles were old and the gas evacuation—high vacuum—were new, still there might be invention. But the essential parts and principles of the mechanism, comprising a tube, cathode, anode and grid, were old, and high vacuum in the tube also was old. So the inventor was forced to admit the presence of these old elements, yet, still insisting he had created something new, he was compelled to avoid the common art terms applicable to these elements and particularly that of "high vacuum" in disclosing his invention and use technical terms which, as I understand them, mean the same old things. With this necessarily general preface to a highly complicated situation arising out of a difficult art, I come to the matters in hand.

In an effort to find what Langmuir invented, it is well to begin at the beginning. I shall therefore turn to his application for a patent, for in that instrument must appear the substance of the invention as the basis for subsequent amendments and for the patent as it eventually matured.

A recital of the prosecution of a patent application through the Patent Office is dreary reading yet, in this instance, it shows quite clearly that even the applicant was far from certain what he had invented. Naturally I hesitate to say this about Irving Langmuir, a great physicist, yet, saying it with entire respect, I am convinced that the history of the application establishes that fact and therefore is pertinent to the ever present inquiry: What did Langmuir invent?

The patent issued on October 20, 1925. The application was filed on October 16, 1913; renewed March 14, 1916. These are critical dates. The original application contained five claims; two for process of removing ionizable gas from vacuum electron discharge devices, that is, in plain words, for obtaining a high vacuum, and three for methods of preparing such devices, and no claims for discharge devices themselves. The specification conformed to these claims, referred to the art, stated the problem, disclosed construction adapted to the operative principle of such tubes and showed how they can be "evacuated" of gases by heating the glass walls, heating and bombarding the metal parts thereby expelling occluded gases, and drawing off both free gases and expelled gases "by a suitable evacuating means, for example, a Gaede molecular pump."

It should be noted that when the application was filed in 1913 the radio art was in its infancy but that, in 1925, when the patent issued, the art had attained an amazing growth. It is pertinent to inquire what happened to the application during this span of twelve years during which the mysteries that had enveloped the early art were largely dispelled and replaced by a broad knowledge of its principles.

After the application was filed in 1913 it lay practically dormant for several years, the applicant filing enough amendments by additions and cancellations to keep it alive. Amendments to the specification occurred as follows: two in 1913; eight in 1914; one in 1915; five in 1916; three in 1917; three in 1919 and forty-five in 1925, the year the patent issued.

Amended claims were filed and additions thereto and cancellations thereof made as follows: four in 1913; fifteen in 1914; twenty in 1916; five in 1917; nine in 1919; five in 1921 and forty-two in 1925, the year of the patent.

Analyzing these amendments, it appears that the five original claims (which were for process and method) were at different times wholly cancelled. Late in the year 1913 Langmuir first made claim to invention of a structure or device, that is, to invention of a tube. This he did by four claims. The first was amended four times and cancelled in 1925. The second also was amended four times and cancelled in 1925. The third was amended four times and was not cancelled. The fourth was amended once and cancelled in 1925. Of the thirty-two claims allowed in the issued patent, four are for method and process, being amplifications of the original method and process claims cancelled; twenty-eight are for a device. Of these device claims one was filed by amendment in 1913; one in 1917; nine in 1919; three in 1921 and fourteen in 1925, the year the patent issued. Bearing on the question whether Langmuir knew and disclosed in 1913, or indeed in succeeding years, what he had invented, it is significant to note that during twelve years, and mainly in the latter part of that period when the art had grown and reached a high stature, he rewrote, by sixty-seven amendments, the major part of his specification and cancelled all the original method and process claims and by one hundred amendments added, changed and cancelled claims until finally he was allowed the thirty-two claims of which twenty-eight, the claims for a device, are entirely new. It would be instructive, yet impossible within the permissible bounds of an opinion, to trace the progressive changes from the method and process claims of the original application to the device claims of the matured patent. But device claims having been allowed, they inevitably bring into the case certain devices of the prior art of which two are presently pertinent.

Long before Langmuir applied for a patent, Fleming, an English inventor, brought into a very feeble art a practical electron discharge device, comprising a cathode and anode in a vacuum tube. Also long before Langmuir's application, DeForest improved on Fleming by producing an electron discharge tube which he described as an oscillation detector and called an "audion." The improvement consisted in adding a grid to Fleming's elements. The construction and functions of both devices are given in an elementary way in the opinion in Westinghouse Electric & Mfg. Co. *v.* DeForest Radio T. & T. Co., 21 Fed. (2d) 918, 919. The audion as conceived by Fleming and improved by DeForest at once became and has ever since continued to be the basis of the modern art of transmitting sounds great distances both by wire and through the air. Just here dates are important. A patent for the audion (No. 879,932) issued to DeForest in 1908. The audion vacuum tube was therefore in existence and its principles of operation presumably known by Langmuir when in 1913 he filed his application for a method of evacuating such a tube, although he had not seen one until that year. In 1912 or 1913, the American Telephone & Telegraph Company, committed to the operation of transcontinental telephony by the opening of the San Francisco Fair, acquired rights under the DeForest patent and, first exhausting the gas and heightening its vacuum, used the DeForest audion as an amplifying telephone relay, thus making possible the first transmission of vocal words from coast to coast by wire. In 1917 the DeForest Radio Telephone Company, assignee of the DeForest patent, granted (with certain rights reserved) a license to the Western Electric Company to make, use and sell the invention for certain purposes with the right to grant sub-licenses. In 1920 the General Electric Company, the plaintiff in this suit and the assignee of the Langmuir patent in suit, acquired through mesne conveyances a sub-license to make, use and sell the DeForest audion, DeForest Radio T. & T. Co. *v.* Radio Corporation of America, 20 Fed. (2d) 598, 599, 600, which (probably with a heightened vacuum) it did on a vast scale until the DeForest patent expired in 1925, the year in which the patent in suit, after twelve years of travail in the Patent Office, issued to Langmuir, assignor to the General Electric Company, for an electron discharge tube including the essential parts and now universally accepted principles of the Fleming-DeForest tube. The Langmuir patent now completely covers the field previously occupied by the audion of the expired DeForest patent, and will, on the decree of this court, continue to cover it for twelve years more; hence the importance of this litigation.

Turning to the patent as it issued, the specification must first be looked at, for it contains some references to the behavior of electricity in a vacuum tube, old and well known, which are necessary to an understanding of the case. First there is a description by words and diagrams of mechanism for a vacuum tube. If new, this, it would seem, is unimportant as the specific mechanism is not claimed. Its importance resides in the fact that the patented device comprises the three elements of the general mechanism found in the art—the cathode, anode and grid, variously positioned in a vacuum tube to get the best electrical result—and in the fact that, as I read the record, these three elements, separately and in combination, operate on the same principle in which they operated in the art. Describing their operation, as the art then knew it, Langmuir said:

> "The passage of an electric current across a tube ordinarily involves the movement of negative charges called electrons which, under the influence of the impressed voltage, pass from the cathode to the anode through the vacuous space. If these electrons when moving above a certain velocity collide with gas molecules they tend to ionize the molecules, splitting them up into electrons and larger and more slowly moving ions. Under these circumstances the phenomena of conduction across the tubes are the result of the action and interaction of electrons and the ions; * * * The cathode under these conditions is disintegrated, * * *, which causes its rapid destruction * * * The bombardment of the cathode by positive ions also causes heating of the cathode. The ionization of gases at low pressures by collision with electrons occurs at definitely determinable voltages, these voltages being known as the ionization voltages * * * (It should, for later use, be noted here that Langmuir said nothing about gas being a supposed medium for conducting electrons from one electrode to the other.)
>
> "If for a given cathode temperature the voltage is sufficiently high to call all the electrons emitted or liberated at the cathode to be drawn away, then a further increase in voltage produces substantially no change in the current. The current thus determined is called the saturation current, and the range of operation in which the current is substantially independent of the voltage or approaches this condition may be called the saturation range

> or more briefly designated merely as saturation. If for a given cathode temperature the voltage is not high enough to cause all of the electrons which are emitted or liberated at the cathode to be drawn away, the operation occurs in a range below the saturation range. Operation in this range may be spoken of as operation below saturation."

Predicated on these two definitions of ionization and saturation Langmuir by claim 2, which has been treated in this litigation as a typical claim, said that his invention is:

> "A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range, below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization."

That, as I read it, simply means "high vacuum," for a tube properly fashioned and shaped by skilled workers and highly (thoroughly) evacuated of gases—free and occluded—will in conjunction with a two electron group or with a group of two electrons and a grid produce these results; both groups, then and now, being in common use for different purposes by the art and by the plaintiff itself.

For the purposes of this case, vacuum means gas evacuation, high vacuum means vacuum above the ionization point, and, by the same token, a high vacuum tube means a non-gaseous tube. If the language of the claims means high vacuum, it is prior art, for the art was entirely familiar with the fact and effect of such a vacuum; and if prior art, Langmuir invented nothing.

When the patent came into litigation in this case in the District Court of the United States for the District of Delaware the learned trial judge, having trouble with the claims, endeavored to get from the plaintiff a definition of the invention, asking time and again, as did this court on appeal: If not high vacuum, what is the invention? An answer to this question seemingly had its difficulties. The plaintiff, of course, could not say that the invention was high vacuum alone, or high vacuum in combination with Fleming and DeForest parts alone, for that would be an admission of old art and would instantly avoid the patent. It was forced to admit that the Langmuir device included all these old elements but claimed it included "something else." So, eventually, in order to show this something else—something new—it produced, under the insistence of the trial court, this carefully constructed definition of Langmuir's invention, on which the case was tried below and on which it was first argued and decided in this court on appeal:

> "The Langmuir invention is a coordination of elements having a new functional relation between various factors, producing a new result. It is not a matter merely of maintaining a certain vacuum, far less of *producing* a certain vacuum which will be destroyed the moment the tube begins to operate. It involves primarily a relation between the shape, size and space relation or 'geometry' of the parts of the tube and the nature and pressure of the gas therein contained, coordinated and adjusted with respect to the conditions of the electric circuit."

That, I surmise, would be a bad patent claim. However, as it was intended to describe the invention more clearly and more definitely than Langmuir had disclosed it in the patent claims I shall take it as it is written and try to find what it means. I discern in its generalization three factors: (1) gas pressure in the tube; (2) "shape, size and space relation or geometry of the parts of the tube"; and (3) the relation of one to the other.

The first factor of gas pressure, or, more properly, the lack of it, if it means anything, must mean a minimum of gas. This in turn means high vacuum. If it does not mean high vacuum there is no new vacuum factor of invention in the device, for low vacuum was old and that is an end to the case. If it does mean high vacuum then again it is not new, for high vacua, their uses and effect and how to produce them, were long known and practiced in the art.

The second factor, or "geometry," of the physical tube elements is not, so far as the claims reveal, involved in the invention. The physical elements themselves were old. This the plaintiff admits. Though differing in shape from some others, they are not claimed to be inventively novel in themselves. Indeed, each claim describes the invention not so much by its parts as by its characteristics of operation and results—characteristics inherent in any electron discharge tube possessing a high vacuum. Nor was this an inadvertence for when the Examiner, on rejecting certain device claims on prior art references, said:

> "If applicant's device is an improvement over the reference he should define the difference by structural limitations," the applicant (Langmuir) replied by saying:
>
> "The 'structural limitations' in this case are to be found in the *difference of vacuum.*"

So, thus far, the invention, with old parts and a high vacuum, gets back to the question whether there was invention in the "difference" between low vacuum and high vacuum, a difference existing in and known to the art.

The third factor, the relation of the two factors of gas pressure and physical parts, appears nowhere in the claim unless it be implicit in the words "the gas content or residue of said tube and the relation of the *parts* of the tube being such" as to produce a certain result. (Gas pressure is scarcely a *part* of a tube.) If it is so implied, Langmuir cannot claim invention by implication. The claim therefore is void for inadequate disclosure. If it is not so implied, there is no claim for the third factor.

Whether I am right or wrong in this analysis of the plaintiff's statement of Langmuir's invention or in my disposition of its elements is not important for the validity of the patent depends not on the plaintiff's conception and definition of the invention but on the claims of the patent.

So I come back to the claims of the Langmuir patent to find Langmuir's invention. But before doing that I am arrested by still another entirely new definition of Langmuir's invention, this time made by the court in its opinion. The court did not adopt the plaintiff's definition of coordinating elements with functional relations but, stating that a non-gaseous electron discharge device did not exist before Langmuir, found the invention to reside in his producing a non-gaseous tube in place of a gaseous tube of the prior art or, in other words, in substituting a high vacuum for a low vacuum, the very thing which all along the plaintiff was forced to avoid in its definition because it was old. Without conceding its predicate, I agree with the court's succinct definition of the invention; but as the invention so defined was old I cannot agree to hold a patent for it valid.

It now appears, and I say this with entire respect, that in interpreting and sustaining the patent broadly for a non-gaseous tube the court has given the plaintiff more than it ever dared to claim. A high vacuum or non-gaseous tube being old, the plaintiff knew that an admission that the invention was a non-gaseous tube and nothing else would defeat the patent. Langmuir also must have known that a non-gaseous tube was old for otherwise, if he had believed he was the first to conceive and make one, he could, and doubtless would, have claimed it in a half dozen words: "A non-gaseous discharge tube," or "an electrical discharge device with a high vacuum tube," whereas in his original application for a patent he made no claim for a tube of that kind or, indeed, for a tube of any kind, the inevitable inference being that at that time he thought all he had invented was a new method or process of gas evacuation, that is, a new way to produce an old thing. But that the plaintiff realized the necessity of claiming for the invention something more than a high vacuum tube or non-gaseous tube is evidenced by its earnest and repeated contentions that Langmuir's invention, while including a non-gaseous tube—high vacuum—admittedly old, included "something else," that something else being disclosed by the remainder of the long claims and interpreted in its quoted definition. The plaintiff nowhere and at no time has claimed that Langmuir invented a non-gaseous tube *per se*. And wisely so, for it well knew that, while not in universal use, non-gaseous tubes were in commercial use before Langmuir for some purposes and that gas evacuations were as thorough as the instrumentalities of the art in 1913 would effect, and that was substantially above the ionization point, which is the crux of this case.

Returning to the patent claims and using claim 2 for convenience, it appears that the invention is an electron discharge tube which is capable of being operated below saturation and above ionization voltages. Langmuir called this a "pure electron discharge device"—"pure" because unaffected by gas ionization which is either entirely absent or negligible.

Electricity is an elusive subject. Therefore I shall, for the immediate purpose, restate in plain words, if I can, the theory of ionization.

Ionization is an effect produced by passing an electric current through gas which remains in a vacuum tube when it has not been thoroughly evacuated. The myriads of electrons, when passing from cathode to anode above a certain velocity, collide with and break up the molecules of gas present and charge the resultant broken parts or ions with positive charges of electricity. Thus electric reaction is inevitable. The ions (with their positive charges of electricity) fight against the electrons (with their negative charges) in the normal flow of the latter from cathode to anode resulting, at high voltages, in a blue glow which is the indication of bad action, a thing to be avoided. The central point of this statement is that ionization occurs at certain voltages in an electron discharge tube when, not being thoroughly evacuated, it contains air or gas, whether gas free in the tube or gas occluded in its parts and liberated by heat during operation. The amount of ionization depends upon the amount of gas present. Langmuir prescribed in his specification that occluded gas should be expelled from the tube parts; from the tube by heating its glass walls; from the cold electrodes by electron bombardment—the liberation of gas by the electric discharge itself; and from the incandescent cathode by the heat of an electric current; all old; and after this, that both the expelled gas and free gas should be pumped out of the tube during the heating process (old) by "a suitable evacuating means (old) for example, a Gaede molecular pump," then a new German invention.

Thus the capital requirement, if not the sole requirement, of Langmuir's claimed invention, is as nearly as possible to withdraw from the tube all gas, free and occluded; in other words, to obtain as high a vacuum as possible. When that is done ionization is avoided and a pure electron discharge follows. Was this new with Langmuir?

Langmuir was met in the Patent Office with the Law Examiner's statement that:

> "It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. *An evacuated tube having therein an incandescent electron emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube were also well known and available to persons skilled in the art.*"

Was that statement of the Law Examiner correct? I think it was. Just here occurs my sharpest departure from the opinion of the court which is based, as I have before stated, on what I am constrained to believe is an erroneous theory or finding that all discharge tubes before Langmuir were gaseous and that Langmuir's invention is a non-gaseous tube.

If that was his invention, clearly he must have been the first to conceive it and reduce it to practice. That the Examiner was right in saying that high vacua in electron discharge tubes were old before Langmuir and that a pure electron discharge—the inevitable result in a high vacuum non-gaseous tube and an impossible result in a gaseous low vacuum tube—also was old is sustained by many prior publications and patents. The same prior publications and patents contradict, I think, the court's holding that Langmuir was first to make and invent a non-gaseous tube. They are so numerous that it would not be permissible to quote them in an opinion. I shall therefore do nothing more than cite a few of them, ranging from 1881 to 1912, found in the record and to be used by anyone who should desire to check up this statement or who may be charged with the duty of retrying the issue. They are: Lilienfeld, Fleming, Doane, VonBaeyer, Bissel & Hagen, Malignani, Edison, Dwyer, Duncan, Leonard, Soddy, Thatcher, Child; illumined by the testimony of Waterman and Chaffee.

On these references I stand; and on them I would hold the patent invalid for want of invention.

Passing from the literature and patents of the prior art as affecting the validity of the patent for want of invention, I come to the question of prior use. The trial court found the patent also invalid because of prior use by DeForest on evidence as to which there is little dispute on the facts as distinguished from inferences. The test is the voltage at which ionization ordinarily occurs in a "gassy" tube. It is given at from 20 to 30 volts. That is not disputed; they are Langmuir's figures.

Prior to August, 1912, DeForest was the electrical engineer of the Federal Telegraph Company of California and was engaged in developing the transmission and reception of messages by radio. In this work he used his oscillation detector or audion then normally having a gas content. It was a "gassy" tube. But desiring to use it not as a detector but as an amplifier, as later it was almost universally used and indeed as made for that use by the plaintiff itself under license and by the Westinghouse Electric & Manufacturing Company, its sublicensee, he had the audion exhausted of gas as far as it was possible in that day. That is, he sought and obtained as high a vacuum in the tube as existing means would produce. When the vacua were too low and the amplications poor he complained to the manufacturer and had the tubes re-exhausted. During that period (1910, 1911 and 1912) the Federal Telegraph Company used DeForest's amplifying audion at 54 and 67½ volts. This was possible only because he had exhausted the tubes of gas, which otherwise would produce ionization at 20 to 30 volts, and thereby heightened the vacuum above that danger line. This was "high vacuum" within the definition of vacuum above the point of ionization and was therefore high vacuum within the sense of those words as used in this case. It was not so high as that later attained by more modern means, for instance the Gaede molecular pump, which had just come into the art at the time of the patent application, referred to by Langmuir in his application and invented not by him but by Gaede. I agree with the court that DeForest did not then understand the change in operative principle for in later years he expressed views contrary to those advanced both before and after that time. But DeForest did change the vacua of his tubes in changing their function from detectors to amplifiers. Whether he knew the principle of the change is of no consequence. The fact is he did it. And he did it before Langmuir. And by doing it he got rid of the ionization of low vacuum and obtained, and put into commercial practice for nearly three years before Langmuir, the very electron discharge of Langmuir's claimed invention.

What I have said about the device claims applies equally to the method and process claims.

On the subject of validity as involving invention I shall conclude this phase of the discussion by referring very briefly to the claimed advance made in the art by Langmuir's invention, matter with which the plaintiff very earnestly began and ended discussion in its brief and at the argument and matter by which the court was impressed. Admittedly, when invention is in doubt—yet *only* when it is in doubt—favorable reception by the art may be placed in the scale. As the four judges who heard this case have divided evenly on the question of invention, I shall, for that reason only, assume there is doubt as to invention. The plaintiff says that today everybody uses "the Langmuir tube," a name given it not by the art (as the plaintiff frankly admitted at the argument) but by the plaintiff itself; that Langmuir, seeing through the mysteries of the art, made an invention that revolutionized the industry and made possible the transmission of sounds through the air for great distances which without his invention would be impossible.

Much litigation in respect to the radio art has drifted to this circuit. Oddly enough, in every case the plaintiff has claimed for his invention the whole credit for its growth. I am satisfied from the number of cases we have heard that the whole credit for the amazing advance of the radio art cannot be given to any one invention or even to a few of them. In truth, the art is the product of innumerable impulses. The original impulse was, of course, the vacuum tube appearing years age in the incandescent lamp art. Another impulse given in the incandescent lamp art and transferred to the radio art was that of the Just and Hanaman unstable squirted tungsten filament displacing Edison's bamboo filament; still another was Coolidge's method for obtaining a filament of pure tungsten, strong and stable. Impulses in the radio art itself came from many inventors. At one time there were seven thousand applications for patents pending in the radio section of the Patent Office. To mention only one or two inventions, they include discharge devices of the Fleming two electrode type and the DeForest type with a grid added to Fleming, the feedback circuit invented at different times by DeForest, Armstrong, Langmuir and Meissner. There are many more, without any one of which it has always been said by the particular inventor that the art would have gotten nowhere. And now the plaintiff here says the same of Langmuir. Important and indeed great as some of these inventions were, no one of them is entitled to all credit for what has been accomplished in this great art, for the art has been impelled forward by hundreds of inventors and thousands of skilled workers. What Langmuir claims to have done—procured pure electron discharge above ionization voltages in tubes of the DeForest type—appears to me to be the natural growth of the art, begun by others before Langmuir and by them reduced to practice with means then available, and developed to their later perfection during the twelve years of his patent prosecution through the Patent Office.

I thought after the argument, and still think, the Langmuir patent invalid because of lack of invention and prior use. If I am wrong and the patent really involves invention, then, again, I think it invalid for, as I read the evidence, Langmuir was not the first and original inventor. On this point, to avoid repetition, I refer and subscribe to the opinion of Judge Morris holding on evidence substantially greater than the evidence in the interference proceeding that, if invention, Arnold was the first and original inventor.

And so this court, one judge dissenting, affirmed the decree of the District Court, on its opinion, holding the Langmuir patent invalid.

In due course the plaintiff filed a petition for rehearing based on this proposition:

> "In simple language, Langmuir's invention consisted in taking out the conductor (gas) which was in the Fleming valve and the DeForest audion and putting nothing in its place; he dispensed with what was regarded as an essential element in the operation of the tube (gas) and by doing so made a tube which worked infinitely better."

The petition was allowed and the reargument was based on this entirely new statement of Langmuir's invention made for the first time four years after suit was brought, five years after the patent was issued and seventeen years after the application was filed. Of course if the facts asserted were facts established by the evidence there would be no doubt about what Langmuir did and no doubt that it was invention and, if claimed, no doubt he was entitled to a patent.

The plaintiff rests its proposition upon its own statement that "Both Fleming and DeForest depended upon the conductivity of gas as the fundamental basis of the operation of their tubes." It makes this statement without distinguishing between detectors and amplifiers and supports it by carefully selected quotations from scientific publications in the early days of the art ranging from 1905 to 1912 (one in 1915) when scientists were feeling for the theory of electron movement in electron discharge tubes, some of whom based it on conduction by rarified gases or air, some on conduction by ionized gases, and some not on conduction at all but on free passage of electrons through space in a high vacuum, that is, in the absence of gas or air. And in addition the plaintiff to support its statement points to an adverse criticism by DeForest in 1915 of Langmuir's "extremely high vacuum" quoted in the court's opinion. The plaintiff ignored all the testimony on the subjects of prior art high vacua and pure electron discharge, which means absence of gas as a conductor, their advantages and uses, to which I have previously alluded with citations.

Of course, if the belief and practice of the art were that gas conducts the electrons, that gas therefore is necessary to conduction and Langmuir discovered it to be wrong, that in fact gas is an enemy to conduction, and omitted gas as an element in his tube yet obtained the same or a better result, clearly he made an invention. These are the things which now the plaintiff and also the court say he did. But Langmuir did not say so. If that was his invention he should have disclosed it in his claims for we are called upon to judge the patent on Langmuir's disclosures, not on the plaintiff's definitions of his invention. To be sure, he did refer in his specification to several tubes—the Geisler tube and the Roentgen X-ray tube—"whose operation depends upon gas ionization." He might, more or less correctly, have added to the list detectors with gas content, then and now in common use for certain purposes, whose usefulness depends on their sensitiveness and their sensitiveness on gas content. But he nowhere said in his patent that before his invention electron discharge tubes used for amplifying purposes in order more faithfully to reproduce sounds (one of the purposes of the DeForest audion and the thing we are dealing with in this case) depended on low vacuum or that the art regarded, as an essential element of such a device, gas as a conductor, for he probably knew the contrary was true. To show that the plaintiff's last definition of Langmuir's invention is without foundation in the evidence I refer to, but shall not repeat, what I have said about prior knowledge and prior use of high vacuum tubes. I shall endeavor, very briefly, to show that Langmuir by his own words contradicts the plaintiff's last definition of his invention and refutes the theory on which the court has in part based its judgment.

In Langmuir's original specification he stated that when there was enough gas in the tube to become ionized by the discharge of electrons "The positive ions (gas molecules) *take part* in the *conduction* of current, giving at first erratic readings on measuring instruments connected in circuit," which is what the plaintiff now says. Continuing, he said, that the audion, the DeForest tube, was a device that took advantage of that phenomenon. *But he cancelled the quoted statement before the patent issued.* At the trial he was examined with respect to that statement in his patent application and was asked whether the sentence would be true if it read: "The positive ions take part in the conduction of current by acting as *conductors* or carriers of current." He answered: "In my opinion the sentence would have *no sensible meaning* if the word 'conductor' was left in for *it is inconceivable that ions could be conductors of current.* I will, therefore, confine myself to the case where the positive ions act as 'carriers.' With this correction I can say that the statement would not have been true."

With this cancellation and explanation Langmuir rested. Neither by amendment nor in his testimony did he again advert to a prior art theory of gas conduction which the plaintiff now says "was regarded (by the art) as an essential element of the operation."

In the interference proceeding Langmuir testified with respect to the early work of Lilienfeld, as follows:

> "Lilienfeld proved beyond question, I think, that he obtained discharges, in some cases at least, in which the effects that he measured *were not dependent upon gas ionization.* * * *
>
> "Lilienfeld probably succeeded in obtaining a discharge *high vacuum substantially free from effects of positive ionization* in the device he described in his 1910 paper * * *
>
> "Lilienfeld in his experiments of 1910 heated the walls of the vessel, *he reduces the gas pressure to a low value,* and in some of his experiments *he heated his electrodes* by *electronic bombardment* * * *
>
> "*Heating of glass and electrodes, and exhaustion to low pressure,* are elements which were used by Lilienfeld and were known *prior* to Lilienfeld's article * * *
>
> "Factor No. 1 which I gave in answer to XQ84, viz., that the bulb should be heated *during* exhaust to a temperature materially higher than the operating temperature, was used by Lilienfeld in much of his work * * *
>
> "Factor No. 4, which is that which I gave in the first part of my answer to XQ87, refers to the lowering of the pressure to such a point *that a further lowering brings about no further change.* In many of Lilienfeld's experiments, this condition *was realized.*"

Von Baeyer stated as early as 1909 that his "experiments were of course carried out in the highest possible vacuum to avoid the influence of ionization." Langmuir admitted that "Wehnelt claimed that * * * currents of the order of 10 milliamperes could be obtained even in the highest vacuum."

Referring to an interview with Richardson in 1912 Langmuir said:

> "Richardson * * * expressed himself as confident that even in the highest vacuum thermionic currents could still be obtained."

Langmuir admitted in the interference proceeding that "prior to 1912 (the year before his application) there were some experimenters who took precautions to remove gases from the walls, from vessels and from electrodes."

This, I think, shows that the reargument, based on an incorrect premise, should leave undisturbed the court's first finding that the patent is invalid.

The plaintiff, however, prevailed. The court reversed its previous decision and will now enter a decree holding the patent valid. From the opinion announcing its judgment, in so far as it will reverse the decree of the District Court on the first (Langmuir) patent in suit, I dissent.

This is a long dissenting opinion. In view of the gravity of the court's decision and its effect upon the art I make no apology for its length. I frankly admit that it is written with the hope that it will arrest the attention of the reviewing court.

A true Copy:

Teste:

Clerk of the United States Circuit Court
of Appeals for the Third Circuit.

No. 630, October term, 1930. DeForest Radio Company, petitioner, *v.* General Electric Company. Ordered, that the opinion in this case be amended as follows:

(1) By substituting for the words "In July, 1912," in the 12th line of the last paragraph of the opinion, the following:

"August 20, 1912, the earliest date claimed for Langmuir, was rejected, rightly, we think, by the District Court, which held that Langmuir was anticipated by Arnold in November, 1912. But before the earlier date,"

(2) By substituting for the 3d ~~sentence~~ from the end of the opinion, the following:

"By August, 1912, the Telegraph Company used De Forest amplifying audions at 54 volts, and, by November, they were used by another at 67½ volts. This was possible only because the tubes had thus been exhausted of gas which would otherwise have ionized with blue glow at from 20 to 30 volts."

SUPREME COURT OF THE UNITED STATES.

No. 630.—October Term, 1930.

De Forest Radio Company, Petitioner,
vs.
General Electric Company.

On Writ of Certiorari to the United States Circuit Court of Appeals for the Third Circuit.

[May 25, 1931.]

Mr. Justice Stone delivered the opinion of the Court.

Certiorari was granted, 282 U. S. 836, to review a judgment of the Court of Appeals for the Third Circuit, holding the Langmuir Patent, #1,558,436, granted October 20, 1925, for "electrical discharge apparatus and process of preparing and using the same", valid, and infringed by petitioners. The District Court for Delaware, in which respondent, the assignee of the patent, brought suit for infringement, held the patent invalid for want of invention, and because of prior use and prior invention, and gave judgment dismissing the complaint, 23 F. (2d) 698, which the Appellate Court at first affirmed, and then, on reargument, reversed. 44 F. (2d) 931.

Infringement is conceded if the claims of the patent are valid. It is known as a high vacuum tube patent, and the alleged invention is exemplified in high vacuum tubes of familiar use as detectors or amplifiers in the art of radio communication and telephony. Correct appreciation of the contentions made requires, at the outset, an understanding and some exposition of the scientific principles which it is agreed are brought into play in the high vacuum tube or which at least are accepted as working hypotheses accounting for its operation.

A radio tube of the audion or three electrode type consists of a bulb, within which a vacuum has been created, enclosing a filament, which is a negative electrode, or cathode; a plate, which is a positive electrode, or anode; and a third electrode, known as a grid, located between the filament and the plate. The grid is connected with an input circuit, over which electrical radio activity, actuated at the sending station, is gathered from the ether and passes to the grid. When the tube is used as an amplifier, the plate is connected in circuit with a telephone receiver or loud speaker. In operation, the filament is heated to incandescence by passing an electric current through it. In its incandescent state, electrons, or negative charges of electricity, are developed at the filament and pass to the plate, attracted to it by its positive potential, and cause a flow of electricity through the plate-loud-speaker circuit. The sounds given out by the loud speaker are produced by variations in the current passing to it. Radio amplification depends on producing in the more powerful current of the loud speaker circuit, variations exactly corresponding to the variations in the weaker input or voice current which are actuated by the sending station.

In the vacuum tube of the three electrode type, this is accomplished by passing the input or voice current over the grid. Variations in that current produce variations in potential of the grid which, by reason of its location between the filament and plate, effects like variations in the effective potential of the plate with corresponding variations in the loud speaker circuit. The number of electrons emitted by the filament is determined by its temperature. But the current passing through the plate loud speaker circuit depends on the number of electrons drawn from the filament to the plate, and this in turn depends on the voltage of the current passing to the filament. When it is high enough to force all the electrons emitted by the filament to pass from filament to plate, increase in the voltage at the filament will not produce an increase in current in the loud speaker circuit and the tube is then said to be "saturated". As successful operation of the tube depends on the response of the loud speaker current to changes in voltage effected by the voice or input current, the tube is most efficiently operated at a voltage of a range below saturation, and a current within this range is known as the "space current".

Of critical importance in the present controversy is the effect of the presence of gas within the tube. As in the practical art of bulb manufacture no scientifically perfect vacuum can be attained, air or other gas is always present within the vacuum tube. This consists of a small amount of residual gas, after the vacuum is created by pumping out the tube in the process of manufacture. There is also gas in the walls of the bulb and the electrodes, described as "occluded," which, if not expelled from them and removed in the course of manufacture, is later freed in varying amounts when the tube is in use, by the action of the heat of the filament and the electrons generated there.

The passage of electrons from filament to plate at certain voltages produces changes in the gas, known as "ionization". Ionization is the manifestation of a rearrangement of the constituent electrons of the gas atoms which occurs, in low vacuum tubes, if other factors of causation remain constant, at known voltages within a range of from 20 to 30, but varying somewhat with different gases. The atom, according to present day scientific theory, is composed of an electrically positive nucleus, around which revolve at high speeds electrically negative electrons. In its normal state, the atom, whose nucleus and electrons are in electrical balance, exhibits no electrical effects; but within a thermionic tube, the impact upon the gas atoms of the electrons, passing from cathode to anode at velocities induced by ionization voltages, forces off negative electrons from the atoms. The atoms from which the electrons have thus been detached are then electrically positive and are known as ions. Ionization, which begins at the ionization voltage, is increased with increasing voltages as the tube approaches saturation, when extreme ionization takes place; and, for reasons which need not be elaborated here, the tube then ceases to function as a radio tube, a condition visibly manifested by a blue glow within it.

Gas ionization in the vacuum tube is of great importance because of its effect on the current passing from filament to plate. Ionization, when it occurs, may operate within the range of the space current to increase "conductivity" of the tube, that is, the discharge from filament to plate, above what it would be at the same voltage in the absence of ionization, through the development of the positive ions, which pass to the cathode, and of the negative electrons, which pass to the anode. The ions facilitate the flow of electrons from cathode to anode and increase their number by impact on the former, which raises its temperature. The result is that, in low vacuum tubes, saturation with the blue glow effect is reached, other factors remaining constant, at lower voltages than in high vacuum tubes. Hence, in the range of voltage above ionization and below saturation, within which the tube is commonly operated, a low vacuum tube, because of the increase of current due to ionization, is more responsive to slight changes in voltage produced by the operation of the grid or input current. In consequence, the low vacuum tube is more sensitive both as a detector and as an amplifier than a tube of high vacuum.

But this advantage is accompanied by a serious disadvantage, especially when the tube is used for amplification, in that ionization produces variations in the electronic discharge from filament to plate, which correspondingly affect the current passing through the loud speaker circuit. Ionization is affected by the amount of gas in the tube, and hence by the degree of vacuum and the amount of occluded gas freed in operation by heat and bombardment. Since the discharge varies with the amount of ionization, the effective current in the loud speaker circuit varies with different tubes and with the same tube at different times; and critical adjustments of the current flowing to the filament are necessary to improve operation.

From what has been said, it is apparent that the problem of securing evenness or regularity of discharge from filament to plate and hence of current flowing through the loud speaker circuit is dependent upon the reduction of ionization in the tube, and this in turn is dependent, within certain ranges of limits, upon a number of variables, the more important of which are (1) the geometry of the tube, that is, its size and shape and the location of electrodes, (2) heat of the filament, (3) voltage of the filament, and (4) of vital importance here, amount of gas, that is, pressure within the tube. With the other variables controlled so as to remain approximately constant, as is practicable, reduction of pressure reduces ionization and increases steadiness of current and in turn raises the saturation point of the tube, permitting its use with higher than ionization voltages.

As in the low vacuum tube regularity or evenness of the loud speaker current was more or less imperfectly secured by varying the voltage at the filament with different tubes and at different times with the same tube, the desired result may also be attained, and far more effectively, by reducing the pressure in the tube and keeping other factors constant. When a vacuum is produced of as low a pressure as a few hundredths of a micron (a micron is equal to 1/1000 of a millimeter of mercury in terms of barometric pressure), the discharge is independent of the degree of vacuum, when the tube is used with appropriate space charge. The discharge then passing from cathode at constant temperature to anode, varies directly with the 3/2 power (square root of the cube) of the voltage imposed on the cathode. This is equivalent to saying that steadiness of current through the loud speaker circuit is obtained, with an increase in power, until saturation, in known relationship to the increase of the imposed voltage. While the effectiveness of the low vacuum tube begins to diminish, in the upper range of ionization voltages, with high vacuum tubes, currents of much higher voltages may be used without loss of effectiveness.

The desired reduction of pressure in the tube involves the use of methods for producing a high vacuum and reducing to a minimum the effects of occluded gas. By evacuating the tube by pump or other suitable means, and at the same time freeing it of occluded gas by heating tube and electrodes, and also, as may be done, by passing a current through the filament, causing "bombardment" of the electrodes by electrons, a high vacuum tube is produced. By such procedure, the disturbing influence of ionization may be removed with consequent stability of discharge. The result is of great importance, since by adaptation of the procedure to manufacturing methods, tubes giving uniform stability of current may be commercially produced, suitable for use in the complex modern radio receiving sets employing multiple tubes, without necessity for the critical adjustments of the filament circuit necessary with low vacuum tubes.

It is the high vacuum tube of this type which respondent says embodies the Langmuir invention. As a product or structure it differs from the low vacuum tube, of which the Fleming valve and De Forest audion are well known types, only in that the pressure has been reduced to such a point that there is no appreciable ionization, with the resulting constancy of current in the amplifier circuit.

In the light of the explanation given of the operation of the vacuum tube, we now examine the claims of the patent. The application, filed October 16, 1913, was pending for twelve years before it was issued October 20, 1925, a period which witnessed the most important beginnings and many of the chief developments of the radio art. The original application was for a process or method patent only. It contained five claims covering methods of obtaining a high vacuum in vacuum tubes and expelling occluded gas from them. These claims were all ultimately cancelled. Other process claims, substituted by amendment, of which four only survived in the patent as issued, were amplifications of the original method and process claims. Late in 1913 Langmuir first made claim to invention of the tube as a structure or device, in four claims, all of which were amended one or more times. All but the third, which was amended four times, were cancelled in 1925, the year the patent issued. There are twenty-eight claims for the structure or device in the patent as issued. Of these one was filed by amendment in 1913, one in 1917, nine in 1919, three in 1921, and fourteen in 1925. During the twelve years the patent was pending, there were sixty-seven amendments of specifications, of which forty-five were in 1925. Amended claims filed, and additions and cancellations of them made, number one hundred in all, of which forty-two were in 1925.

The process claims cover methods of creating the high vacuum tube in the manner already described, that is, freeing the tube of occluded gas by heating tubes and electrodes and by electronic bombardment, at the same time evacuating the tube of air or gas by approved methods, such as the use of the Gaede molecular pump or chemical means. The court below did not rest its holding of validity of the patent on these claims, and respondent does not seriously urge their validity here. It suffices to say that an examination of the prior art discloses that long before the earliest date claimed for Langmuir, the necessity for removing occluded gas from tubes or other electrical discharge devices in order to procure a high vacuum, and the methods of doing it by heating and electronic bombardment were well known, as was the procedure for constructing the high vacuum tube by expelling occluded gas while evacuating the tube. An article by Duncan, American Electrician, May, 1896; one by Doane, Electrical World and Engineer, of May 21, 1904; the Dwyer Patent, No. 496,694, January 4, 1893, for a process for producing high vacuum in incandescent lamps or similar receptacles during their manufacture; the Soddy Patent, No. 859,021, July 2, 1907, for the employment of certain reagents in the process of producing high vacuum; the Thatcher Patent, No. 1,028,636, June 4, 1912, application filed March 30, 1910, for method of exhausting vessels; and an article by Lilienfiled in 1910, to be mentioned later, disclosed before Langmuir the essentials for producing a high vacuum, described in the present process claims. They were in use in laboratory practice by Millikan and others before 1911.

It was upon the claims for the high vacuum tube structure or device that the court below based its decision, and they are urged upon us here as the grounds for sustaining the patent. They put forward, in a great variety of forms, claims for an electrical discharge device consisting of a tube with cathode and anode within it, with relation of parts and degree of evacuation (vacuum) such that the device is capable of operation with higher than ionization voltages in a range below saturation, substantially unaffected by ionization. Claim 2, which respondent selects as typical, reads:

"2. A discharge tube having a cathode adapted to emit electrons and an anode adapted to receive said emitted electrons, the tube walls being fashioned or shaped to permit the direct passage of a useful proportion of said electrons from cathode to anode, the gas content or residue of said tube and the relation of the parts of the tube being such that the tube is capable of being so operated in a range below saturation and materially above ionization voltages that the space current is governed or limited by the electric field of said electrons substantially unaffected by positive ionization."

But this claim, as well as all others of the Langmuir patent, must be read in the light of the fact, fully accepted by the parties to this litigation, that electrical discharge devices such as the Fleming valve and the De Forest audion, patents on the latter of which expired in 1925, which were well known before Langmuir, comprise all the elements of the combination claimed except the presence within it of a high vacuum. It is conceded that if the requisite high vacuum be created in a De Forest audion, it becomes the high vacuum tube of the patent and is an infringing device if the patent is valid. The degree of the vacuum within the tube is therefore the crucial feature of the invention claimed. Langmuir, in describing in his patent the method of producing the device, says: "The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned." In at least 13 of the claims, the device claimed is one in which the gas within the tube, or the pressure, is sufficiently reduced, or the vacuum raised high enough, (all of which are synonymous), to produce the desired result, that is, a discharge unaffected by ionization when the tube is operated by the appropriate space current, which may be of higher voltage than that for the low vacuum tube.

The characteristics of the discharge named by the inventor in the specifications "in order to distinguish electron discharge devices made in accordance with my invention from the prior art" are the following: (1) gas ionization absent or negligible; (2) cathode not heated by the discharge; (3) no blue glow or visible evidence of discharge; (4) 3/2 power relation of current to voltage; (5) discharge independent of degree of vacuum within intended limit for particular tube; (6) regularity and reproducibility. But all these characteristics may be summed up in the simple statement that in the tube of the patent, there must be an absence of harmful ionization; and since, as already indicated, harmful ionization disappears when the requisite vacuum is attained, the device or structure of the patent is one in which such a vacuum has been produced.

That the high vacuum tube was an improvement over the low vacuum tube of great importance, is not open to doubt. Even though the improvement was accomplished by so simple a change in structure as could be brought about by reducing the pressure in the well known low vacuum tube by a few microns, still it may be invention. Whether it is or not depends upon a question of fact, whether the relationship of the degree of vacuum within the tube, to ionization, and hence to the stability and effectiveness of discharge passing from cathode to anode, was known to the art when Langmuir began his experiments. If that relationship was then known, it required no inventive genius to avoid ionization and secure the desired result by creating the vacuum in a DeForest tube or other form of low vacuum discharge device.

That this relationship was known was the fact found by the District Court and not challenged by the opinion of the Court of Appeals. In 1910 Lilienfeld, in a paper published in Annalen der Physik, Vol. 32, on "The Conduction of Electricity", made a complete and explicit disclosure of the essentials of all the structures and methods of the Langmuir patent. The paper described methods of obtaining the "extreme vacuum" desired by freeing electrical discharge devices of occluded gas in the manner already described and at the same time evacuating the tube. He described the space charge effect, not mentioned in Langmuir's original specification, but later recited in the claims of the patent, in the following language: "One can formulate more generally the conditions for high voltage and large current density as follows: The production of a state in which the volume density of the electrons carrying the current is as large as possible compared with the density of gas molecules in which there exists therefore a tendency for the formation of the maximum possible space charge in the path of the current." To one skilled in the art, this could only mean that increased effectiveness of an electrical discharge device, to which a suitable current is applied, could be obtained by raising the vacuum in the manner which the writer had described. He also stated that "from a definite maximum density of the gas downwards, the discharge phenomena are independent of the gas density in the region investigated", a statement equivalent to the fifth characteristic of the discharge in the Langmuir specification, namely, that it is independent of degree of vacuum within the intended limit for the particular tube.

Lilienfeld also deduced from meter readings and stated, the 3/2 power relation of current to voltage, as Langmuir later stated it in his patent. From this the conclusion is inescapable that Lilienfeld knew and stated, in terms which could be understood by those skilled in the art, that in a high vacuum the current produced is under control, stable, and reproducible; and, as he employed high voltages, that high power levels of the discharge may be obtained by the employment of a high voltage in a high vacuum tube. Space charge effect was also described by Lilienfeld in Physikalische Zeitschrift, in 1908, in which he pointed out that by raising the vacuum there is an increase in the number (volume density) of the negative electrons, and said: "The higher the vacuum, the greater the current density, the more pronounced this new kind of discharge becomes."

The very fact that Lilienfeld knew and described the methods of the patent for obtaining high vacuum carries with it as a necessary corollary that the device itself, apart from its functioning and use, is lacking in patentable novelty. Hence, invention, if any there be, is embraced in the discovery of the principle that discharges above ionization voltages can be produced without substantial ionization if the vacuum be sufficiently high, and the disclosure that the device of the claims constitutes suitable means for putting the principle into practice. But Lilienfeld, in his paper of 1910, disclosed that he obtained discharges free from the effects of ionization, as Langmuir testified in interference proceedings in the Patent Office, and that he accomplished this through the attainment of high vacua by the very methods later described in the Langmuir patent.

Fleming, the inventor of the Fleming valve, in a paper read before the Royal Society on the conversion of electric oscillations into continuous current by means of a vacuum valve, February 9, 1905, pointed out the possibility of creating "an ideal and perfect rectifier for electric oscillations" by enclosing within a tube a hot carbon filament and a cold metal anode "in a very perfect vacuum"; and he described a method of procuring the vacuum by exhausting the bulb while freeing it of occluded air. In his Patent, No. 803,634, November 7, 1905, he describes the method of securing a high vacuum within the bulb by freeing it of occluded gas by heating the bulb and filaments to incandescence and at the same time evacuating it. ~~He defined a high vacuum as one reduced to "one hundred millionth of an atmosphere", which is less than the 1/100 of a micron, the pressure in the tube of the patent; and in an article in "The Scientific American," supplement for January 20, 1906, on "electric conductivity of a vacuum", he disclosed not only that electrons are emitted by hot cathodes in a high vacuum, but also "that a high vacuum may be a very good conductor, provided the negative electrode is rendered incandescent."~~ Thus Fleming knew, and stated, the advantages of the high vacuum, its definition, and the method of procuring it. The state of the art and the progress of scientific knowledge in this field was accurately summed up in the statement of the law examiner in the Patent Office who passed on the Langmuir claims:

"It is apparent after a review of the record that there is no single element which is broadly novel in the assemblage of elements making up an electron discharge device of the character defined in the issue. An evacuated tube having therein an incandescent electron emitting cathode and an anode was old prior to the filing of Langmuir's application, and methods of attaining high vacua, sufficient to give a relatively pure electron discharge in a properly designed tube were also well known and available to persons skilled in the art."

In an article in "The Scientific American," supplement for January 20, 1906, on "electric conductivity of a vacuum," he defined a high vacuum as one reduced to "one hundred-millionth of an atmosphere," which is less than the 1/10 of a micron, the pressure in the tube of the patent; and he disclosed not only that electro are emitted by hot cathodes in a high vacuum, but also "that a high vacuum may be a very good conductor, provided the negative electrode is rendered incandescent."

The narrow question is thus presented whether, with the knowledge disclosed in these publications, invention was involved in the production of the tube, that is to say, whether the production of the tube of the patent, with the aid of the available scientific knowledge that the effect of ionization could be removed by ~~reducing~~ increasing the vacuum in an electric discharge device, involved the inventive faculty or was but the expected skill of the art. The question is not, as respondent argues, whether Lilienfeld or others made a practical high vacuum tube, but whether they showed how it could be made and demonstrated and disclosed the relationship of the discharge to reduced pressure, and how to reduce it. See *Corona Co.* v. *Dovan Corporation,* 276 U. S. 358, 384. That the production of the high vacuum tube was no more than the application of the skill of the art to the problem in hand is apparent when it is realized that the invention involved only the application of this knowledge to the common forms of low vacuum discharge devices such as the Fleming and De Forest tubes. Once known that gas ionization in the tube caused irregularity of current which did not occur in a high vacuum, it did not need the genius of the inventor to recognize and act upon the truth that a better tube for amplifying could be made by taking out the gas. Arnold, who was skilled in the art, and who had made studies of electrical discharges in high vacua, when shown a DeForest audion for the first time on November 14, 1912, immediately recognized and said that by increasing the vacuum the discharge would be sufficiently stable and have adequate power levels to enable the tube to be employed as a relay device in transcontinental telephony. The very fact that all of significance in the Langmuir improvement was obvious to one skilled in the art as soon as he saw the unimproved tube, as the District Court said, "lies athwart a finding of invention".

Respondent recognizes the force of this objection to patentability, but seeks to avoid it by insisting that the invention claimed is not as we have described it, but that "Langmuir's invention consisted in taking out [of the tube] the gaseous conductor upon which the prior art relied, and putting nothing [a vacuum] in its place." It adopts also the statement in the opinion of the court below, upon which its decision turned, "a vacuum, or, indeed, change of vacuum, isolated and standing by itself, is not the Langmuir invention, but it is a working tube in which all the elements, cathode, plate, vacuum, so coordinate and interwork that the current flow is not affected by gas," a statement which, as we have already pointed out, takes no account of the scientific knowledge, available before Langmuir, that increase of vacuum in well known devices was all that was necessary to produce the desired result. Respondent elaborates, by saying that "in the practical prior art devices [that is to say, low vacuum tubes] the conduction of current depended upon gas ionization; the art, moreover, believed that unless there was enough gas to act as a conductor no current could flow and the tube would not work." It says that the high vacuum tube of the patent works on a different principle, that of the "pure electron discharge" and it was the recognition of this scientific truth and the adaptation of the device to it in which the invention consists.

But if Langmuir's invention is so to be defined, it is not the invention claimed by the patent. Respondent puts forth as sustaining this definition, statements in the specifications of the patent, to the effect that in the device of the patent, in which gas ionization is absent, the discharge is "distinct in its characteristics" from the described discharge taking place in an ionized gas, and again that it is "characterized by regularity and reproducibility with given conditions". But, while these and many other statements in the patent indicate that high vacuum was an effective means of producing in the old tubes of the art the stable current which could not be produced in the presence of ionization, they do not suggest any discovery of a scientific truth that essentially different principles control the discharge in low vacuum tubes from those which operate in high, other than that ionization, present when gas is present, has certain effects, notably on stability of current in a low vacuum, which is absent in the high, when ionization is absent, as Lilienfeld and others had disclosed.

If it were necessary to a decision we could not find that any such scientific truth is established by this record. Respondent, to support the contention, does not rely on evidence, but on a collection of more or less casual statements by various writers, made before 1915, to the effect that the gas or ionized gas of the low vacuum tube is a conductor. Before the development of the electron theory, "conductivity" of substances was a convenient expression for explaining the flow of electric currents. Fleming, in a statement in 1906, already quoted, referred to the high vacuum as a good "conductor" if a hot cathode was used. The present tendency is to ascribe the flow of current from a hot cathode through both high and low vacua to the flow or discharge of electrons. Millikan the eminent physicist testified that this theory was generally accepted before 1912. Langmuir himself so explained the flow of current in a gaseous tube in his specifications. The known truth is that current flows through both low and high vacua and is unfavorably affected by ionization in the former; but that the flow is due to conductivity of the ionized gas in one and to something different, pure electron discharge, in the other, is not established by the evidence before us. There is some testimony to the contrary. Nor is our attention directed to anything which suggests that Langmuir thought there was such a difference, or relied upon it to remove ionization effects, rather than upon the simple expedient of removing the gas known to be responsible for them.

Even if the asserted difference were established, it is no more than the scientific explanation of what Lilienfeld and others knew, before Langmuir, of the effect of the high vacuum on the discharge, and the methods and devices for procuring the vacuum. It is method and device which may be patented and not the scientific explanation of their operation. See *LeRoy* v. *Tatham,* 14 How. 156, 174-6.

Only when invention is in doubt may advance made in the art be thrown in the scale to support it. If we were to assume that invention here was doubtful, we can find little to suggest that the high vacuum tube when produced satisfied a long felt want or that its present utility is indicative of anything more than the natural development of an art which has passed from infancy to its present maturity since Langmuir filed his application. There was little or no practical use for a high vacuum tube in 1913. The De Forest audion was not in general use and Langmuir did not see one until that year. The many amendments of Langmuir's application during its long pendency, disclosing his uncertainty as to what he had invented, and the exhibits in this case, constitute a history of the development of the art, which indicate unmistakably that the resort to the high vacuum tube for discharges above ionization voltages was but the adaptation to the natural development of the art, by those skilled in it, of the scientific knowledge which had been accumulated by investigation and experimentation. When the need became apparent, De Forest and

Arnold, as well as Langmuir, found ready at hand the knowledge which would enable one skilled in the art to satisfy it.

The court below, contenting itself with finding invention, said nothing of the finding of prior use by the District Court. We hold that this finding of the District Court was supported by the evidence and should have been given effect. As we have concluded that the Langmuir patent did not involve invention, we refer only briefly to the facts which establish prior use. In 1911 and until September of 1912, De Forest was in the employ of the Federal Telegraph Co. of California, then engaged in the commercial transmission and reception of radio messages, in which audion detectors as well as audion amplifiers were used. In July, 1912, De Forest sought and obtained a high vacuum in the audions used as amplifiers, and observed that when the vacuum was too low the blue glow effect occurred at from 15 to 20 volts. In order to secure higher voltages from the audions used as amplifiers and to procure the requisite high vacuum, he had some of the bulbs re-exhausted while super-heated. Before August, 1912, the Telegraph Company used De Forest amplifying audions at 54 and 67½ volts, which was possible only because he had exhausted the tubes of gas, which would otherwise have ionized at from 20 to 30 volts. The vacuum was lower than that obtained by later and improved methods; but the effect of high vacuum upon voltages above the point of ionization was then known, and the knowledge was thus availed of in practice. Whether De Forest knew the scientific explanation of it is unimportant, since he did know and use the device and employ the methods, which produced the desired results, and which are the device and methods of the patent.

Reversed.

Mr. Justice McReynolds concurs in the result.

with blue glow

A true copy.

Test:

Clerk, Supreme Court, U. S.